Universidade de Aveiro Departamento de Economia, Gestão e Engenharia Industrial
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Otimização Económica de Parques Eólicos em Função do Custo da Energia Produzida

Economic Optimization of Wind Farms in Function of the Cost of Energy Produced

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Economia, realizada sob a orientação científica do Professor Doutor António Jorge Fernandes, Professor Auxiliar do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro e Professor Doutor Joaquim José Borges Gouveia, Professor Catedrático do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro.

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CIÊNCIA E TECNOLOGIA
SECRETARIA DE ESTADO

I dedicate this thesis to my wife, Francidalva, my sons, Heron and Darah, my lovely relatives, Antonio and Ebenezer.

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palavras-chave Otimização económica, parques eólicos, custo de energia produzida, energia renovável, fator de competitividade.

resumo

Esta tese apresenta um estudo sobre otimização económica de parques eólicos, com o objetivo de obter um algoritmo para otimização económica de parques eólicos através do custo da energia produzida. No estudo utilizou-se uma abordagem multidisciplinar.

Inicialmente, apresentam-se as principais tecnologias e diferentes arquiteturas utilizadas nos parques eólicos. Bem como esquemas de funcionamento e gestão dos parques. São identificadas variáveis necessárias e apresenta-se um modelo dimensionamento para cálculo dos custos da energia produzida, tendo-se dado ênfase às instalações *onshore* e ligados a rede elétrica de distribuição.

É feita uma análise rigorosa das características das topologias dos aerogeradores disponíveis no mercado, e simula-se o funcionamento de um parque eólico para testar a validade dos modelos desenvolvidos. Também é implementado um algoritmo para a obtenção de uma resposta otimizada para o ciclo de vida económico do parque eólico em estudo.

A abordagem proposta envolve algoritmos para otimização do custo de produção com multiplas funções objetivas com base na descrição matemática da produção de eletricidade. Foram desenvolvidos modelos de otimização linear, que estabelece a ligação entre o custo económico e a produção de eletricidade, tendo em conta ainda as emissões de CO_2 em instrumentos de política energética para energia eólica.

São propostas expressões para o cálculo do custo de energia com variáveis não convencionais, nomeadamente, para a produção variável do parque eólico, fator de funcionamento e coeficiente de eficiência geral do sistema. Para as duas últimas, também é analisado o impacto da distribuição do vento predominante no sistema de conversão de energia eólica. Verifica-se que os resultados obtidos pelos algoritmos propostos são similares às obtidas por demais métodos numéricos já publicados na comunidade científica, e que o algoritmo de otimização económica sofre influência significativa dos valores obtidos dos coeficientes em questão.

Finalmente, é demonstrado que o algoritmo proposto *($LCOE_{wso}$)* é útil para o dimensionamento e cálculo dos custos de capital e O&M dos parques eólicos com informação incompleta ou em fase de projeto. Nesse sentido, o contributo desta tese vem ser desenvolver uma ferramenta de apoio à tomada de decisão de um gestor, investidor ou ainda agente público em fomentar a implantação de um parque eólico.

keywords

Economic optimization, wind farms, cost of energy produced, renewable energy, competitiviness factor.

abstract

This thesis presents a study on economic optimization of wind farms, with the goal of obtaining an economic optimization model for wind farms through the cost of energy produced. The study used a multidisciplinary approach.

Initially, the main technologies and different architectures used in wind farms. As well as the operating schemes and management of wind farms. Variables needed are identified and presented a sizing model for calculation of the cost of energy produced; we had focused on *onshore* installations and distribution power *on-grid* applications.

It is made a rigorous analysis of the characteristics of real and topology of aerogenerators simulating the operation of a wind farm to test the validity of models developed. Is also implemented an algorithm for obtaining an optimal response for economic life-cycle of the wind farm in the study.

The proposed approach involves algorithms for production cost optimization with multiple objective functions based on the mathematical description of the electricity production. Models have been a developed optimization linear model, which establishes the link between the production cost and CO_2 emissions in energy policy instruments for wind power.

Expressions are proposed for calculation of the cost of energy with nonconventional, such as, for the variable production of the wind farm, capacity factor, and overall system efficiency coefficient. For the latter two, is also shown the impact of the distribution of predominant wind in wind energy conversion system. It is noticed the results achieved by the proposals are similar to those obtained by other numerical calculation already published in scientific community, and the algorithm for economic optimization significantly is influenced the values obtained for the coefficients in question.

Finally, it is shown the proposed algorithm *($LCOE_{wso}$)* is useful for dimensioning and calculation of the wind farms cost of capital and O&M, within incomplete information or in the planning phase. Accordingly, the contribution of this thesis should be a tool of support for manager/investor or a public agent in supporting the implementation of a wind farms.

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LIST OF ACRONYMS

Notation	Description
AAE	Asociación Empresarial Eólica
AG	Asynchronous Generator
APERC	Asia Pacific Energy Research Centre
AWEA	American Wind Energy Association
BWEA	British Wind Energy Association
BNDES	The Brazilian Development Bank *(Banco Nacional de Desenvolvimento Econômico e Social)*
BOP	Balance Of the Plant
CanWEA	Canadian Wind Energy Association
CAPM	Capital Asset Pricing Model
CEC	Clean Energy Council
CERs	Certified Emission Reductions
CoPS	Complex Product System
CSCF	Constant Speed Constant Frequency
DCF	Discounted Cash Flows
DD	Direct-Drive
DDSG	Direct-Drive Synchronous Generator
DFIG	Doubly-Fed Induction Generator
DG	Distributed Generation
DGGE	Directorate General for Geology and Energy *(Direcção Geral de Geologia e Energia)*
DSO	Distribution System Operator
DTI	Department of Trade and Industry
ECOA	Economic Optimization Algorithm
EDP	*Energias de Portugal* (Energies of Portugal)
EEA	European Environment Agency
EER	Emerging Energy Research
EIA	Energy Information Administration
EMP_{yr}	Expected market price
ENOA	Engineering Optimization Algorithm
EPC	Engineering Procurement Construction
ERSE	The Energy Services Regulatory Authority *(Entidade Reguladora dos Serviços Energéticos)*

ES	Evolutionary Strategies
EU	European Union
EWEA	European Wind Energy Association
FDE	Frequency Domain Experiments
FESG	Field-Excited Synchronous Generators
FinDE	Finite Difference Estimation
GA	Genetic Algorithms
GBSM	Gradient Based Search Methods
GST	General System Theory
GWEC	Global Wind Energy Council
HAWT	Horizontal Axis Wind Turbines
HM	Heuristic Methods
HVAC-HVDC	High Voltage Alternative And Direct Current
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IG	Induction Generators
IMF	International Monetary Fund
IP	Index of Performance
IPPs	Independent Power Producers
IS	Importance Sampling
ITC	Investment Tax Credit
LIDAR	Light Detection And Ranging
LR	Likelihood Ratio Estimators
LWST	Low Speed Wind Turbine Program
MACRS	Modified Accelerated Cost Recovery System
NASA	National Aeronautics and Space Administration
MC	Multiple Comparison
MPPT	Maximum Power Point Tracking Technique
NEA	Nuclear Energy Agency
NO_x	Nitrogen Oxides
NREL	National Renewable Energy Laboratory
NS	Net Savings
NWCC	National Wind Coordinating Collaborative
NWF	Nearshore Wind Farm
NZWEA	New Zealand Wind Energy Association
O&M	Operations and Maintenance
OECD	Organization for Economic Cooperation and Development
OEMs	Original Equipment Manufacturers

OFWF	Offshore Wind Farm
OOR	Overall Rate-of-Return
OWF	Onshore Wind Farm
OWFLO	Offshore Wind Farm Layout Optimization
PA	Perturbation Analysis
PC	Performance Criteria
PCC	Point of Common Connection
PI	Performance Index
PMSG	Permanent Magnet Synchronous Generators
PPA	Power Purchase Agreement
R&D	Research and Development
RD&D	Research, Development and Demonstration
RE	Renewable Energy
REN	National Electric Grid *(Rede Eléctrica Nacional)*
REPs	Renewable Energy Projects
RES	Renewable Energy System
RETs	Renewable Energy Technologies
RSM	Response Surface Methodology
RH_n	Research Hypothese *"n"*
RS	Ranking and Selection
SA	Simulated Annealing
SCADA	Supervisory Control And Data Acquisition
SCIG	Squirrel-Cage Induction Generator
SIR	Savings-to-Investment Ratio
SM	Statistical Methods
SO	Stochastic Optimization
SO_2	Sulfur dioxide
SS	Simplex Search
TPWind	The European Technology Platform for Wind Energy
TS	Tabu Search
TSO	Transmission System Operator
UKERC	United Kingdom Energy Research Centre
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
US DOE	United States Department of Energy
VAWT	Vertical Axis Wind Turbines
VSCF	Variable Speed Constant Frequency
VSVF	Variable Speed Variable Frequency

WCD	World Commission on Dams
WECS	Wind Energy Conversion System
WECs	Wind Energy Converters
WEO	World Energy Outlook
WPU	Wind Power Unit
WT	Wind Turbine
WWEA	World Wind Energy Association

LIST OF SYMBOLS

Symbol	Description	Unit
α	Inverse of *URCF*	[–]
ρ	Air density (1.255 kg/m^3)	[kg/m^3]
β	Equivalent to *UCRF*	[–]
ς	Unit cost per WF_{cap} for CP_{CM} calculation	[\$/MW$_e$]
κ	Percentage of capital costs for contingencies	[%]
ε	Final value paid by government	[\$/kW$_e$h]
ε_c	Government credit given for each MWh$_e$ of $LCER_{CO_2}$	[\$/MW$_e$h]
ε_0	Initial value paid by government	[\$/kW$_e$h]
∇	Gradient function	[–]
ϖ	Percentage of $LCCCM_{WF}$ for $O\&M_{fixed_{CM}}$ cost calculation	[%]
ψ_{total}	Final value of subsidies for REI_{CM} calculation	[\$/kW$_e$]
ψ_0	Initial value of subsidies for REI_{CM} calculation	[\$/kW$_e$]
ξ_n	Percentage for each energy policy instrument for *REPIM*	[%]
γ	Coefficient of *skewness*	[–]
v_w	Wind speed	[m/s]
η_e	Electrical transmission efficiency	[–]
η_m	Mechanical transmission efficiency	[–]
η_{wecs}	Wind power plant efficiency	[–]
$\eta_{wecs_{(ref)}}$	Wind power plant efficiency reference	[–]
η	System electro-mechanic efficiency	[–]
a_i	Equality constraint functions	[–]
A	Swept turbine area	[m^2]
AAR	Average Annual Revenue	[\$M]
AAR_{yr_n}	Average Annual Revenue in year "*n*"	[M\$/yr]
A_{WT}	Area per wind turbine for *S&RV* calculation	[m^2/wt]
AEP_{avail}	Annual Energy Production Available	[kW$_e$h]
AEP_{gross}	Annual Energy Gross Production	[kWh]
AEP_{net}	Annual Energy Net Production	[kWh]
AEP_{rated}	Annual Energy Rated Production	[kWh]

AEP_s	Cumulated Annual Energy Production	[kWh]
AFF	Annual Failure Frequency	[–]
$Amort$	Amortization	[$M]
AR_{CM}	Annual Replacement Cost Model	[$/kW]
b	Learning parameter	[–]
BCR	Benefit-to-Cost Ratio	[–]
b_k	Inequality constraint functions	[–]
Bld_{area}	Building area for SI_{CM} calculation	[m^2]
Bld_{cost}	Building cost for SI_{CM} calculation	[$/m^2]
BOP	Balance Of Plant	[$M]
c	Current costs for *TI* calculation	[$/kW]
C	Constant in *Eqn 5.11*, *5.12* and *5.13*	[–]
c_0	Initial costs for *TI* calculation	[$/kW]
CAB_{cost}	Cables costs including skilled labor	[$/m]
C_F	Capacity factor	[%]
CF_{wf}	Wind farm capacity factor	[%]
C_i	Cash inflows	[$M]
$C_{Mhr_{RM_{WT}}}$	Cost of man-hour for RM_{WT}	[$/m-h]
C_{Mhr}	Cost of man-hour	[$/m-h]
C_o	Cash outflows	[$M]
$C_{O\&M}$	Cost of Operations and Maintenance	[$M]
Co_0	Initial Investment	[$M]
COE	Cost Of Energy	[$/kWh]
COP	Coefficient Of Performance	[–]
Co_t	Cash outflows in period t	[$M]
$C_{Mhr_{RM_{CT}}}$	Cost of man-hour for RM_{CT}	[$/m-h]
$C_{Mhr_{S\&RV}}$	Cost of man-hour for *S&RV*	[$/m-h]
$C_{md_{RM_{WT}}}$	Cost per day for RM_{WT}	[$/day]
$C_{md_{S\&RV}}$	Cost per day for *S&RV*	[$/day]
$D_{m_{RM_{WT}}}$	Time of utilization for machines/equipment for RM_{WT}	[day]
$D_{m_{S\&RV}}$	Time of utilization for machines/equipment for *S&RV*	[day]
$Depr_{WT_{inst}}$	Depreciation of wind turbines with towers	[$/kW]
$Depr_{Y_{RC}}$	Depreciation in the year of major review	[$/kW]
C_{kW}	Cost of kW installed for CM_{WT} calculation	[$/kW]
C_{md}	Cost per day for DCM_{WF} calculation	[$/day]
CM_{WT}	Cost of wind turbine for manufacturer	[$/kW]
C_P	Coefficient of dynamics performance	[%]
C_{PBetz}	Betz Limit`s coefficient of performance $(C_{PBetz}=16/27)$	[%]

CP_{CM}	Collecting Point Cost Model	[$/kW]
CRF	Capital Recovery Factor	[–]
C_{steel}	Cost of steel	[$/kg]
D	Rotor diameter	[m]
DCM_{WF}	Wind Farm Decommissioning Cost Model	[$/kW]
D_m	Time of utilization for machines/equipment	[day]
DPB	Discounted Payback	[years]
DT	Development	[$/kW]
D_v	Disinvestment value	[$M]
E_A	Annual energy of the array	[kWh]
E_{avail}	Available electrical energy	[kW_eh]
EF_c	Electrical facilities for wind farm substation	[$/kW]
EF_{el}	Electricity Emission Factors	[tCO_2/MW_eh]
EG	*Engineering*	[$/kW]
$EOAP$	Economic Optimization Algorithm Proposed	[–]
E_{pi}	Energy policy instruments	[–]
$E_{theo}(park)$	Theoretical electrical energy	[kW_eh]
E_T	Annual energy of one isolated turbine	[kWh]
FCR	Fixed Charge Rate	[–]
F_t	Fuel expenditures in the year *t*	[$M]
F_{CM}	Financing Cost Model	[$/kW]
FLH_{wf}	Full load hours of production for a wind farm	[h]
FS	Feasibility Studies	[$/kW]
$GHG_{EM_{ff\ CO_2}}$	GreenHouse Gas Emission of CO_2 from fossil fuel	[tCO_2/MW_eh]
$GHG_{EM_{wecs\ CO_2}}$	GreenHouse Gas Emission of CO_2 from WECS	[tCO_2/MW_eh]
g	Annuity	[–]
G_{bd}	Hours for grid breakdown	[h]
G_{main}	Hours for grid maintenance	[h]
GW	Gigawatt	[–]
GWh	Gigawatt-hour	[–]
H_{prod}	Hours of production	[h]
H_h	Hub height	[m]
i	Discount rate	[%/yr]
if_r	Inflation rate	[%/yr]
IPT	Industrialized Product Taxes	[%]
IRR	Internal Rate of Return	[%]
I_t	Investment expenditures in the year *t*	[$M]
K_0	Present value	[$M]

k_{col}	Coefficient for number of wind turbines in a column	[–]
KE	Kinetic energy	[J]
kg	Kilogram	[–]
kPa	Kilopascal	[–]
k_{row}	Coefficient for number of wind turbines in a row	[–]
K_t	Payment value	[$M]
kV	Kilovolt	[–]
kW	Kilowatt	[–]
kW_e	Kilowatt electric	[–]
kWh	Kilowatt hour	[–]
$LCER_{CO_2}$	Life-Cycle Emission Reduction of CO_2	[tCO_2/MW_eh]
$LCCCM_{WF}$	Wind Farm Life-Cycle Capital Cost Model	[$/kW]
$LCOE$	Levelized Cost Of Energy	[$/kWh]
$LCPM_{WF}$	Wind Farm Life-Cycle Production Model	[kWh/yr]
$L_{w_{av}}$	Average losses of WECS	[–]
$LCOE_{wso}$	Levelized Cost Of Energy proposed by WSO	[$/kWh]
$LEPC$	Levelized Electricity Production Cost	[$/kWh]
LF	Layout Factor	[kW_eh]
L_g	Local grid length	[m]
LLC	Land Lease Cost	[$/kWh]
LRC	Levelized Replacement Cost	[$/kW]
$LRCM$	Levelized Replacement Cost Model	[$/kW]
L_t	Transmission line length	[m]
L_{wt}	Wind turbines layout	[–]
$LWTG_{CM}$	Local Wind Turbines Grid Cost Model	[$/m/kW]
$L_{x_{row}}$	Area with length (for row)	[m^2]
$L_{x_{col}}$	Area with length (for column)	[m^2]
m	Mass	[kg]
M_t	Operations and maintenance expenditures in the year t	[$M]
$M_{hr_{RM_{WT}}}$	Man-hour for RM_{WT}	[m-h]
$M_{hr_{RM_{CT}}}$	Man-hour for RM_{CT}	[m-h]
$M_{hr_{S\&RV}}$	Man-hour for $S\&RV$	[m-h]
MC_A	Market Cost Adjustment	[$/kW]
M_{hr}	Man-hour	[m-h]
MLC	Maintenance Labor Cost	[$/m-h]
MR	Machine Rating	[kW]
MW	Megawatt	[–]
MW_e	Megawatt electric	[–]

MWh	Megawatt hour	[–]
N_{row}	Number of wind turbines rows in the wind farm	[–]
N_{col}	Number of wind turbines columns in the wind farm	[–]
n_{ε}	Time of policy energy instrument for ε calculation	[yr]
NB	Net Benefits	[$M]
n_{fin}	Duration of pre-operational phase	[yr]
n_{Ψ}	Time of policy energy instrument for ψ calculation	[yr]
N	Lifetime of wind farm/Number of periods	[yr]
n_{mlh}	Number of maintenance labor hours	[h]
n_{tlh}	Number of technical labor hours	[h]
N_m	Number of machines/equipment	[–]
$N_{m_{RN_{WT}}}$	Number of machines/equipment for RN_{WT}	[–]
$N_{m_{S\&RV}}$	Number of machines/equipment for $S\&RV$	[–]
NPC	Net Present Cost	[$M]
NPV	Net Present Value	[$M]
N_{rs}	Rotor speed	[rpm]
n_t	Number of towers	[–]
n_w	Period of warranty for O&M costs	[yr]
N_{WT}	Number of turbines in the wind farm	[–]
$O\&M_{ccm}$	Costs covered by manufacturer	[%]
$O\&M_{fixed_{CM}}$	Fixed costs of operations and maintenance	[$/kWh]
$O\&M_{manag}$	Operations and Maintenance management of wind farm	[–]
$O\&M_{variable_{CM}}$	Variable costs of operations and maintenance	[$/kWh]
$O\&M_{WFCM}$	Wind Farm O&M Cost Model	[$/kWh]
P	Air pressure	[Pa or N/m^2]
$P\&D_{LM\,factor}$	P&D Losses Model factor	[–]
$P_{w_{av}}$	Average power production by WECS	[kWh]
$P_{w_{avail}}$	Electrical power output available	[W$_e$]
$P_{w_{(e)}}$	Electrical power output	[W$_e$/m^2]
P_A	Available power density	[W/m^2]
P_D	Power delivered	[kWh]
PO_{CM}	Pre-operational Cost Model	[$/kWh]
$PPAR$	Power Purchase Agreement	[$/kWh]
PR	Progress Ratio	[–]
PTC	Production Tax Credit	[$/kWh]
PV_{ci}	Present value of cash inflows	[$M]
PV_{co}	Present value of cash outflows	[$M]
PV_{sAEP}	Present value of cumulated annual energy production	[kWh]

P_w	Wind turbine power	[W/m^2]
$P_{w_{out}}$	Power extracted by rotor	[W/m^2]
R	Specific gas constant for air (287 J/kg K)	[J/kg K]
r	Discount rate	[%/yr]
RC	Repair Costs	[$/kWh]
RCM_{WF}	Wind Farm Removal Cost Model	[$/kW]
R_{CT}	Removal of concrete	[$/kW]
RC_{WT}	Percentage cost for the wind turbine component	[%]
RC_T	Percentage cost for the wind tower component	[%]
r_D	Debt cost before tax	[$M]
r_{debt}	Debt interest rate	[%/yr]
r_E	Equity cost	[$M]
REI_{CM}	Renewable Energy Investment Credit Mode	[$/kW$_e$]
REP_{CM}	Renewable Energy Production Credit Mode	[$/kW$_e$h]
$REPIM$	Renewable Energy Public Incentive Mode	[$/proj]
RM_{WT}	Removal of wind turbines	[$/kW]
RR	Required Revenues	[$M]
R_{taxes}	Revenue taxes	[%]
RVM_{WF}	Wind Farm Residual Value Model	[$/kW]
r_{WACC}	Tax of Weighted Average Cost of Capital	[%/yr]
$S\&RV$	Seeding and re-vegetation	[$/kW]
SB_c	Substation cost of transmitting	[$/kWh]
$SC_{O\&M}$	Scheduled maintenance	[$/kWh]
SD_x	Separation distances between wind turbines	[m]
$SD_{x_{row}}$	Separation distances between wind turbines (for row)	[m]
$SD_{x_{col}}$	Separation distances between wind turbines (for column)	[m]
SI_{CM}	Supporting Infra-structure Cost Model	[$/m^2/kW]
SPB	Simple Payback	[$M]
T	Air temperature in Kelvin (ºC +273)	[K]
T_{mass}	Mass of each tower	[kg]
t_x	Taxes for *WACC*	[%]
t'	Linear approximation for SPB	[yr]
t	Number of periods for Eqn 5.14	[–]
TAC	Total Annualized Cost	[$M]
T&D losses	Transmission and Distribution losses	[%]
T_{CM}	Towers Cost Model	[$/kW]
TI	Technology improvements	[$/kW]
TLC	Technical Labor Cost	[$/m-h]

TL_c	Transmission line cost	[$/m]
TLCC	Total Life-Cycle Cost	[$M]
TL_r	Transmission line thermal rating	[1/kW]
TO_{CM}	Technological Obsolescence Cost Model	[$/kW]
TS_{CM}	Transmission System Cost Model	[$/kW$_e$]
TSR	Tip Speed Ratio	[–]
TS_{VM}	Tower Scrap Value Model	[$/kW]
TWh	Terawatt hour	[–]
UCRF	Uniform Capital Recovery Factor	[–]
UPAC	Unitary Present Average Cost	[$/kW]
$USC_{O\&M}$	Unscheduled maintenance	[$/kWh]
V	Current cumulative volume for *TI* calculation	[kW]
V_0	Initial cumulative volume for *TI* calculation	[kW]
W	Watt	[–]
WACC	Weighted Average Cost of Capital	[%/yr]
$WACC_{proj}$	Weighted Average Cost of Capital for the project	[%]
$w_{F_{CM}}$	Percentage of $WACC_{proj}$ for F_{CM} cost calculation	[%]
W_D	Capital Structure	[%]
WF_{PE}	Wind Farm Production Efficiency	[%]
WF_{CM}	Wind Farm Capacity Model	[kW$_e$/yr]
WT_{main}	Hours for wind turbine maintenance	[h]
WT_{bd}	Hours for wind turbine breakdown	[h]
WF_{cap}	Wind farm electric installed capacity	[kW]
WT_{inst}	Wind turbines installations	[$/kW]
WT_{weight}	Weight of a wind turbine	[kg]
WT_{CM}	Wind Turbines Cost Model	[$/kW]
WT_{rated}	Wind Turbine rated capacity	[kW]
WTS_{VM}	*Wind Turbine Scrap Value Model*	[$/kW]
x	Set of all the independent variables	[–]
Y_{RC}	Year of the replacement or overhaul	[–]

God made a wind blow over the Earth.
Genesis 8:1

CHAPTER 1

INTRODUCTION

This chapter starts by describing the context of the Ph.D. research work. The interest and scope of this thesis is briefly explained. The main objective of this research is also presented. The scientific publications and communications resulted from this research is listed. In the end is added a short description of the chapters with the respective references.

1.1 PRESENTATION

Interest in the use of renewable energy sources has grown dramatically during the last decade, largely as a reaction to concerns about the environment impact of the use of fossil and nuclear fuel. However, the subject of renewable energy is of far wider interest than to environmental issues alone. The use of fossil and nuclear fuels is so central to industrialized societies that any examination of the difficulties they cause or their potential solutions raises a wide range of issues: of technology and design, politics, social structure, economics, planning and even history. This is an area in which there are many views, of varying degrees of insight and expertise, but little certainly.

One of the most exciting aspects of the study of renewable energy is that it is inherently positive. It is an area which offers the possibility of solutions to some of society´s most difficult problem. Again, this appears most clearly when a broad approach is taken. Thus the study of renewable energy involves much more than the technical possibilities of replacement of fossil and nuclear fuels. Some of the major scientific areas of interest are:

i. *Environmental science* — the comparative impact of fossil, nuclear and renewable energy sources on the atmosphere, waterways, and the plant and animal life on the earth. This includes considerations of the greenhouse gases effect, acid rain and pollution of the seas. Related issues include the dynamics of climate ant its relationship to the biosphere.

ii. *Earth sciences* — the origins of and physical principles underlying the various forms of renewable energy.

iii. *Technology* — the design and implementation of renewable energy based technologies, and their integration with existing technologies and distribution systems. Related issues include the technical possibilities for improving the efficiency of present energy use, in buildings, machinery, appliances, power plants, etc.

iv. *Social sciences* — the technological/economical/social/philosophical issue of large-scale systems versus small-scale local systems. The difference between the relatively concentrated reserves of fossil fuels in some countries and the wider distribution of renewable energy resources has major political implications and may influence patterns of industrialization and economic development. Changing fuels prices have a dramatic effect upon the world´s economies.

v. *Planning* — the sitting of power stations, transmission lines, wind farms, tidal barrages, biomass plantations or hydroelectric plant, which has a major planning impact, with legal and social implications. Transport planning, too, is intimately related to the mix of fuels and other energy sources available.

vi. *Architecture, building and design* — the design of buildings and neighborhoods for energy efficiency and to incorporate integrated energy supply systems which mix renewable and others sources.

As can be noticed, for studying renewable energy sources and technologies it is necessary a multidisciplinary understanding, so the way these projects can be measure or optimized take us to a body of knowledge for a complete and more comprehensive analysis of a power station planning and management, case of wind farms, at a microeconomics view.

To optimize a wind farm, each aspect and typical assumption must be challenged and carefully evaluated. The challenge in the evaluation has been determining the life-cycle economic implications of aspects such as lost availability, losses at full load, and no-load losses so they can be included in the design process∴Three economic factors condense the complexities of the wind farm business model into a form that can be conveniently used in simple spreadsheet calculations to optimize techno-economic power plant for maximized profitability (Maddaloni, 2005). These factors can be determined from the unique economic characteristics of a specific project, including wind regime, cost of money, tax treatment, and expected project return on investment.

Wind energy investment decisions are driven by economics, not necessity. The wind farm must have the lowest possible total life-cycle cost for the project to maximize its economic potential. A specific design choice may have a complex effect on the project financial performance, affecting capital costs, taxes, insurance, energy revenue, maintenance costs, and government subsidies. A method is required to simplify the calculations so that alternate design proposals may be compared and an optimal solution chosen based on the specific economic and engineering factors of the particular wind farm project.

An optimal solution is a result of an optimization process. Optimization is an important tool in decision science and in the analysis of physical systems. To use it, we must first identify some *objective*, a quantitative measure of the performance of the system under study. This objective could be profit, time, potential energy, or any quantity or combination of quantities that can be represented by a single number. The objective depends on certain characteristics of the system, called *variables* or *unknowns*. Our goal is to find values of the variables that optimize the objective. Often the variables are restricted, or *constrained*, in some way (Nocedal & Wright, 1999).

The process of identifying objective, variables, and constraints for a given problem is known as *modeling*. Construction of an appropriate model is the first step — sometimes the most important step — in the optimization process. If the model is too simplistic, it will not give useful insights into the practical problem, but if it is too complex, it may become too difficult to solve. Once the model has been formulated, an optimization algorithm can be used to find its solution. Usually, the algorithm and model are complicated enough that a computer is needed to implement this process. There is no universal optimization algorithm. Rather, there are numerous algorithms, each of which is made to a particular type of optimization problem. It is often the user's responsibility to choose an algorithm which would be more appropriate for their specific application.

This research aims to develop an algorithm for *Economic Optimization of Wind Farms in Function of the Cost of Energy Produced*. The cost of energy produced that has to be minimized by changing the design variables and others parameter influence cost of energy such as wind speed, wind farm layout, wind production losses, O&M cost parameters and control parameters. The optimization must maximize the profit obtained during the useful lifetime of the wind farm studied.

1.2 INTEREST AND SCOPE OF THE RESEARCH

There is not a single price and cost of energy for wind farms. Both depend on the location, size and number of turbines, in addition to being influenced by political incentives or subsidies granted by governments. The initial investment costs — cost of equipment, feasibility study, installation, and O&M are essential to determine the final cost of the technology. In general, the main variables that make up the production cost of wind energy are the investment costs of fuel and operations and maintenance (Morthorst & Chandler, 2004; Wizelius, 2007).

In the case of wind power there is no dependence of the cost of fuel, but the investment cost is still higher than that of conventional sources. However, the costs of wind farms are decreasing, indicating that this trend is likely to continue due to several factors such as the development of larger turbines and more efficient, technological advancement, reduction in the cost of O&M, among others. An extremely important factor that contributes to raise the cost of wind power is its capacity factor, generally around 30% to a maximum of 40%, while conventional plants varies between 40% and 80%. The cost of electricity production by wind in Europe declined in the last 15 years approximately 80%. At the same time, the installed capacity has increased exponentially in scale, from less than 100 MW to 34,400 MW in 2004. During the past ten years the price of wind turbines decreased by 5% each year, while at the same time revenue increased by 30% (Zervos & Kjaer, 2008).

Despite the reduction on the costs in recent years, some problems still there are hindering investments in wind energy projects. When connecting a wind farm to the electricity grid transmission, it is needed to check the power factor, voltage and final production of harmonics caused by the turbines, and investment costs are still higher than the conventional power plants of oil and natural gas. Moreover, the presence of wind turbines may threaten birds and cause visual and noise impact (Gipe, 1995; Heier, 1998).

With regard to wind energy production, economic optimization and evaluation of projects in renewable energy, it is also needed on other factors, such as potential exposure from this source in the energy world, especially in regions where wind speeds are expressive. As the output power is extremely sensitive to wind speed, variability significantly impacts on financial investments and O&M costs. Given to this, it is highlighted the importance of developing evaluation methodologies for economic and financial evaluation and management for energy projects considering the uncertainties associated with this type of technology (EWEA, 2009).

Both onshore and offshore wind energy minimizing the cost per kWh produced it is necessary because when it is going to be sold to the grid, the high and variable cost of wind energy represents a real risk to the investor or wind farm promoter. So when a wind farm is evaluated by deterministic indicator such as NPV, IRR, SPB, DPB and others economic and financial indicator usually applied for it, but such evaluation reflects a set of parameters adjusted and assumptions considered in order to show the results for a unchangeable market situation. In Economics Sciences it´s called *“coeteris paribus”*.

On the other hand, the wind energy system and *green* energy markets have some inherent features that should be taken into consideration∴As renewable energies have been receiving supports by government's incentives such as production tax credits (PTCs), modified accelerated cost recovery system (MACRS) and others finance supports which become wind energy technology competitive comparing to conventional ones and other renewable energies technologies. However, given the fast growth of wind power during the last decade and the expectations for the future, wind power penetration levels may increase to levels where engineering and economic optimization for this kind of system starts to be more and more necessary. Note that in this thesis, the *optimization model* is defined as a suggested methodology able to evaluate a wind farm in both economical and engineering aspects.

According to Benatiallah, Kadia, and Dakyob (2010) the main objectives of the optimization design are power reliability and cost. Minimizing the total cost, we can achieve an inexpensive and clean electric power system. In addition, the proposed method can adjust the variation in the data of load, location. Various modeling techniques are developed by researchers to model components of Wind system. Performance of individual component is either modeled by deterministic or probabilistic approaches. The economic study should be made while attempting to optimize the size of integrated power production systems favoring an affordable unit price of power produced. The economic analysis of the wind system has been made and the cost aspects have also been taken into account for optimization of the size of the systems. The total cost of system takes into account the initial capital investment, the present value of operation and maintenance cost, the inverter replacement cost and the wind system replacement cost.

The key objectives of the researches have been to find the lowest cost and highest reliability design of a wind farm. Developing methodologies with approaches for structural and economic optimization of onshore and offshore wind farms are still a challenge due to its multivariable nature and its nonlinear behavior. The importance of using new optimization techniques for short-term energy planning is due to the existence of multiple uncertainties (Fleten, Maribu, & Wangensteen, 2007).

For Baños et al. (2011) the investment decision on production capacity of a wind farm is difficult when wind studies or data are neither available nor sufficient to provide adequate information for developing a wind power project. Some researchers have analyzed in detail how to determine the probable wind power availability at a given site according to historical wind speed data, and its capacity to meet a target demand. At the start of this research project, the primary concern was about the correlation between wind speed and cost of energy produced at a specific site, but after an extensive literature review it became clearly that an economic evaluation by classical economic engineering approach considering deterministic methodologies such as Discounted Cash Flow (DCF) analysis would not be sufficient. It is a multivariable problem and engineering aspects must be taken into consideration. The central research question of this thesis is:

What is the minimum difference between maximum power production and minimal total costs based on LCOE/NREL methodology proposed for a wind farm? If any, which possible strategies could be followed?

1.3 THESIS OUTLINE

The Ph.D. thesis is composed of three parts. The first one, which includes five chapters has been shown the interest and scope of the thesis, research objective and approach; the relationship among energy, economy and society; global status of wind energy; wind energy conversion system with the theoretical foundation of the research work, providing a framework on wind energy, economic measurements for wind energy and physics relations. The second part of this thesis, which includes two chapters, the methodological aspects with its details, mathematical model developed and numerical simulations and validation of theoretical framework developed for optimization process. The last part, third one, of this thesis, which also includes two chapters, has been shown the results and discussions with conclusions and impactions for theoretical contributions and managerial implications, limitations and suggestions for future research.

Chapter 2 has presented an historical overview of the humanity in the energy resources context. This chapter has been addressed the evolution and revolution of changing human societies in the History in order to establish a framework for men's relation within himself and the environment. It was explored the development of societies and energy resources; the influence from energy resources in the structure of societies; energy and environmental impacts of some renewable energy resources and some impacts of electricity production activities (hydroelectric, biomass and wind).

Chapter 3 has presented an overview of the global status of wind energy market. This chapter addresses wind energy situation worldwide in order to establish a context for understanding the contemporary wind energy industry. It explores the global character of wind energy sector, describing its R&D trends, technological evolution and diffusion process, investment focus, wind energy policy, global market share and the global drivers for the expansion of this renewable technology, both in terms of demand and supply, giving a special focus on the onshore wind energy projects.

Chapter 4 has reviewed the relevant literature concerning the wind energy conversion system (WECS), aiming to introduce the history and its evolution∴It examines the wind energy converters types, physics basics, describes how energy is extracted from the wind, explain about power coefficients and its limitations on wind power systems. It also demonstrates the design of converters, which factors determine the conversion process and what problems must be considered. In addition, it presents specificities of the wind farms designs (layouts), with a special focus on onshore wind energy conversion system.

Chapter 5 has reviewed the relevant literature concerning the economic measures and optimization models applied for renewable power systems, aiming to introduce and confront the different techniques of economic evaluation, in a microeconomic view. It is also reviewed optimization models applied to wind energy projects in different application: design of wind farm layout for maximum wind energy capture, electrical system design, O&M cost reduction, maximize the NPV, etc. This chapter also examines the importance and limitations of the different approaches and methods studied. It also demonstrates how to process an economic evaluation of power projects, what steps should be taken, which variables determine a significant impact on results and what problems or limitation to face. In addition, it presents specificities of wind energy projects, with a special focus on the onshore wind energy projects.

Chapter 6 has discussed the way in which the research process was carried out. It introduces the rationale of the study and the research framework, providing the main objectives and research questions, and describing the theoretical framework, including the hypotheses. The research design, focusing on the relation of variables and research boundary, mathematical model structuring and numerical simulation and validation process, is also presented. After discussing and justifying the methodological choices for the research, the Chapter 7 describes in details the numerical simulation and validation of the optimization model proposed for economic evaluation of wind farms and Chapter 8 has presented the results and discussion of the model proposed too.

Chapter 7 has shown the simulations of a hypothetical wind farm. It starts by presenting the full description of mathematical model developed and power system features, both economic and technical issues.

Chapter 8 has demonstrated and interpreted the results of the simulations carried out in Chapter 7. It starts with the analysis of the behavior of the wind farm performance, relationships among variables studied.

Finally, in the last chapter, the main findings and the overall conclusions of the thesis are discussed. It also provides a review of the theoretical and managerial implications of the study, and finishes with a discussion about its limitations and suggestions for future research.

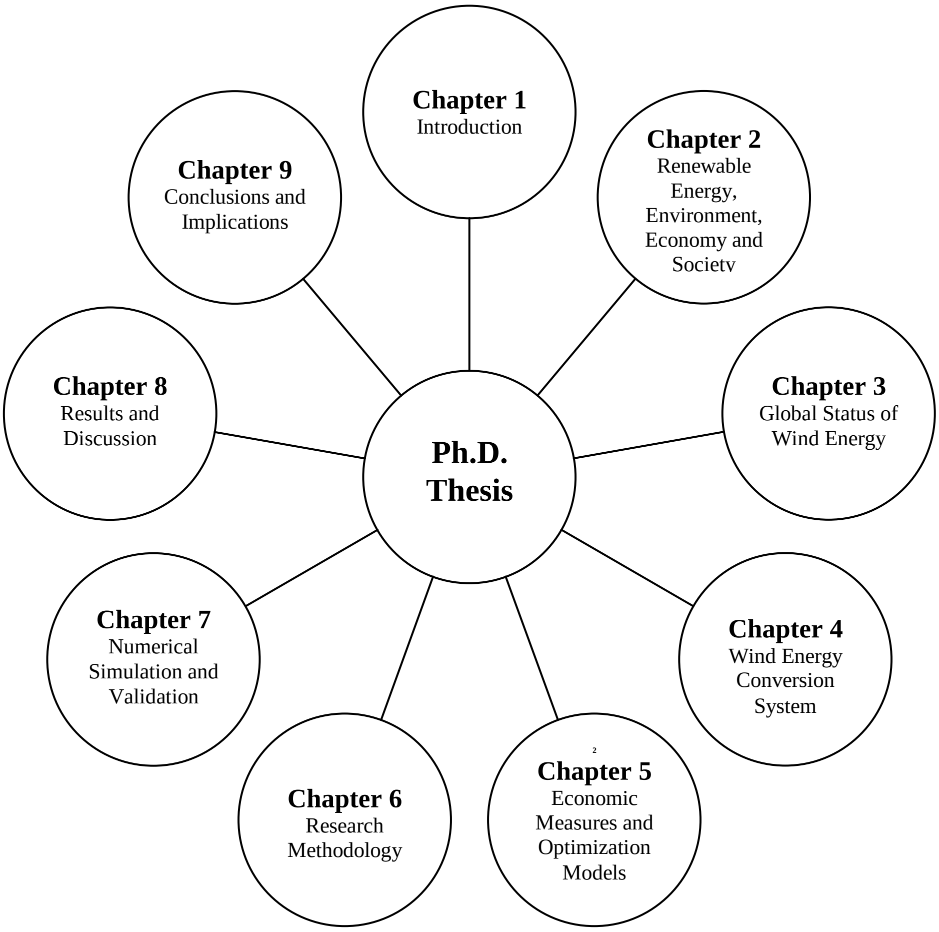

Figure 1.1 Ph.D. thesis` structure overview. Source: Own elaboration

1.4 LIST OF PUBLICATIONS

The major results obtained during this work were submitted to the scientific international community through the following papers.

1.4.1 PAPERS IN SCIENTIFIC JOURNALS

1. Oliveira, W.S. and Fernandes, A.J. (2012). *"A Review of Wind Energy Conversion System"*, Engineering Journal (EJ), Vol ? (?) *"Accepted – in Reviewing"*
2. Oliveira, W.S. and Fernandes, A.J. (2012). "*Economic feasibility analysis of a wind farm in Caldas da Rainha, Portugal"*, International Journal of Energy and Environment (IJEE), Vol 3 (3), 333-346.
3. Oliveira, W.S. and Fernandes, A.J. (2012). "*Global Wind Energy Market, Industry and Economic Impacts"*, Energy and Environment Research (EER**)**, Vol 2 (1), 79-97. doi: 10.5539/eer.v2n1p79
4. Oliveira, W.S. and Fernandes, A.J. (2012). "*Cost analysis of the material composition of the wind turbine blades for Wobben Windpower/ENERCON GmbH model E-82"*, Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Renewable Energy (JRSE), Vol 3, No. 1 January Edition.
5. Oliveira, W.S. and Fernandes, A.J. (2012). *"Optimization model for economic evaluation of wind farms* - *how to optimize a wind energy project economically and technically"*, International Journal of Energy Economics and Policy (IJEEP), Vol 2 (1), 10-20.
6. Oliveira, W.S. and Fernandes, A.J. (2012). "*Cost-effectiveness analysis for wind energy projects"*, International Journal of Energy Science (IJES), Vol 2 (1), 15-22.
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9. Oliveira, W.S. and Fernandes, A.J. (2011). "*Economic feasibility applied to wind energy projects"*, International Journal of Emerging Sciences (IJES), Vol 1 (4), 659-681.
10. Oliveira, W.S. and Fernandes, A.J. (2011). "*Economic evaluation applied to wind energy projects"*, Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Renewable Energy (JRSE), Vol 2, No. 9 September Edition.

11. Oliveira, W.S., Fernandes, A.J. and Gouveia, J.B. (2011). "*Economic metrics for wind energy projects"*, International Journal of Energy and Environment (IJEE), Vol 3 (6), 1013-1038.

1.4.2 ORAL COMMUNICATIONS IN SCIENTIFIC MEETINGS AND CONFERENCES

1. Oliveira, W.S. and Oliveira, F.V. (2012). *"Energy citizenship: educational and behavioral aspects in energy consumption"*. Proceedings of the 3rd International Conference on Financial Education, Aveiro, Portugal, 3rd to 4th July (Available on http://pmate4.ua.pt/conferencias/edufin2012)

2. Oliveira, W.S., Fernandes, A.J. & Pereira, E.T. (2010). "*Emissions of Greenhouse Gases: Case of Aveiro".* Proceedings of the Earth Summit: global heating, society and biodiversity/International Forum of Environment, Vol 1: 37-47, ISBN: 978-85-7745-532-4, Olinda, Brazil, 26 to 29 May.

3. Oliveira, W.S., Fernandes, A.J. & Pereira, E.T. (2009). *"Analysis of Alternative Scenarios of GHG Emissions to Av. Dr. Lourenço Peixinho in Aveiro – Portugal".* Proceedings of the 5th Conference of Engineering "Engineering 2009 - Innovation and Development", Covilhã, Portugal, 25th to 27th November.

4. Oliveira, W.S., Fernandes, A.J. & Gouveia, J.B. (2009). *"Methodological review of unit cost calculation by life-cycle cost and RETScreen® for wind energy".* Proceedings of the 1º Congresso Lusófono sobre Ambiente e Energia/3ª Jornadas de Energia de Cascais, Estoril, Portugal, 20th to 22th September.

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"Be fruitful and multiply and fill the earth and subdue it and have dominion over the fish of the sea and over the birds of the heavens and over every living thing that moves on the Earth."

Genesis 1:28

CHAPTER 2

RENEWABLE ENERGY, ENVIRONMENT, ECONOMY AND SOCIETY

This chapter has presented the relationship among energy, economy and society. It discusses about the development of societies and energy; energy and structure of societies. It is discussed the environmental impacts from energy production and utilization, contribution to greenhouse gases and other pollutants emissions. Summary and conclusions are presented at the end, with the respective references.

2.1 INTRODUCTION

Over the centuries, mankind has used energy from many sources to meet their food needs, housing, transportation, health and improve their living conditions. The two main sources of energy, the sun and nuclear fission, and their relative abundances, influenced and still do in the current human activities. As alternating forms of social grouping of men, so too would be changing the use of energy resources. The primitive savages who hunted and collectively, their food in nature depended primarily on their own energy. Today in much of the world population is able to resort to fossil fuels, but also in developing countries makes the use of animal power, human strength and wood fuel (Cook, 1976). Whatever type of energy used, the man always had to expend energy to meet their survival needs. Vast supplies of fossil energy allowed countering the increase in population. Birth rates remain high while the reserves of energy, especially fossil fuels are declining∴That's how we look to the future, when the world population to be served has nearly doubled compared to the present day. We are concerned to know what strategies can be applied to meet a demand for energy increased so tremendously.

Before we can draw up plans to introduce greater efficiency and renewable energies in the current energy matrix, it becomes necessary to gather much information about the costs of energy used in different processing systems for the production and distribution of goods essential for survival of mankind. Such costs must be brought into confrontation with the energy supplies that would be available. Accordingly, this chapter is to explore the interdependencies between energy, economy and their impacts on society∴It is my hope that such analysis as a basis for understanding the context and that in fact the economic process in any society defines the profile of energy production and consumption, as well as its impact on society as a whole. For Akella, Saini, and Sharma (2009) renewable energy technologies can have dramatically reduced as well as widely dispersed environmental impacts, rather than larger, more centralized impacts that in some cases are serious contributors to ambient air pollution, acid rain, and global climate change. Keeping in mind, the social, economic and environmental effects of renewable energy system could also mean a way to start changing the modern humankind energy behavior.

This chapter has characterized the environmental impacts from the use of energy sources derived from fossil and renewable resources. Man evolution is closely linked to energy, since the beginning of time man has to know it and seeking it ever more on the environment. He began to enjoy and benefit from its potential fossil and renewable resources. The use of more efficient technologies, along with the application of sustainable energy policies has contributed to a general reduction in the intensity of CO_2 emissions by energy production and consumption∴It begins with a contextualization of the development of societies and energy (section 2.2), and briefly presents the energy resources the influence on structuring of societies (section 2.3). Section 2.4 has discussed about energy resources and environmental impacts in demand and supply side, the relation of energy and environment (section 2.4.1) in the point of view of consumption and emissions of CO_2. The impacts of electricity production was also discussed in section 2.4.2, especially with renewable technologies such as hydroelectric (section 2.4.2.1), biomass (section 2.4.2.2) and wind power (section 2.4.2.3). Finally, section 2.5 presents the summary and conclusions of the whole chapter. Section 2.6 presents the references used.

2.2 DEVELOPMENT OF SOCIETIES AND ENERGY

Societies throughout history of mankind in order to ensure their basic survival needs - food and health, housing and safety - always found itself closely linked to energy supply, so the energy in all its forms is part of their own nature of man. Along this route, man has used energy from many sources. Starting with your own energy and sunlight (solar energy), then passed to the wood fuel, animal traction, force of water and wind. Later it was developed into power of machines powered by wood, coal, oil and nuclear energy∴The man power used to modify or manipulate the land, water, plants and animals in order to provide himself food, clothing and shelter materials. Discover, control and use power forward took the man's primitive life to a stable civilized. Man is the only animal capable of thinking creatively and using science and technology, getting benefits from energy and other environmental resources.

Energy is also used to control disease organisms; to obtain and purify and store water, to produce antibiotics and other chemical drugs, and to implement various public health measures. Although public health is an aspect of security, is both to stability are also associated with the protection of men among themselves, a group of people against the actions of other rival groups. Social harmony depends not only on the rules set by governments but also the efficiency of police and military forces used to enforce the law. Both governments and police forces and military spend enormous amounts of energy. In so-called *"civilized societies"* of developed nations in the world today, the amount of energy used by the government and police and military forces is significantly higher than that used to grow food for the population governed (Cottrell, 1955).

The availability of surplus energy enables the man creates more complex structures that the first hunter-gatherers∴The present state of utilization of energy resources represents a dramatic change in relation to that one of a recent past in the search for adequate food was the main concern of the man and ran their activities. According to White (1943) the evolution of man can be broken down into three main stages: (1) population *"wild"* in the hunter-gatherers who lived from natural feeding, (2) population *"barbaric"*, primitive agricultural and pastoral societies and (3) *"civilization"*, the development of machines and intensive use of fossil energy to produce food and other useful items. These steps are all related to changes in supplies of energy used by man∴White [3] considered that *"this would have stayed indefinitely at the level of savagery if I had not learned the amount of power under his control"*. This includes the total amount of energy controlled by man and the surplus energy that he has higher than necessary to meet the essential needs of food, clothing, shelter and health.

Energy use has accommodated the modern society in such way that societies with little access to energy resources present consequently lower evolutions than for other societies that have increased access to energy. Countries located in continents like Africa, have very low rates of energy consumption, but the poverty rate is high due to lack of technology supported by strong energy sources. With the lack of energy the Government weakens and impoverishes society. Given the continued dependence of man on energy, and knowing perfectly fits an overall historical society constantly seek new outlets for production, without which you cannot get a strong, competitive economy (Willrich, 1978).

It may be noted that currently, at what humankind has done and continues to do in pursuit of energy kind. We highlight here the oil, which continues to keep wars. Countries seek power over that coveted energy potential, which is able to influence society in such way that moves a country and makes the mankind drives through essential principles for harmony between peoples. It is also evident that so-called developed countries are those with greater energy consumption, this because they need energy to keep all their energy potential and technology, it can be noted by observing that countries like the United States and much of Europe where energy consumption is very high, thus causing pollution indexes thunderous∴However, we can highlight concerns about the relentless pursuit of energy, a quest that will surely come to an end.

The government assumes leading role in the development of each society, and must provide access for the whole society to energy resources, acting as a valve which regulates how much and how to use energy resources, which cannot be neglected, governments can fulfill its role of accessibility to all energy forms becomes a major factor for the evolution of a society, but that does not fulfill that role will eventually contain the development of its population in addition to harming the environment (Hinrichs & Kleinbach, 2004)∴Energy is essential for the development of any society. Given the constantly evolving experience that is in modern society and knowing that it is highly linked with this indestructible goods called *energy*, should be imposed on society information about the rational use and respect the environment, from which it is extracted, so that we do not achieve results in the formation of a harmful at all, thus implying the reverse evolution (Hammond, 1972).

Modern economies have been depending on incessant and increasing amount of fossil fuels and electricity, but the relationship between economic growth and energy resources use has been both dynamic and complex: It changes with developmental stages, and although it displays some predictable regularity, a closer analysis reveals many specificities that drive any normative conclusions about desirable rates of energy supply and consumption. High-energy civilization is now really and factual global — but millions of people still has no access to electricity and its benefits remain far away. Although the huge international differences in the use of commercial energy have narrowed considerably since the 1960s, an order-of-magnitude difference in *per capita* consumption of fuels still separates most poor from rich nations, and the gap in the use of electricity remains even wider. There are also large disparities among different socio-economic groups within both high and low-income nations (Smil, 2000).

2.3 THE ENERGY AND STRUCTURE OF SOCIETIES

The hunting-gathering societies were small, rarely more than 500 individuals and were simple. As the demand for food and shelter was time consuming and a lot of energy, almost there were no other individual and collective activities∴However, with the development of agriculture, became available larger amounts of food, fiber and energy surplus. Concurrently, there are, in human societies, the greater interdependence among people and more incentives to increase productivity (Bews, 1973; Lee. R.B. & DeVORE. I., 1976; Service, 1962). This factor was also important the fact that, as they increase their output of food, also increased the stability of food supplies. Companies once forced to be nomads to monitor their food supply has improved with regard to safety and permanence∴Even in primitive agricultural societies, food production was still the principal activity of man and as a consequence, their social interaction remained relatively narrow. The introduction of animal draft power in crop production released greater amounts of time and energy of man∴This surplus of energy and more time allowed the man to participate in several new activities, which led to making more complex social systems.

The water wheel and windmill added new forms of energy to those who initially has used the man in their production processes, particularly in the food production system. Now, instead of using draft animals whose feed and care require energy, man resorted to force of the water and wind. With this change, the man was to have more power at less cost (calculated in terms of human energy expenditure) than in the past. Thus, the amount of surplus energy available to the society was largely increased. The transportation of goods and similar things were done by the direct utilization of human force, as has been shown in Figure 2.1.

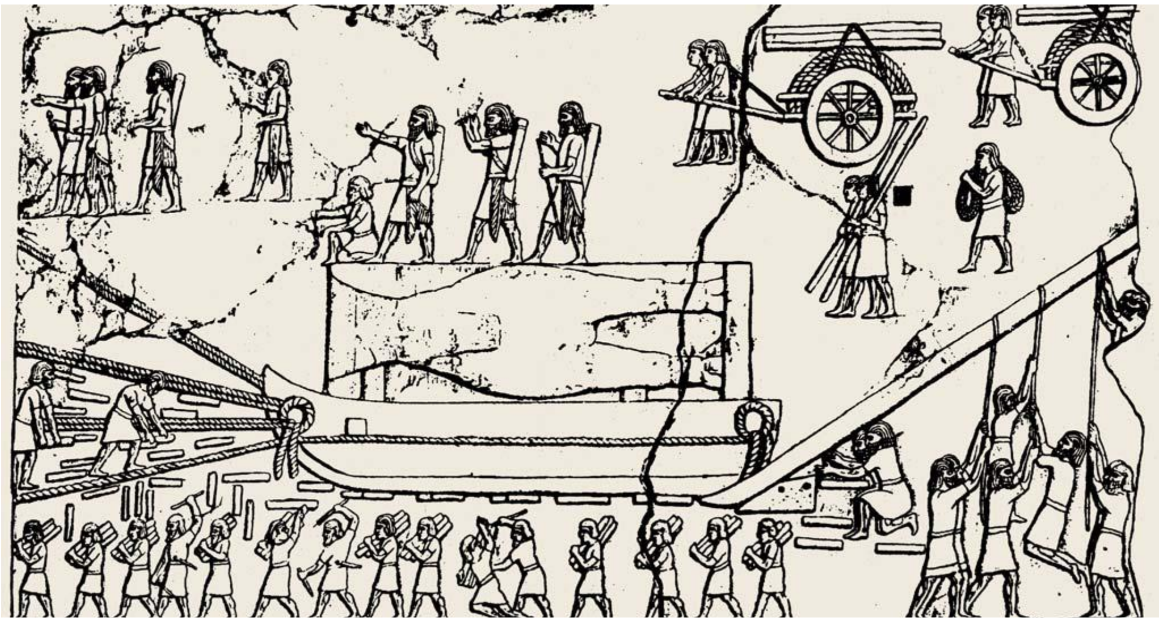

Figure 2.1 Transport of solid stone monument in 660 bC. Source: Loftness (1984)

The invention of the steam engine was a highly significant milestone in energy use, as marking the beginning of the use of fossil fuels as primary energy source. This machine, and later those who used coal and liquid fuels, has given the man an immense power to control their environment and change the whole economic structure, political and social society, while there is greater stability and expertise of work.

The society´s structure of the first hunter-gatherers was minimal. At most, a boss or a group of elderly people ran the camping or village. Most of these leaders were forced to hunt and collect together with other members, because they were scarce surplus food and other vital resources to allow it work at all times a chief or a village council. The agricultural development has altered this pattern of work monotypic. The primitive family farm could reap 30 to 10 kg of grain per kg sown. Part of this surplus food/energy was returned to the community and ensured the maintenance of non-farmers, such as chiefs or village councils, doctors, priests and even warriors∴The non-farmers in those primitive societies assumed the government and ensured the stability and security to the farmer population, so that could increase the surplus of food production/energy (Cottrell, 1955; Fakhry, 1969). Under favorable conditions in agriculture and improving agricultural technology began to obtain considerable energy surplus and as a result, there have been major population groups or even cities. With the population concentration in larger cities, appeared the specialization of tasks∴Specialists such as masons, carpenters, blacksmiths, merchants, traders and sailors, proved more efficient than the non-experts. Goods and services provided by artisans-technologists have determined an improved quality of life, a higher standard of living and, for most societies, an increased stability.

Egypt, during the reign of the Pharaohs, is a striking example of a primitive society that has environmental resources in favor of establishing a stable agriculture, which created an efficient agricultural technology. The Nile brought water to the cultivated land and valuable nutrients, which replaced those crops of cereals and other products taken from the soil. Thanks to its periodic flooding, the Nile deposited nutrient-rich sludge to arable land, which thus remained productive. He was also a source of water for irrigation trustworthy∴Furthermore, and with equal importance, had to consider the hot climate of Egypt is highly conducive to agricultural production. This productive agricultural system sustains 95% of Egypt's population directly involved in agriculture, and provided enough surplus food/energy to keep 5% of population that does not worked in agriculture. To sustain the small ruling class, a relatively small quantity of food energy was enough. The naturally isolated location of Egypt ensured protection against intrusions without requiring large expenditures to sustain a military class. Consequently, the 5% of the population engaged in agriculture were not used by the Pharaohs as slave labor to build pyramids and storing these goods and materials for a life that, according to the Egyptians believed would follow the life on Earth (Cottrell, 1955).

Throughout this period, the Egyptian population has remained relatively constant because of demand made by the heads∴Once the men were in excess sufficiently capable to work were used to build the pyramids. These men were forced to perform many hours of hard work and were literally *"used until death"* during a period of a few years of slave labor. When they died, were replaced by new elements selected from among the redundant workers. All this was done without compromising the fundamental agricultural system that required the efforts of almost all the Egyptian people. During the age of the Pharaohs, which occupied the years from 2780 to 1625 b.C., Egypt had a population of about 3 million, far less than the 38 million nowadays. An excess energy of 5% in about 3 million people is not much. In *per capita* basis of 100-150 kcal[1] per day, equivalent to 10-15 kg of wheat per person per year. In relation to 3 million, the total reaches 30-40 x 106 kg of wheat per year surplus (Cottrell, 1955; Fakhry, 1969).

The construction of the pyramid of Cheops over 20 years has used an amount of energy that equaled the surplus energy produced during the life of about 3 million Egyptians∴During the construction period, the labor force was applied to some 100,000 slaves per year. Assigning each slave 300 to 400 kg of food per year, the total cost would have been 30-45 x 106 kg, or the whole of the surplus food/energy from agriculture in Egypt. In later periods of Egyptian history, similar levels were used to maintain large military forces that won some of the neighboring countries of Egypt∴These military operations have provided some additional land and food and often conquered peoples were brought to Egypt as slaves. However, long distances in desert regions that the Egyptian troops were forced to travel and limited supply of these military operations. It was necessary to spend large amounts of energy only to protect the roads and transport military supplies.

On other occasions, when the population increased greatly in relation to land resources and agriculture, there is no longer in Egypt surplus agricultural resources. Under these conditions on overcrowding and failure instead of surpluses, the Egyptian society was only able to sustain itself. Sometimes, under these pressure conditions, there were civil wars and social problems. Such conditions often led to declines in effective population size, since those societies were not productive either unstable in agriculture and in other essential activities.

Thus, the primitive history of Egypt is an excellent example of the role that energy, measured in surplus food/energy, played in the structure and activities of a primitive society. Although the structures of the societies of today are much more complex, the energy continues to be an important factor in the development of mankind∴Humanity will have to adapt and find new energy potential, as it did throughout its history. New energies come exhaustible or not, clean or not, but they will be distributed equally? It does not help the vast energy production if the same will not be distributed and enjoyed by all people equally.

[1] Historically, the definition of a calorie was a quantity of heat required to increase by 1 degree Celsius temperature of 1 gram of water. With the development of measurement technique, it was found that the specific heat was not constant with temperature. So we tried to standardize it to a narrow range and calorie was then redefined as the heat exchanged when the mass of one gram of water from 14.5°C to 15.5°C. A kcal is the amount of energy required to increase up by 1 degree Celsius temperature of 1 kilogram (kg) (equivalent to 1 litter) of water. Thermodynamics: An Engineering Approach, 5th edition by Yunus A. Çengel and Michael A. Boles.

2.4 ENERGY AND ENVIRONMENTAL IMPACTS

The production and use of energy have environmental and social consequences locally, regionally and globally. These impacts are spread over the lifetime of a system of energy based on fossil resources and can manifest itself in a shorter time scale, medium or long term. Proper assessment of these impacts and their inclusion in decision-making process on energy is a key to ensuring a sustainable energy sector (UNDP, 2000)∴Local impacts, although affecting a small group of people can be extremely important, especially if involving occupational diseases and accidents affecting workers or members of the public. Local impacts are also more relevant to renewable technologies. For example, concern over the development of wind farms typically refers to visual intrusion on landscape and noise emissions (European Commission., 1995).

However, large thermal power plants or renewable energy or fossil fuels also can have adverse effects on local resources related to excessive consumption of water, soil and groundwater pollution, or deforestation. The sustainable energy strategies of the plan of the *United Nations Development Program* (UNDP) presented some examples of regional impacts related to energy production, such as acid deposition, habitat destruction, large-scale displacement of people due to construction and operation of projects large hydroelectric or radiation due to accidents at nuclear power plants (UNDP, 2000). Globally, the link between energy and the effects of global warming around the world is documented∴Other relevant global impacts include loss of biodiversity and land degradation.

European Commission. (1998) states that impacts should be evaluated over their lifetimes. Although EC presents uncertainties for the long term impacts such as global warming or high level radioactive waste disposal. Likewise, Weisser (2007) recalls that in economies where the carbon has a fixed price or emissions of greenhouse gases (GHGs), embarrassed, do not respond adequately to GHG emissions in the life cycle in the production of electricity, can be advantage for transnational technologies, which makes the accounting for significant emissions within the lifecycle of a project outside the boundaries of laws and policies to mitigate greenhouse gases.

This section examines the impacts of different electricity production technologies based on literature review. Section 2.4.1 focuses on the close relationship between energy and environment, detailing trends in CO2[2] emissions from the consumption of primary energy and electricity production activities, outlined in the Kyoto Protocol and European Union regulatory in promoting environmental performance in the energy sector∴The impacts of the activity of electricity production are described in section 2.4.2 for both fossil fuels and the main renewable energy technologies. This section discusses in detail the environmental and social impacts of hydroelectric, biomass and wind energy technologies, discusses the effects of integration on the electrical system and discusses the social acceptance of these technologies.

[2] There are six greenhouse gases recognized under the Kyoto Protocol. The analysis focuses principally on CO_2. This is the most important anthropogenic greenhouse gas accounting for 82% of total emissions greenhouse gas emissions in EU-27 and 79% of emissions of greenhouse gases in Portugal in 2005.

2.4.1 ENERGY AND ENVIRONMENT

Energy production and consumption is strongly associated with the environmental pressure on the planet. For example, emissions of SO_2 (sulfur dioxide), greenhouse gases and other CO_2 and NO_x (nitrogen oxides) for a certain period, depends on the amount of electricity produced and the technological mix of plants operating in each electrical system for some period∴The actions of each of the fossil fuels, nuclear and renewable operate with the efficiency of each production center represent the key mechanisms available to assess the environmental performance of the electricity system of a country.

According to the report of the EEA (2007) for the EU-15[3], the main factors responsible for reduction of CO_2 emissions from the system for producing electricity and heat are the improvement in efficiency, fuel substitution derived from coal to gas and to a lesser extent, increasing the share of renewable energies. Portugal is a particular case in which CO_2 emissions are heavily dependent on rainfall conditions∴The emission level shows significant variations in relation to fluctuations accentuated hydropower production, which is heavily dependent on annual rainfall. However, the close relationship between energy consumption and CO_2 emissions from the energy sector is evident.

Figure 2.2 has shown the close relationship between energy consumption and CO_2 emissions worldwide. World consumption of primary energy is increasing and between 1990 and 2004 grew 29%. CO_2 emissions showed a similar trend in 2004 also has increased about 27% compared to 1990∴The small difference between the rates of increase allows a small reduction in CO_2 emissions per unit of energy consumed.

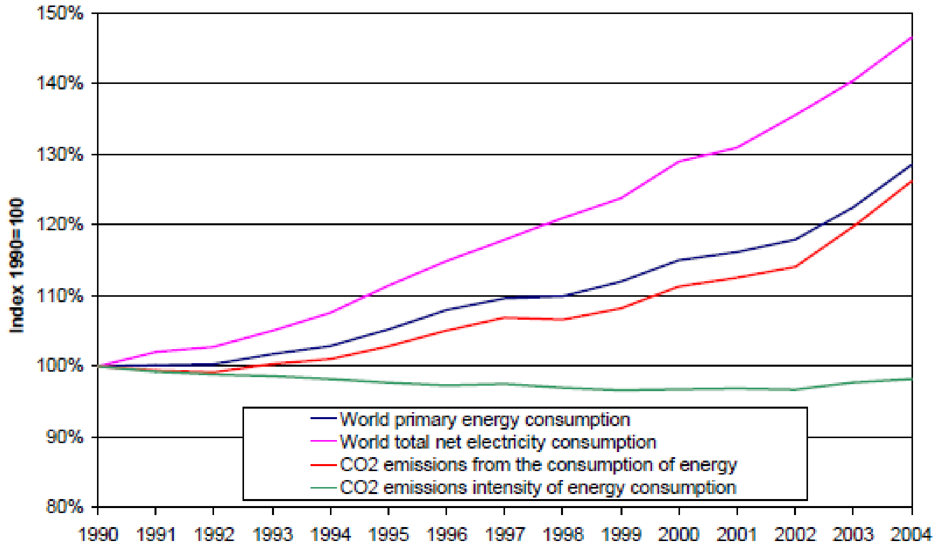

Figure 2.2 Trends in global consumption of energy and electricity, CO_2 emissions and CO_2 emissions intensity of energy consumption. Source: EIA (2007)

[3] Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Spain, Portugal, Sweden and United Kingdom.

At EU-15 there is a general trend of increasing consumption of energy, as shown in Figure 2.3. However, the use of more efficient technologies and renewable energy, along with some structural changes that occur in members of the EU and the introduction of specific policies and measures, contribute to a less significant increase in CO_2 emissions∴As a result, between 1990 and 2005, CO_2 emissions per unit of energy consumption dropped by 12%.

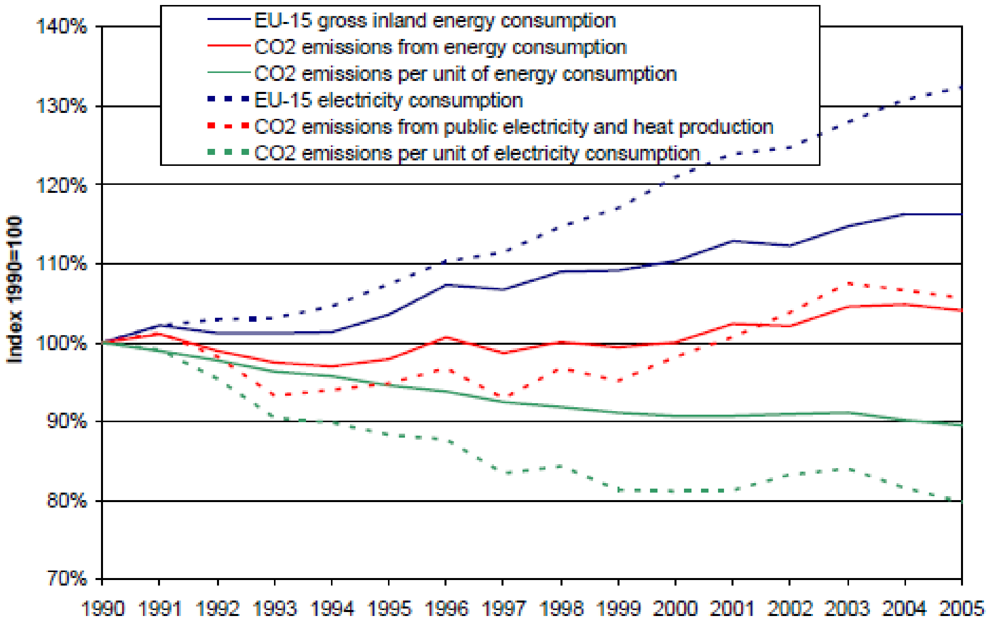

Figure 2.3 Trends in the EU-15 and electric energy consumption, CO_2 emissions and intensity of CO_2 emissions from energy consumption. Source: EEA (2007); EIA (2007)

Demand for electricity is growing fast and, to some extent, offset the increase in consumption of the environmental benefits achieved through technological advances and fuel switching∴A similar effect occurs in the transport sector∴Transport emissions in the EU-15 increased significantly during the same period as a result of a continued increase in demand for road transport. This has offset much of the decline in other sectors (EEA, 2006). In general, the CO_2 emissions associated with energy consumption and real electricity showed a downward trend between 1990 and 2005, indicating movement toward the mix of less carbon intensive fuels in Europe.

Energy production and consumption are the major emission sources of GHGs in the EU. Figure 2.4 has shown that in 2005 the CO_2 emissions produced by industry in Portugal and the EU-27[4]. About 90% of total CO_2 emissions in Portugal are related to energy, which means they are a result of the activities of energy consumption. This figure rises to 94% in EU-27∴Particularly relevant is the

[4] Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and United Kingdom.

role of the sector of electricity and heat. About a third of CO_2 emissions deriving from fossil fuels to generate electricity, with each core are able to send millions of tons of CO_2 annually.

Limit the concentration of CO_2 in the atmosphere requires a reduction in CO_2 emissions across the economy. The electricity production sector has some special characteristics that makes it an important target for reducing CO_2, as have pointed out by Johnson and Keith (2004) in relation to emission sources distributed in the sector of transportation, electricity production plants can achieve reductions depth with minimal impact on energy infrastructure, property and centralized management of the power industry regulation and facilitates the producers have gained considerable experience in recent years with increasingly tight controls on conventional pollutants, and it is unlikely that producers of electricity movement for the least-regulated as could happen for the industry.

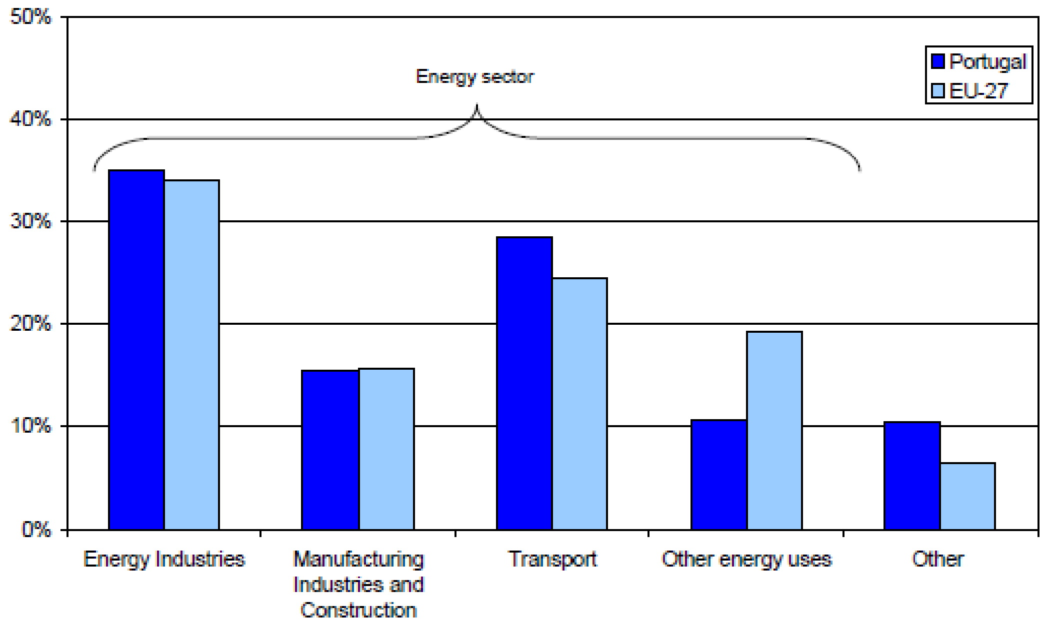

Figure 2.4 Percentage of CO_2 emissions of air pollutants by activity in 2005, EU-27 and Portugal. Source: EEA (2007); EIA (2007)

In Portugal, in 2005, CO^2 emissions from the operation of a coal were about 844g/kWh (EDP, 2006). Whereas from the operation of central CCGT[5] this value was about 375g/kWh (Turbogas, 2006). The results of Hondo (2005) have indicated that, even nuclear power plants emit approximately 24g CO_2/kWh during its life cycle, particularly uranium enrichment. The wind power plants are responsible for 29g CO_2/kWh mainly released during the construction and

[5] Combined Cycle Gas Turbine. A production plant uses a combined cycle gas turbines and associated steam in a single center, both producing electricity from the burning of same fuel. The heat in the exhaust gases of gas turbines is recovered to generate steam necessary to drive the steam turbine. Thermodynamics: An Engineering Approach, 5th edition by Yunus A. Cengel and Michael A. Boles.

installation. Renewable energies have generally low CO_2 emissions and are heavily favored by environmental regulations for the energy sector.

An important factor in future development of energy sector and the definition of current and future energy policy is the Kyoto Protocol. Under the Kyoto Protocol, the EU pledged to reduce emissions of greenhouse gases to 8% during the first commitment period, from 2008 to 2012. This objective is shared between the Member States under a legally binding burden-sharing, which sets emission targets for each individual Member State. In particular, Portugal could increase the average emissions of 27% of 1990 emissions level. Growth reduction in electricity consumption will be crucial in the environmental point of view, especially in relation to consumption of electricity produced by fossil fuels.

The renewable energies sources do not generate CO_2 (or very little), do not throw radioactive waste, and generally have significantly lower levels of other pollutants. Improving the environmental performance of fossil fuel plants is also essential and can be reached with the increasing use of abatement technologies effectively and improve efficiency. The need to reduce the pressures imposed on the environment through the use of energy worldwide and in the continuing effort to promote and utilize renewable energies sources and supplemented by changes in consumer of energy behavior.

2.4.2 IMPACTS OF ELECTRICITY PRODUCTION ACTIVITY

There is growing recognition of the importance of social and environmental impacts of the production of electricity. As described in the previous section, the energy production process involves, in which the shares of producers of electricity cannot be adequately reflected in market prices of product. EIA (1995) has classified the externalities attributable to electricity production in four categories: air pollutants, greenhouse gases, quantity and water quality and land use values.

Clarifying the full costs of energy production for regulators and policy makers is particularly critical because of the non-price differentiation between suppliers of electricity produced from different sources with emissions of pollutants potentially very different. The basic purpose of social accounting is to make explicit the full magnitude of the direct costs and environmental costs of electricity derived and supported by society in order to influence decision makers in making investment decisions in the energy sector to improve the welfare social (Venema & Barg, 2003).

Develop defensible estimates of externalities are a complex and costly exercise (Rowe, Lang, & Chestnut, 1996). Externality values for the production of electricity have been developed in the U.S. and Europe. Freeman III (1996) and the EIA (1995) have presented some key studies on estimates of external environmental costs that result from adding the ability of a system for producing electricity.

The European Commission, together with the Department of Energy launched a joint research project to assess the environmental externalities of energy use in 1991. During the project, an accounting framework for the operational assessment of external costs of energy technologies, called *ExternE* (Externalities of Energy) was developed. The U.S. suspended its participation in the project at the end of the first phase. The methodology and results are widely accepted and have been used to support other studies and projects, some relating to different sectors or regions as APERC (2005), Venema and Barg (2003), NEA (2003), HEATCO (2006) among many others[6].

Table 2.1 Overall results of the ExternE

Technologies models	Air pollution impacts (PM_{10}) and other impacts	Greenhouse gas impacts
✡ Biomass technologies	High	Low
✡ Existing coal technologies (no gas cleaning)	High	High
✡ Natural gas technologies	Low	High
✡ New coal technologies	Low	High
✡ Nuclear	Low	Low
✡ Wind	Low	Low

Source: adapted from European Commission. (2003)

In general, as shown in Table 2.1, wind power technologies are environmentally friendly with respect to emissions of pollutants, including emissions of greenhouse gases. However, the results also indicate some variation of external costs attributed to wind due to noise impacts or other utility, mainly depending on local conditions of each park studied. Nuclear technologies have low emission levels and generate low external costs, even considering the low probability of accidents with high consequences. As for biomass, due to the large number of technologies, changes in external costs are high, although in general they generate greenhouse gas emissions very low in their life cycle. The gas technologies are clean with respect to conventional pollutant (not including greenhouse gases), but depending on the efficiency of the technology can impact on climate change due to CO_2 emissions. Coal technologies generate high emissions of CO_2, even for new, more efficient technologies. Old coal plants are highly polluting units for each type of pollutant considered (European Commission., 2003).

For fossil fuels, global climate change is very fundamental question that dominates the current energy policy. For nuclear fuel, potentially large consequences of an accident, and long-term impacts of radioactive waste are the key to the major decision. The expansion of renewable energy technologies has resulted in a growing opposition in certain portions of affected local population on account of the impacts of increasing usefulness. Potential impacts on the local ecosystem by, for example, hydro, offshore wind farms or biomass plantations in particular have raised objections from interest groups that traditionally consider green renewable energy technologies as a viable alternative instead of nuclear energy (Krewitt, 2002). The calculations of Mirasgedis, Diakoulaki, Papagiannakis, and Zervos (2000) have indicated that mortality associated with the effects of air

[6] A list of related projects can be found in ExternE at http://www.externe.info/.

pollution and the effects of global warming are the major components of externalities attributed to conventional power plants.

For biomass power plants, the external costs associated with global warming are considered void and the impacts of high priority are close to those identified for the plants to conventional oil. As for wind farms and hydroelectric plants, the main external cost refers to the noise and accidents. Although renewable energy sources are generally associated with lower external impacts on the power plants that use fossil fuels, particularly coal, are not entirely free of impact. In fact, significant negative impacts were studied for the most common renewable energy technologies used. The potential of renewable energy sources is enormous as they can in principle meet many times the world's energy demand. Renewable energy sources such as small hydropower, wind, solar, biomass, and geothermal can provide sustainable energy services, based on the use of routinely available, indigenous resources (Akella et al., 2009).

2.4.2.1 Some impacts of hydroelectric

As for the hydroelectric sector, a large number of benefits or positive impacts can be described in Almeida, Moura, Marques, and de Almeida (2005), U.S. Department of Energy[7] and World Bank[8]:

- Energy impacts associated with: the economic value of electricity and energy supply, economic benefits of potential reserves, drive dynamic response of these technologies and emissions avoided. Furthermore, it is a source of domestic energy and renewable. REN (2006) notes that high levels of availability and production flexibility are two major advantages of hydropower.

- Impacts of water resources, associated with the contribution to irrigation, water supply and minimum in stream flows during the dry season.

- Socio-economic development impacts associated with the creation of new activities or sports-related tourism, producing new jobs and diversifying the economy. Agricultural activities can also benefit from flood control and water availability. Most hydropower installations are required to provide public access to the reservoir to allow him opportunities to exploit.

However, some important disadvantages or negative impacts are also reported in the literature as Almeida et al. (2005), U.S. Department of Energy, World Bank, International Rivers Network[9]):

- Environmental impacts associated with loss of habitat and biodiversity, loss of fish stock, landscape changes or obstruction of movement of migratory fish. Dams also change the pattern of river flow, reducing its overall volume and seasonal variations. All parts of the ecology of a river may be affected by changes in their flow.

[7] For more details, check on http://www1.eere.energy.gov/windandhydro/hydro_ad.html.
[8] For more details, check on http://www.worldbank.org/html/fpd/em/hydro/ihd.stm.
[9] For more details, check on http://www.irn.org/index.php?id=basics/impacts.html.

- Energy impacts. The capacity of electricity production is heavily dependent on rainfall conditions.

- Socioeconomic impacts. New hydro can compete with other land uses that may be more valued than electricity production. Local people could lose their homes and lands. Local cultures and historic sites can be invaded.

- Loss of local convenience. Noise and vibration due to construction activities can disturb the local wildlife and human populations nearby.

A detailed description of the impacts of hydropower can be found at the World Bank, along with a description of possible mitigation measures.

The WCD (2001) supports the idea that the dams have been promoted as an important means for meeting water and energy needs and long term strategic investment with the ability to deliver multiple benefits. Regional development, job creation and promotion of an industry base with export potential are often cited as benefits. However, these benefits must be weighed against the environmental and social impacts of large dams. The huge investment required to build large dams, and its enormous impact social, environmental and economic projects makes them highly controversial.

2.4.2.2 Some impacts of biomass

Bioenergy is a heterogeneous aggregation of different feed materials, conversion technologies and use of energy resources thin. In the European context, the biomass is taken to include agricultural and industrial waste as a potential source of fuel for heating and electricity (McKay, 2006). The main positive and negative impacts of biomass technologies in the literature are listed below:

- Environmental impacts. As with other forms of combustion, burning wood emits air pollutants. The amount and type of pollutants depend on both the specific combustion process involved and the extent of controlled burning. Compared with fossil fuel combustion plants fed with forest residues emit similar levels of nitrogen oxides, but significantly less sulfur dioxide (Miranda & Hale, 2001).

- Energy impacts. Among renewable energy sources, biomass is one of the few resources whose availability is not dependent on weather conditions, seasonal and diurnal and can be stored for use on demand (Thornley, 2006). This represents an important advantage, allowing the production of electricity more predictable. Moreover, a source of domestic energy, contributing to the diversification of the fuel mix and supply security.

- Socioeconomic impacts. The bioenergy projects involving energy crops could have significant contribution to rural incomes, or increased employment. Energy crops can lead to changes in patterns of agricultural work and make positive contributions to diversify the rural economy (Thornley, 2006). Results of surveys on local public opinion of a biomass gasifier proposed in the UK indicate that the potential impact on employment was further confirmed the benefit (Upham & Shackley, 2007).

Emissions from transport and infrastructure requirements and associated the new capacity of biomass can result in adverse reaction from segments of the local community (Thornley, 2006). Upreti (2004) has given some examples to show that the major obstacle to the promotion of biomass energy is the opposition of local people. In general, biomass technologies have fewer environmental impacts compared to conventional sources. Moreover, important benefits for rural populations and contribute to the security of electricity supply. However, there are significant local impacts that may raise questions and generate opposition to the development of biomass power stations. The effects of pollutant emissions are a major concern with the loss of quality of life caused by increased traffic and the installation of the plant.

2.4.2.3 Some impacts of wind energy

Studies have been published concerning the impact of wind energy development on the environment, economic development, on the functioning and security of the electricity system as well as the final cost of delivered energy. Manwell, McGowan, and Rogers (2002) have noted that the development of wind energy has positive and negative impacts. On the positive side, the authors point out that wind energy is generally considered environmentally friendly compared to conventional power plants for electricity on a large scale. However, the more wind turbines are installed; the importance of their negative impacts becomes more noticeable. The problems most often cited for the wind farms are the sound and visual impacts of wind turbines on the landscape of public opinion. Other concerns cited include the impact on birds and wildlife and issues regarding the integration of wind energy into electricity grids linked to perceived insecurity, high cost and low efficiency. Other effects are less frequently reported electromagnetic interference and land use (Devine-Wright, 2005; Wolsink, 2007).

- Avian interactions with wind turbines:

  The development of wind farms can adversely affect the birds due to collision and electrocution of birds foraging habits change, reducing the available habitat and change in breeding and nesting. Positive aspects of this technology can also arise, such as protection areas, land supply, hunting and protection of nesting birds or indiscriminate hunting (Manwell et al., 2002). There is no consensus among experts about the importance of the impacts of wind farms on birds. According to Travassos et al. (2005) and Fielding, Whitfield, and McLeod (2006) have indicated that studies in this field are far from homogeneous. The results depend on issues such as the location of wind farms; the type of birds analyzed, or weather conditions. The ExternE report on wind energy (European Commission., 1995) assigns a medium priority for this impact and concludes that the existence of European studies and experience provide no evidence of significant impact for collisions of birds in the turbines. In contrast, Drewitt and Langston. (2006) have concluded that although many of the studies are either inconclusive or indicate that the effects are not significant for a particular kind of place and season, this should not be used as justification for failure or bad rating future developments. According to these authors, there are relatively few studies that indicate significant impact that the improper location of wind farms can adversely affect wild bird populations.

- Visual impact of wind turbines:

  Wind power installations have been heavily criticized for being a new element and they are sometimes located in highly visible locations in order to exploit the wind conditions (Kaldellis, Kavadias K., & Paliatsos A., 2003). The impacts of landscape are sometimes aggravated by the fact that sites with good wind resources are precisely the areas that are exposed upland valued for their scenic qualities, so they are environmentally sensitive (Moran & Sherrington, 2007).

  Authors such as Bishop and Miller (2007), Manwell et al. (2002) and Kaldellis et al. (2003) have agreed that a major public concern and an important factor in determining public opposition to wind farms is the visual impact. The ExternE project considers the visual intrusion of turbines and related equipment, such as an impact that high on wind energy projects (European Commission., 1995). Regarding the visual impact of wind turbines are not well established and evaluation of the landscape is quite subjective (Manwell et al., 2002). Bergmann, Hanley, and Wright (2006) have studied on attitudes of people in relation to renewable energy indicates that the aesthetic pleasure of proposed wind energy is a controversial issue. Some people feel that wind farms are enjoyable to watch and represent renewable energy, while others consider them intrusive and a visual damage to the landscape.

  Wolsink (2007) has examined some works on public attitudes in favor of wind power, concluding that the visual impact of wind on the landscape is by far the dominant factor to explain why some oppose the use of wind power, while other support. Devine-Wright (2005) presents the view that despite the predominant emphasis of the literature on the visual impacts of turbines, there is little evidence that wind turbines are universally perceived as ugly. The view on the visual impact of wind on the landscape varies between different countries and so the emphasis on aesthetics of a wind farm varies from country to country. Moreover, studies in the UK reveal that the preservation of valued landscape motivates most of the opposition (see, e.g. TNS (2003) and Warren, Lumsden, O'Dowd, and Birnie (2005)).

- Noise from wind turbines:

  Noise levels can be measured, but the public's perception of the noise impact of wind turbines is very subjective. The ExternE project gives high priority to the impact and supports the idea that, while technical adjustments can be expected to reduce the problem, public awareness of the effects of noise of the wind turbine can still be significant (European Commission., 1995). Wind farms can be built without significant injury to the convenience, since the turbines are placed at a sufficient distance from homes. Appropriate planning requirements are essential to minimize this impact, but as Manwell et al. (2002) have noted, because of the wide variation in individual tolerance to noise, there is no completely satisfactory way to predict the adverse reactions.

Both mechanical and aerodynamic noise produced by wind turbines decrease with improved technology (Manwell et al., 2002; Moran & Sherrington, 2007). According to Kaldellis et al. (2003) due to the current output at low speed. However, studies such as Van den Berg G. (2004) have shown that there is not an insignificant issue. This author studied the noise of a wind farm in Germany, where residents of more than 500 meters from the park reacted strongly to the noise, as residents up to 1900 meters distance expressed annoyance. The main conclusions were that the actual noise levels were considerably higher than expected, and that wind turbines can produce sound with an impulsive character, further increasing the discomfort.

The economic, social and environmental perspectives are all included in the key elements of a sustainable energy system: sufficient growth of energy supplies to face human needs, energy efficiency and conservation measures, addressing public health and safety issues and protection of the biosphere. Thus, the sustainable development and sustainable energy planning are based on the same three dimensions, we mean, *economic, environmental* and *social* (Jefferson, 2006).

Energy resources have driven humanity life and history is still fundamental for continued human development and evolution. Throughout the course of history, with the evolution of civilizations, the human demand for energy has continuously risen up. The global demand for energy is rapidly increasing with human population growth, urbanization and modernization into societies. The growth in global energy demand is projected to rise exponentially over the next years. The world heavily relies on fossil fuels resources to meet its energy needs — fossil fuels such as oil, gas and coal are providing almost 80% of the global energy demands. On the other hand presently renewable energy and nuclear power are, respectively, only contributing 13.5% and 6.5% of the total energy needs (Asif & Muneer, 2007). The enormous amount of energy resources being consumed across the globe is having adverse implications and complications on the ecosystem of the planet.

2.5 SUMMARY AND CONCLUSIONS

Humankind evolution is closely linked to energy, since the beginning of time man has to know it and seeking it ever more on the environment. He began to enjoy and benefit from their potential. Thus obtained, greater adaptation to the environment that was often hostile and consequently sparsely inhabited. Respecting the means and knowledge of each period of evolution, man became sovereign in the environment, acquired with so much more responsibility, while that on the environment imposed serious changes to meet its development. As it evolved, the company acquired powers stemming from the nature and gradually increased his power over her, needing to preserve the environment in order to continue its development in a healthy way.

The primitive man first discovered, the potential energy contained in his body, received power to feed itself and the rest was consumed in the transportation and protecting other animals. Primitive man learned to use the energy contained in your body and thus dominate other species and survive in poorly relevant to the human race. Started to use the energy contained in the animals that could tame and over time learned to use this trick to get around, from horses and wagons to trains and aircraft. Moreover, he discovered the fire and according to Loftness (1984) the first discovery of man using fire as energy for cooking was their food and keep warm. With the discovery of fire and of course, the mastery over it began to prepare their best food, and not rely solely on the sun for lighting. Still used the fire to defend themselves against other animals or dangerous places that used to live. Thus, there is clearly a capability that the man had since primary season to adapt to the environment in which they live. According to the conditions that were exposed, he learned to manage them so that you could take greater advantage to them and to the society. From the moment we learned to take advantage of the benefits the fire, such as energy, brought to him, the man managed to improve their living conditions, therefore, enabled him to enjoy greater comfort in their day-to-day living day best in their community.

Over time, different energy sources were being explored allowing the evolution of man and society, with this development and from the moment the man was able to provide energy in a comprehensive manner the entire society. Currently available are several potential energy and have as main sources of energy, petroleum, coal, essential for society to evolve until the present time, however, there is great concern about the indiscriminate use, since attitudes yesterday are already reflected in many of the conditions in which we find ourselves. Energy production and use have unquestionable environmental impacts, contributing significantly to greenhouse gases and other pollutants. The use of more efficient technologies, together with the implementation of sustainable energy policies has contributed to an overall reduction in the intensity of CO_2 emissions from energy consumption, particularly evident in Europe. However, the overall increase in energy consumption often outweighs the environmental benefits achieved as described for the particular case of Portugal. The need for renewable energy called for the implementation of environmental legislation, where the environmental performance of electricity production is a priority line of action. Important steps include ratification of the Kyoto Protocol[10] and a large set of European

[10] The *Kyoto Protocol* is an international agreement linked to the *United Nations Framework Convention on Climate Change*. The major feature of the *Kyoto Protocol* is that it sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions .These amount to an average of five per cent against 1990 levels over the five-year period 2008-2012 (Greiner & Michaelowa, 2003).

directives: the promotion of electricity produced from renewable sources, creating the Emissions Trading Scheme and limiting emissions from large combustion plants.

Renewable energies have generally lower emissions than conventional power stations, making them strongly favored by the environmental regulations for the energy sector. However, renewable energy technologies are not free of negative impacts, although the public attitude in relation to renewable energy is generally positive, local people may react negatively to specific projects. In the particular case of wind energy impacts on the ecosystem, noise pollution (noise) and negative impacts on the landscape have been reported. By using variable production technologies such as wind power to generate electricity differs from electricity production by conventional power plants. Fluctuations in wind energy production occur in random pattern and must be compensated by the scalable production capacity compared to conventional production system (Rosen, Tietze-Stockinger, & Rentz, 2007). Because of this, wind power does not work as simple fuel savings because it cannot be controlled easily and accurately predicted (Olsina, Roscher, Larisson, & Garcés, 2007).

To properly assess the potential effects of wind on the system cost of electricity compared to other existing production systems should take into account the fuel savings and emissions avoided. Both the amount of CO_2 reduction and additional costs attributed to the system depends on the characteristics of the electricity system under analysis. As the report stresses the EWEA (2005) the size and flexibility inherent in the power system are crucial aspects that determine the system's ability to accommodate large amounts of wind. Obviously, there are various environmental, social and economic benefits of emission reductions. However, calculating these benefits requires totally different modeling framework that have been considered beyond the scope of econometric and engineering approaches used for this kind of analysis.

Holttinen and Hirvonen (2005) have concluded that wind energy contributes to the reduction of end use of fossil fuel emissions, but in high levels of penetration, an ideal system may require changes in the mix of conventional capacity. Also Rosen et al. (2007) have noted that a growing range of fluctuations is a challenging phenomenon and the resulting effects cannot be ignored, nor the operation of the power system, or in long term planning for the expansion of wind energy. Variations of wind power will affect the scheduling of conventional power plants to an extent that depends on forecasting, as well as the flexibility of conventional energy producers in the geographic area of the system under consideration (EWEA, 2005). Although the possible impacts of wind energy should not be overlooked, it is important to recognize that the systems without the wind energy also have significant variability (Dragoon & Milligan, 2003). So EWEA (2005) has pointed out that both supply and demand of electricity are variable and the variability of wind power can be provided in large measure. Regarding possible negative impacts associated with the irritation of noise intrusion and disturbance of the landscape ecosystem, its magnitude is specific to the local aspect. The installation of wind turbines is a critical issue in determining the level of impact (European Commission., 1995; Manwell et al., 2002).

In general, renewable energy technologies, named the wind power can provide an important contribution to reducing fossil fuel consumption and meet international environmental commitments. However, interconnection capacity, the combination of the existing capacity of production and characteristics of the wind power system to have a significant effect on how the variable production is assimilated by the system and on the extent of their contribution to meet the needs of modern society. The extent of this contribution deserves to be evaluated in economic terms via methods of economic and financial evaluation for these projects and their costs in order to ensure proper integration of wind power to meet current and future energy needs.

As has stated Khatib (2011) in a world in which the majority of us take the absolute availability of electricity and commercial fuels for granted, there are still 1.4 billion people that lack access to electricity. Also 2.7 billion people today still rely on biomass, and likely to increase to 2.8 billion in 2030 according to WEO 2010. This energy poverty is one of the big tragedies of our universe. Till today more than 40% of the world's population relies on non-commercial fuels in the form of biomass, waste, trees, dung, etc. to provide them with the necessary energy for cooking and heating.

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The wind blows to the south and goes round to the north, round and round goes the wind, and on its circuits the wind returns.

Ecclesiastes 1:6

CHAPTER 3

GLOBAL STATUS OF WIND ENERGY

This chapter presents the current situation of global wind energy industry. It is discussed about organizational model in wind energy industry within its diffusion process, R&D trends, innovation support schemes and the analytical framework for wind power business. World wind resources available and global wind energy market outlook are also presented. Summary and conclusions are presented at the end, with the respective references.

3.1 INTRODUCTION

Humanity is facing several critical global challenges at the beginning of the 21st century. One of which includes the quest for alternative energy resources that mitigate the dependence on fossil fuels. Whereas fossil fuels are available *in situ* at all times, the utilization of renewal energies has to cope with large temporal fluctuations ranging from seconds to seasons. The passing shadow of a cloud over solar panels causes the fastest variability of power output followed by the gustiness of the wind, the rise and fall of the tides and the seasonal and annual variations of the availability of biological resources for energy production. Thus, the kinds of questions being asked of the research community have changed over the last decades, reflecting the increasing awareness of the finite nature and the instability of fossil fuel supply.

Capturing wind energy has been widely employed for centuries — i.e. the traditional windmills of the Netherlands being a significant landscape element for centuries. To date, the emerging market for wind power energy is experiencing remarkable global growth rates which affect not only the problem of how to technically link these into existing power systems, but also effect deeply rural landscapes and local livelihoods. In many instances, initial positive local acceptance altered to the contrary, leading to sometimes strong opposition against the installment of wind turbines and wind farms in rural landscapes∴Hence, solving this problem requires additional input of economists and social-political scientists. The emerging interdisciplinary research increased the understanding and helped to develop adequate solutions to many of the problems revolving around wind power energy. However, the disciplinary integration and interdisciplinary understanding must be much further advanced.

This chapter is a compilation of the different aspects of wind energy power systems. It combines several scientific disciplines to cover the multi-dimensional aspects of this yet young emerging research field. It brings together findings from natural and social science and especially from the extensive field of numerical modeling. Harvesting wind power requires the erection of towers with rotating wings in the landscape or at sea. Such artificial buildings with moving parts modify drastically the natural views of the panorama. This raises the question of what are the initial necessary societal preconditions and attitudes to erect a wind turbine.

This chapter examines the topic of global status of wind energy in order to establish a context for understanding the contemporary wind energy industry. It begins with a contextualization of the organizational model in wind energy industry currently (section 3.2), and briefly presents the diffusion model of wind power evolution (section 3.2.1), trends in R&D for wind energy (section 3.2.2), structures and technologies to support innovation in wind power (section 3.2.3) and analytical framework for wind power business (section 3.2.4). Section 3.3 relates wind resources worldwide with the global wind distribution, while the following section presents mains concerns and how wind resources worldwide are spreaded globally. Section 3.4 is related to world wind energy market outlook, especially emphasis on global wind energy market (3.4.1), wind energy converters manufacturers (3.4.2) and economic impacts from wind energy industry (3.4.3) which devotes special attention to the job creation by wind energy industry. Finally, section 3.5 presents the summary and conclusions of the whole chapter. Section 3.6 presents the references used.

3.2 ORGANIZATIONAL MODEL IN WIND ENERGY INDUSTRY

3.2.1 THE DIFFUSION MODEL OF WIND POWER

Wind power systems are type of CoPS (Complex Product System) which are high-cost, engineering-intensive systems and never mass products for the final consumers. They are designed and produced on a project basis as one-offs for professional business. Unlike the final consumer, intermediate customers are intimately involved in the innovation process throughout the life cycle of the project. Technological accumulation is produced by the design, building and operation of the complex product system. The incremental improvement of technological improvement in complex product systems comes along as technological trajectory and they diffuse throughout the actor of best practice methods in design, manufacturing and construction (Davies & Hobday, 2005; Hobday, 1998). Wind power system also has multiple aspects such as technological system (Hughes, 1983), which receives the influence of non-physical artifact such as institution. To evaluate the effect of technology and policy in the diffusion process and recognize the mechanism which promotes this process is also our concern. In this paper, we propose a dynamic diffusion model in which supply and demand of innovations make progress by coexisting with existing energy system (e.g. fossil power station, nuclear power station). It is supposed more rational that wind power is carried out in complementing the existing energy system rather than supplying electric energy independently.

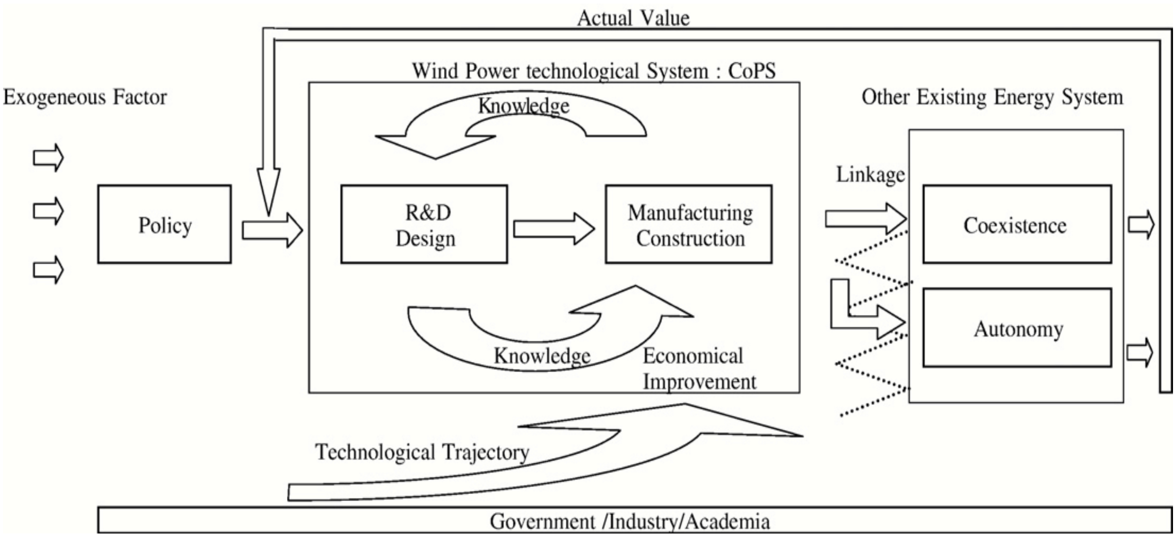


Figure 3.1 Diffusion model for wind power production system. Source: Inoue and Miyazaki (2008)

This diffusion model of wind power is shown in Figure 3.1. To promote the diffusion of wind power, economic factor is essentially important. For example, investment costs should be collected by electricity obtained by wind power. In order to collect investment cost, equipment has to be enlarged and we should pursue raising economies of scale. While the demand level about quality and safety is high in the market for using electricity obtained from wind power, the value is relatively low. Although its electricity is now approaching to produce profits, there are several problems in economic efficiency under the present circumstances. At first, the battle against global warming initiates the supply target of innovation (wind power), which could coexist with other existing energy system and help to reduce global warming. Government, industry and academic organizations are involved and the acts which could solve the above-mentioned problems are taken into consideration institutionally since it would not be a problem attributed only to industry.

The emphasis of technological development is put on safety, improvement in performance and reduction of manufacturing cost so as to penetrate this technology in the market by industry-government-academia collaboration. Industry raises the knowledge in connection with manufacturers to get over the critical point lying ahead. Then learning effect reduces the installation costs of wind power systems. In parallel, government could support the installation of wind power systems to get over the critical point so that the wind power systems have the competitive edge by which running cost can compete with other existing energy system on the basis of net present value∴Even if a wind power system is not able to link directly with the existing energy system economically, the alternative systemic measures that avoid some critical points are taken into consideration in this institution, from the stand point of a battle against global warming or energy security (Mowery & Rosenberg, 1979, 1998).

Often, collaborative R&D needs public support. The EU through the *Sixth and Seventh Framework Programmes* for research and development introduced the concept of technology platforms. These provide an opportunity for collaboration between a wide range of stakeholders, including industry, academia, politicians, the public, etc. In the present technology platforms in the renewable energy sector exist for solar photovoltaic, wind power, solar water heating and biofuels (IEA, 2010).

Rogers (1982) analyzed the diffusion problem most vigorously from a sociological standpoint and he showed the model of the innovation-decision process as a process through which an individual passes and the diffusion curve with labeling for the five adopter categories. Rogers explained the relation between the influence of communicating information and adoption decision in the earlier phase as well as the characteristics of adopters and the relative time progress of diffusion in the latter phase. However, Rogers' model is taking into consideration only for the diffusion process of the demand side. In the case of the standard concept which is unified in producing diffusion of innovations, Rosseger (1996) mentioned that standard versions of a new technology do emerge, ‘bugs’ are worked out by early adopters, market results are reported, and thus the quality of information which is available to later adopters improves. However this assumption is not demonstrated with the on-going phenomenon of supply and demand side (Ortt & van der Duin, 2008).

Institutions are broadly defined by economists and innovation theorists as social, political, and economic organizations that determine the working environment for systems to develop within. Institutional economists emphasize the role that institutions play on the outcomes of economic operations more than their neoclassical-school counterparts. How important an industry’s working environment is when examining technology development and cycles. For instance, the direction of domestic technology innovation can be influenced by knowledge spillovers due to international trade, the flexibility and ease of information flow from the university system, and the structure and patent making ability of the legal system. These institutional dynamics can vary widely across countries, both within and across different development levels. As such, global rates of technology development do not always imply similar rates of technology diffusion in particular domestic markets (Kobos, Erickson, & Drennen, 2006).

The types of institutions influencing innovation, and ultimately technology diffusion, have been categorized as horizontal, nonmarket, and vertical. Horizontal institutions include those in which large technical interdependencies exist between products or organizations. Positive feedbacks can emerge between horizontal institutions as, for instance, RD&D in one industry can lead to innovation or increased market potential in the other. In renewable energy technology, horizontal manufacturing structures may be necessary to successfully penetrate the market. For example, energy efficient home construction would benefit from well-designed solar thermal water heating systems. Nonmarket institutions are designed for goals not explicitly focused on short-run profits. These include professional societies, governmental agencies, and university-level research centers. These institutions often provide the necessary basic research and generic market promotion for incubating new technologies∴They are often designed as subsidies to industry development and their effectiveness is often dependent on political goals and agendas when *''society has found it necessary to supplement the usual market mechanism by additional institutions''* (Mohan Reddy, Aram, & Lynn, 1991).

Government and other organizing entities can often work to administer a coordination system. Figure 3.2 illustrates a conceptual framework for learning between individuals (e.g. workers and groups of workers) and the organization as a whole. The solid arrows represent flows of knowledge spillovers; the dashed arrows represent knowledge feedbacks. These feedbacks reinforce the role of knowledge stock solidarity (standardization) and quality control. For example, a knowledge spillover or *'feed forward'* from the organizational level to the individual level can include implicit on-the-job training. While a feedback from this knowledge transfer (production) would include suggestions and discussions, these individuals have with the management directing the organizational training programs and work environments.

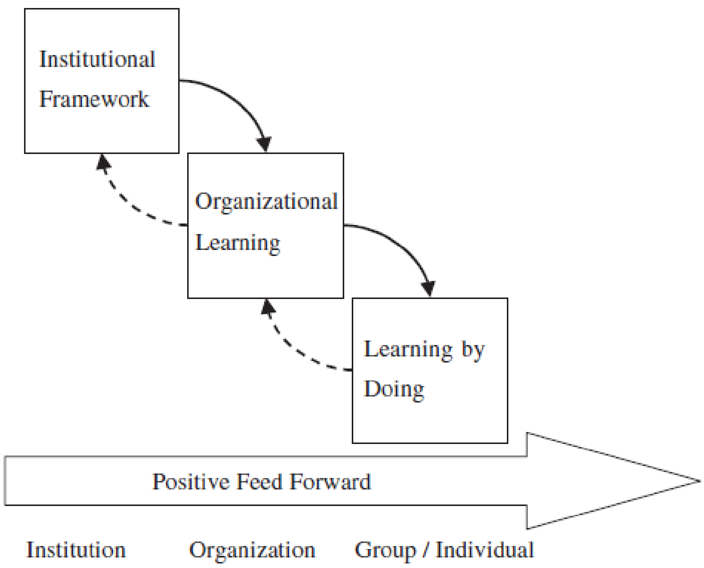


Figure 3.2 A dynamic process of organizational learning. Source: Kobos et al. (2006)

Today, wind power is often subsidized, but it is approaching a cost level that makes it economically attractive compared to established energy production methods, assuming good wind conditions. As the experience curve of electricity produced by wind turbines is not entirely flat — a proposed ratio of 0.91 according to Neij (1997).

Cost reduction effects are specified as a three-parameter functional form, which by design permits the determination of optimized levels of R&D support for a given technology (Miketa & Schrattenholzer, 2004). The experience curves and bottom-up evaluations of wind turbines indicate that further cost reductions will be possible in the future. (However, these cost reductions cannot be seen in the price development path of wind turbines at present). In general, the results show incremental cost reductions for both on-shore and off-shore wind turbines, and the reduction in the cost of wind-produced electricity will be greater than the reduction in the cost of wind turbines. Bottom-up evaluations support an incremental development path of wind turbines —which may be reflected in an extrapolation of the experience curve — i.e. using a learning rate of approximately 10% for both on-shore and offshore wind turbines. To illustrate the greater cost reduction identified for producing electricity (including efficiency improvements and reduction of operating and maintenance costs), a higher learning rate should be used, e.g. a learning rate of 15% for wind turbines placed in less windy areas and a learning rate of 20% for off-shore wind turbines and wind turbines placed in windier areas (Neij, 1997).

A restriction on further cost reductions in wind produced electricity will arise due to the limitation of favorable sites, as many of the best sites for wind turbines have already have been used. However, this will be a greater problem in countries that have already invested in large numbers of wind turbines. Due to the consensus on incremental improvement of wind power, a sensitivity range of 72% of the learning rate is suggested (Neij, 2008). Wind energy has grown a lot over the last years and this spectacular growth has attracted a broad range of players from across the industry value chain — from local, site-focused engineering enterprises to global, vertically-integrated utilities (see Figure 3.3).

Figure 3.3 Wind energy industry value chain. Source: EER (2007)

Since Europe's surge in 2005 to an annual market of over 6.5 GW of new capacity, the industry's value chain has become increasingly competitive as a multitude of enterprises seek the most profitable balance between vertical integration and specialization (EWEA, 2009). More and more utilities take position on the wind energy value chain to comply with national renewable targets, and/or to take the initiative of seeking international expansion with this newer production technology. Large-scale utilities have thus started to build sizeable project pipelines with long-term investment plans what lead to an overall scaling up of the sector. To maximize profitability, utilities have steadily migrated from risk-averse turnkey project acquisition, to greater vertical integration with in-house teams for development and operations and maintenance (O&M). Strategies devised by these players for meeting their objectives have largely depended on their experience in the sector as well as on their desire to expand geographically. At the same time a market remains for independent players able to contribute development skills, capital and asset management experience.

As a result, Europe's wind energy value chain is currently shifting as asset ownership is redistributed, growth is sought in maturing markets and players seek to maximize scale on an increasingly pan-European stage. Utilities build up GW-size portfolios, through their own strategy initiatives or government prompting. IPPs seek to compete for asset ownership in booming Western European markets. In general, development activity continues to shift towards new regions in the east. The proliferation of players looking to develop, own or operate wind farms has pushed competition to a new level, underlining the key elements of local market knowledge, technical expertise and financial capacity as crucial to positioning on the value chain. Before utilities began adopting wind energy, vertically-integrated independent power producers (IPPs) started aggressively exploiting wind turbine technology to improve their positioning. There are two main types of IPP in Europe (EWEA, 2009):

- integrated IPPs, which have capabilities across the project development value chain and exploit these for maximum control and returns on their project portfolio,

- wind project buyers, which tend not to play a direct role in the development of wind plants in their portfolio as these enterprises are often financial investors, rather than energy players.

The number of these players that are active has continuously increased as utilities have sought acquisitions among this field of asset and pipeline holding competitors, though those that are already a significant size may be positioned for long-term growth. In terms of development, integrated IPPs are continuing to expand internationally, through green field project development and acquisitions, in order to compete with utilities∴Players with strong holds in Spain, France or Germany consistently look for growth in Eastern Europe, while some are also taking the plunge offshore. More risk-averse IPPs are seeing the number of quality projects available for acquisition in mature markets continues to dwindle.

As wind power owners, IPPs are facing harder competition from utilities as several project portfolios have been acquired in markets such as Spain, Germany, France and the UK. IPPs generally have higher capital costs than utilities and those that can create assets organically through development on their own are generally better positioned to enlarge their portfolio. As asset managers on the value chain, integrated wind IPPs and project purchases are distinctly different, with integrated players increasingly focusing on O&M to maximize asset values. The boom in MW additions in the last years means many turbines are coming out of their warranty periods, requiring IPPs to make key strategic decisions on how to manage their installations.

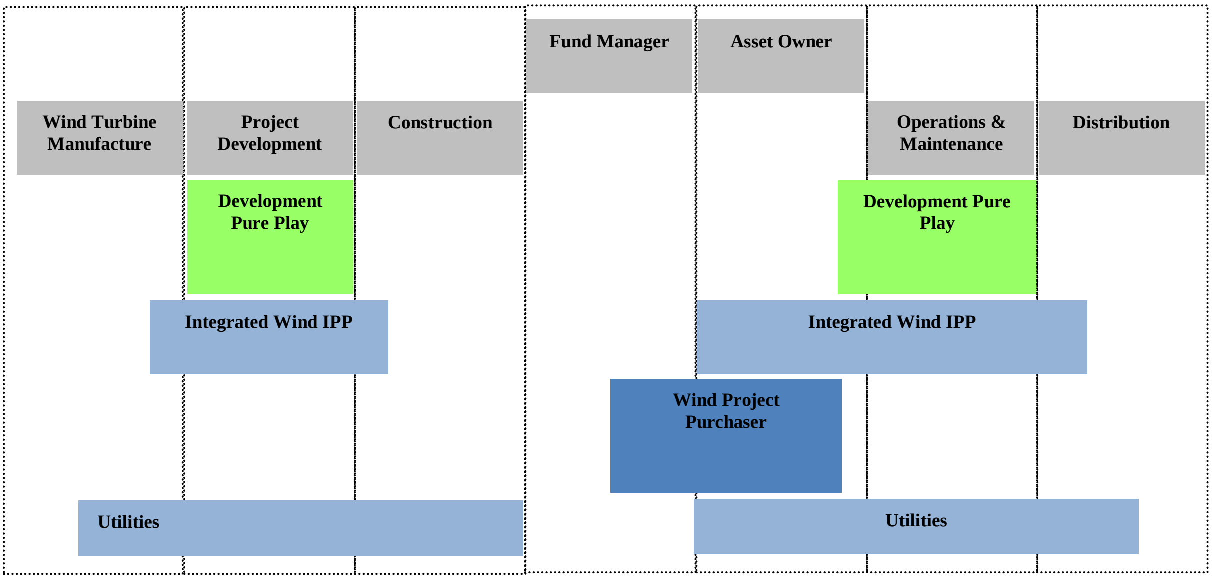


Figure 3.4 Europe wind value chain positioning. Source: adapted from EER (2007)

In the USA, utilities have been, from the beginning on, the main players in the wind energy market. The value chain of a component producer like the China Wind Energy Inc. looks as the following in Figure 3.5.

Figure 3.5 Value chain – production of wind components. Source: EER (2007)

A less well understood feature of innovation processes is the intermediate stage between demonstration and diffusion that can be considered a market formation or *'early'* deployment stage (often referred to as niche markets) (Anadon & Holdren, 2009). Governments can play a crucial role creating initial markets; in doing this, governments can encourage reductions in costs, improvements in quality and functionality, and overall a better definition of the product for the customer (Gallagher, Anadon, Kempener, & Wilson, 2011).

The innovation literature highlights other important findings. Innovation is a product of complex systems, in which feedbacks from the different stages of the innovation chain and the ability to learn from market experience are crucial. Also, major innovations involve co-evolution of technologies and institutions that support them. There may be several reasons for this low inherent innovation-intensity. Processing large amounts of energy may inherently involve big capital investment and long timescales, which naturally increases risk and deters private finance; each stage in the innovation chain can take a decade, and diffusion is equally slow (Grubb, 2004).

3.2.2 TRENDS IN R&D FOR WIND ENERGY

The beginning of the process is the Research and Development (R&D), followed by demonstration and pilot production. This leads to early market introduction and finally, market diffusion. While different RETs are at different phases of market development, the research in diffusion analysis in renewable energy sector points towards the following approaches (Rao & Kishore, 2010). Empirical analysis of the historical development, current status, and future expectations for wind energy electrical power production (i.e. onshore power production) can be summarized as a 3-stage empirical industry life cycle illustrated in Figure 3.6, featuring three generic Stages of Exploration (or Development), Acceleration (or Dominant Design), and Maturation.

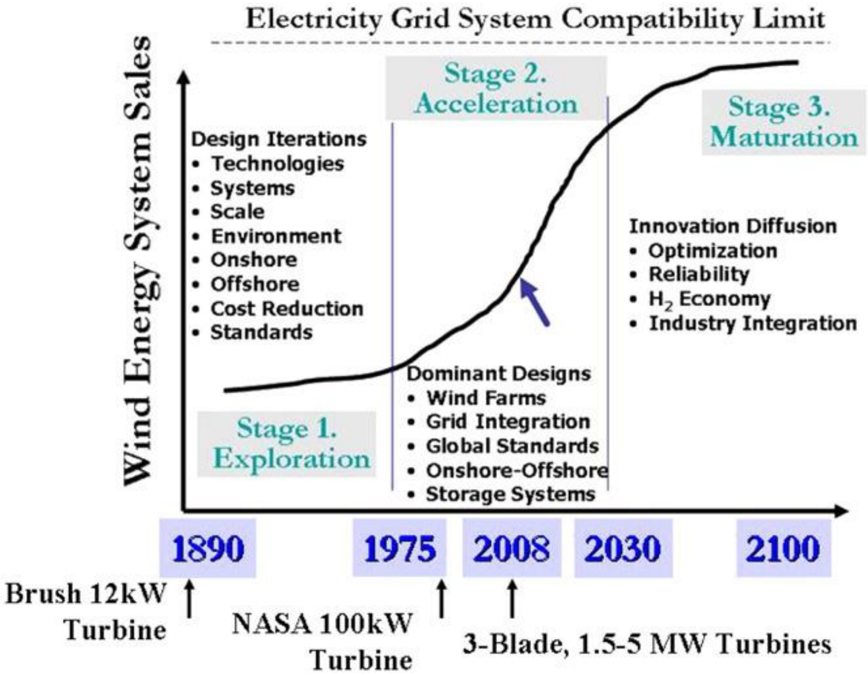


Figure 3.6 Wind energy technological innovation – projected 210 years industrial technology life cycle. Source: Dismukes, Miller, and Bers (2009)

The change in policy to support private research — as opposed to collaborative research in the public domain — is likely to increase the influence of market forces on the choice of the project — and therefore the choice of technology. While this may be beneficial in terms of short-term deployment of new renewable technologies (RETs) alone, this may mean less opportunity that might exist to regulate the support given to specific technologies∴If the trend appears in the field of renewable energy, it is likely that brings a short-term perspective, possibly reducing the support for RD&D in technologies that are considered to have a great potential long-term, but are still relatively distant from the market, compared with more mature alternative (IEA, 2008).

The European Technology Platform for Wind Energy (TPWind) identified as thematic areas for R&D in wind energy for the next 30 years, the following aspects (IEA, 2010; TPWind, 2010b) as shown in Table 3.1.

Table 3.1 Thematic areas with R&D focus for wind energy by TPWind

Thematic areas	Focus
Wind conditions	Develop more efficient methods for determining wind resources and identifying regions rich in poorly-exploited wind resources, in order to enable increased and more cost-effective wind farm assets. *Key areas in this thematic may include: advanced sitting and wind characterization models. Wind resource mapping, advanced wind power forecasting techniques. Advanced measurements techniques including remote sensing.*
Wind power systems	Aspects of wind turbine technology, both offshore and onshore, which have the potential to increase the competitiveness of wind energy, and to minimize the lifetime cost of electricity produced by wind power systems. *Key areas in this thematic may include: Materials, Drive-trains, Blades, O&M and Wind turbine design and efficiency increase.*
Wind energy integration	Large-scale integration of wind power (300 GW), by enabling high penetration levels (>20%) with low integration costs, while maintaining system reliability (security of electricity supply). *Key areas in this thematic may include: Grid codes/communication standards, Grid structure and planning, Grid operation and energy management (prediction tools, probabilistic capacity planning, and storage facilities), Energy market integration (converting stochastic wind energy production into energy market products, providing additional grid services to TSO´s and DSO´s).*
Offshore deployment and operations	Environmental impact, social acceptance, spatial planning and the economic impact of R&D and innovation for offshore wind energy. *Key areas in this thematic may include: safety and access to offshore turbines, new and improved concepts for offshore wind turbines, design and fabrication of offshore substructures, new concepts for assembly installation and hookup of large scale developments, offshore cables and connectors, operations and maintenance, spatial planning and decommissioning.*

Source: Strategic Research Agenda/TPWind (2010b)

It is noteworthy that efforts RD&D already have excellent results, such as core R&D engineering at the University of Risoe, Denmark, successfully completed the first practical tests of a new wind turbine — the gigantic fan responsible for energy production wind — that can anticipate and react to changes in the wind by optimizing the production of electricity. The results show that this system can predict the wind direction, wind intensity and even turbulence. With this, it is estimated that a future production of wind turbines may increase energy production and at the same, reduce extreme loads that impact on their lifetime.

The system added to the wind turbine is a kind of laser anemometer, which scientists call "*LIDAR of wind"*. LIDAR (Light Detection And Ranging) is a kind of *"radar light"*, which uses a laser beam to detect the spatial distribution of temperature and humidity in the atmosphere. It likes a radar sends radio waves and measure their reflections, a LIDAR sends light waves. The *"eco"* in this case, this wave is the reflection of light by different layers of the atmosphere. The incorporation of LIDAR means that wind turbines are now able to *"see"* the wind through the detection of variations in air mass. In predicting the wind to reach the next moment, the turbine can optimize their position and adjust the pitch of its blades for wind to be used more efficiently and last longer than the turbine. The engineers say the laser technology increases energy production by up to 5%, mainly because it allows the use of longer blades∴For a wind turbine with capacity of 4 MW, this represents a financial gain of $ 200,000 per year (DTU, 2010). LIDAR system can be used to enhance the durability of the blades by allowing them better cope with the irregularities in the wind. In a second step, it becomes possible to manufacture blades longer. This will increase the production of energy and make wind electricity competitive. The wind turbine industry is booming, it is expected to grow tremendously in coming years, thanks to the global focus on renewable energy and in response to climate changes (IEA, 2010).

Finally, it is necessary that all countries have access to technologies that enable them to build the most efficient new power plants and industrial facilities and install energy efficient equipment. Much of the development of this technology is currently being undertaken within the OECD countries, but most of its deployment will need to be elsewhere (Clark, 1985). As example of a network which can help in technology development deployment is the IEA Implementing Agreements (in which both member and non-member countries work and co-operate), which provide a framework for joint research projects, discussion of specific technology issues and information exchange.[11]

According to Wagner and Epe (2009) to promote wind energy, the research needs need to be identified and the research work carried out. Initially, there are such environmental and social challenges as integration into the landscape, noise impact, bird flight paths, life cycle analysis and sustainability. And of course, wind turbine and component design have to be improved continually, i.e. basic research in aerodynamics, structural dynamics, dynamic forces, new materials, feasibility studies into new systems, generators using permanent magnets, gear boxes, etc. For planning and building wind turbines and wind farms, commonly accepted certification procedures must be formulated and standardized.

Governments, industry, research institutions and the wider energy sector will need to work together to achieve this goal. Best technology and policy practice must be identified and exchanged with emerging economy partners, to enable the most cost-effective and beneficial development. The technology road map for some of the most important technologies (wind energy) developed by the IEA (2009). At the industry level, two methods to track the diffusion of wind turbine technology provide some insight. If technological change is occurring in wind turbines, we would expect that the cost of electricity from these turbines is decreasing, since cost is the performance characteristic about which users care most. Additional insight is gained from further exploring the trend of

[11] IEA (2007), *Energy Technologies at the Cutting Edge.*

decreasing cost of electricity. The three primary means of reducing the cost of electricity from wind turbines are (1) reducing the capital cost of the turbine, (2) reducing operations and maintenance (O&M) costs, and (3) producing more electricity without an offsetting increase in either capital or O&M costs (Loiter & Norberg-Bohm, 1999).

3.2.3 STRUCTURES AND TECHNOLOGIES TO SUPPORT INNOVATION IN WIND POWER

As currently understood, then, technological innovation is characterized by multiple dynamic feedbacks between different stages of the process; as Fri (2003) states, *"the process of innovation is typically incremental, cumulative, and assimilative."* It is nonetheless often useful for analytical and prescriptive purposes to treat the stages separately, and we frequently do so in this article. The stages of energy technology innovation to be considered comprise fundamental research, applied research, development, demonstration, pre-commercial and niche deployment, and widespread deployment (often also called diffusion). Technology transfer between countries is often envisioned as a part of diffusion, but it can also occur at earlier stages (Gallagher, Holdren, & Sagar, 2006).

The wind energy market surpasses its own record every year. The market growth rates are in the same range of technologies such as high technology (internet, phone and so on). Europe leads the world in terms of facilities and production, with most of the ten largest manufacturers of being European. A popular misconception is to consider wind power as a mature technology, where R&D efforts are not necessarily needed∴As a result, there is a risk of progressive loss of European leadership, as demonstrated by recent developments in wind energy sector*: (i) High demand has increased the time of delivery of wind turbines and the prices of raw materials like steel and copper have increased in recent years, which means that the cost of wind turbines has increased and (ii) Although most manufacturers of wind turbines is still Europeans, two Chinese companies (Goldwind, Sinovel) and an Indian company (Suzlon) entered the market* (IEA, 2010).

The private sector in funding research is significant, but exact figures are hard to find. Many companies can invest in the region of 3-5% of revenues in research. In some cases, the RD&D intensity is even greater. In Europe, after the start of the *Technology Platforms* for individuals and groups of technologies, the private sector is being encouraged to interact with the public sector, especially in long-term research; the intention is that private companies can share the investment with the public sector. The TPWind is the indispensable forum for the crystallization of political and technological research and development paths for the wind energy sector, as well as a new opportunity for informal collaboration between the Member States, including the least developed in terms of wind energy. The aim is to identify areas of TPWind greater innovation, research new and existing development tasks. These, then, to be prioritized based on urgency of the technology sector; the main objective being global (social, environmental and technological) is cost savings∴This will help achieve the objectives of the EU in terms of renewable energy production. The platform is to develop coherent recommendations, detailing specific tasks, approaches, participants and the necessary infrastructure within the private investment in R&D as well as Member State and EU programs, such as FP7. TPWind will also assess the overall funding available for this work, from public and private sources (TPWind, 2010a).

Wind power is the technology leader in renewable energy. Having regard to the right support could provide up to 28% of EU electricity by 2030. However, this target will be achieved if the sector and policy makers continue to think in the short term. Long-term, strategic technology and policy research are fundamental: TPWind facilitates the development of effective and complementary national and EU policy to build markets, and a collaborative strategy for the development of technology. Your ultimate goal is to reduce costs to parity with cheaper technologies for alternative production of electricity (TPWind, 2010a).

TPWind is composed of stakeholders from industry, government, civil society, R&D institutions, financial organizations and most of the energy sector in the Member State and EU. It is unique: the only body with sufficient representation or *"critical mass"* of knowledge wind and specific experience to be able to fully understand and map the paths and realistic priorities for policy and technology R&D, taking into account the wide range of needs the sector. In parallel, the European target of 20 percent of energy production from renewable sources poses new challenges. In its recently published *Strategic Research Agenda*, the European platform for wind energy, TPWind proposed an ambitious vision for Europe and viable. In this view, 300 GW of wind power capacity would be delivered in 2030, representing up to 28 percent of EU electricity consumption. To implement this vision, an average of 10 to 15 GW of additional capacity will be manufactured, delivered and deployed in Europe each year. This is equivalent to more than 20 turbines of 3 MW to be installed on each day (GWEC, 2010; TPWind, 2010a). Moreover, the vision TPWind includes a sub-goal of wind power represents about 10 percent of EU electricity consumption by 2030. They propose an intermediate step of the execution of 40 GW by 2020, compared to 1 GW today. In this sense, R&D is needed on two fronts:

1. An efficient implementation of TPWind vision for wind energy, supporting the implementation of european goals and,
2. Ensuring European leadership in the long term through technological leadership.

According to Xu, He, and Zhao (2010) recently, along with the establishment of market economy system and wind power market, the wind power industry has achieved "*market-oriented operation, industrial management"* and now it has stepped into a fast development stage.

The high degree of complexity for wind energy industry with respect to each of the four generic radical innovation challenges and resultant *hurdles*[12] has exerted a significant influence on life cycle development time. From a science and technology standpoint, the multidisciplinary knowledge needed for successful wind energy electrical systems spanned a number of fields that only came into being progressively during the entire 20th Century. These include: fundamental aerodynamics of converting wind power to electrical power, power electronics, electrical control systems, development and manufacture of large, cost effective composite wind turbine designs, computing, communication and information technology, and reliable and cost effective linking to

[12] According to Dismukes et al. (2009) "*hurdles* "can be understood as *Scientific and Technological Challenges, Business and Organizational Challenges, Market and Societal Challenges,* and *Cluster and Network Challenges*. The authors developed a new ARI model for providing a holistic approach to understanding the dynamics of the industrial technology life cycle for a wide variety of radical innovations as well as wind electrical power. For more information read Dismukes, J. P., Miller, L. K., & Bers, J. A. (2009). The industrial life cycle of wind energy electrical power production: ARI methodology modeling of life cycle dynamics. *Technological Forecasting and Social Change*, 76(1), 178-191. doi: 10.1016/j.techfore.2008.08.011

the electric utility grid.

Technology development stages

↓

R&D seeks to overcome technical barriers and to reduce cost. Commercial outcomes are highly uncertain, especially in the early stages.

↓

Demonstration stage the technology is demonstrated in practice. Costs are high. External (including government) funding may be needed to finance part or all of the costs of the demonstration.

↓

Deployment stage the technology is operated successfully, but may still be in need of support to overcome cost or non-cost barriers. With increasing deployment, technology learning will progressively decrease costs.

↓

Diffusion/Commercialization stage the technology is cost competitive in some or all markets, either on its own terms or, where necessary, supported by government intervention (e.g. to value externalities such as the costs of pollution).

Figure 3.7 Stages of the technological process in the wind energy industry. Source: Adapted from IEA (2010)/R&D Trends Worldwide

According to Figure 3.1 and Figure 3.2 energy policy can influence the development of technology and capturing market (marketing), through the interaction of three main types of policies that target families or subsets of these technologies in progressive stages of technological maturity:

- Policy Research, Development and Demonstration (RD&D);
- Policy deployment market (also called policy of support or promotion), and
- General Policies of the energy market.

As featured in Figure 3.8 the structure of TPWind, where the issues raised by themes, are concentrated in areas where improved technology leads to significant cost reductions.

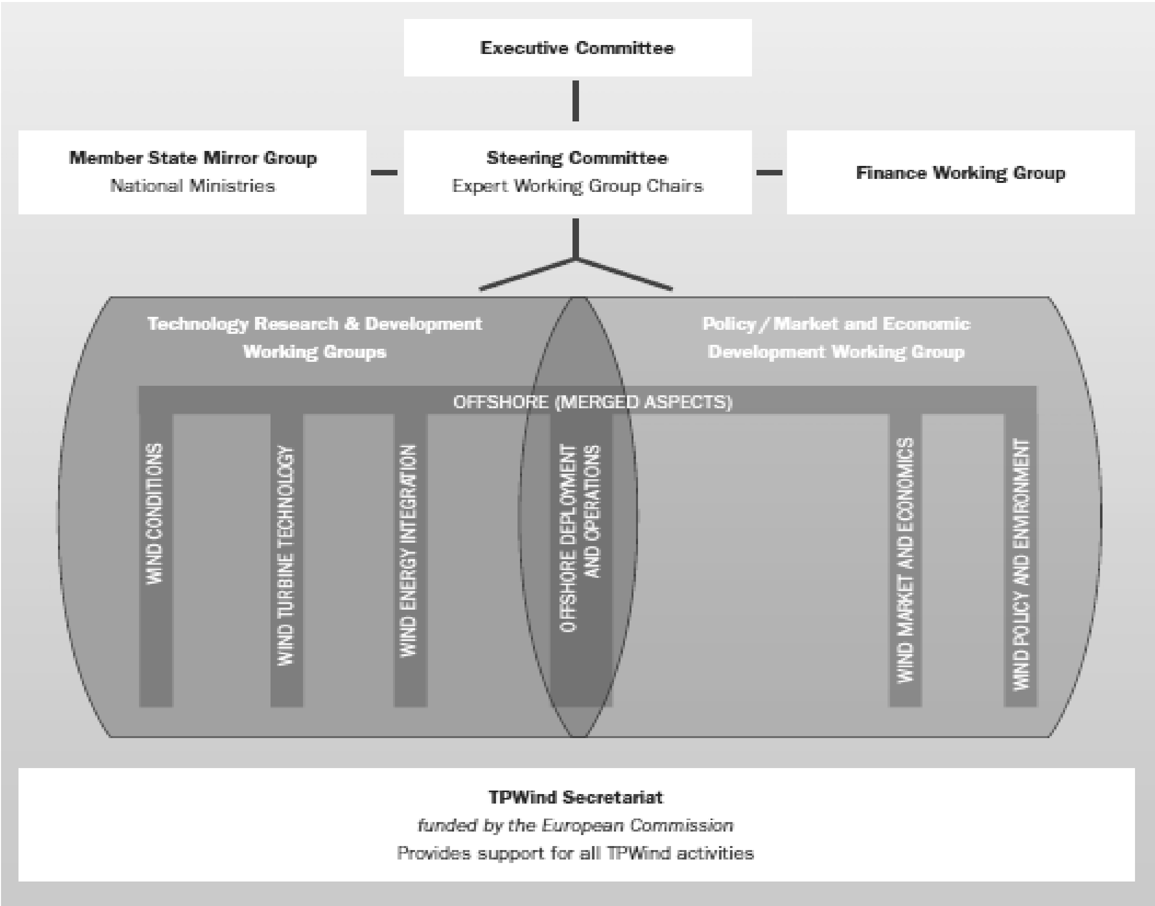


Figure 3.8 TPWind organizational structure. Source: TPWind (2010a)

Through a strategic research agenda, TPWind encourages Member States, EU institutions and the wind industry to intensify research efforts in accordance with market needs, in view of medium and long term. TPWind encourage research results in the long term, taking into account that new prototypes for wind energy are being developed.

For Kaldellis and Zafirakis (2011) what is important to consider is that for the aforementioned goals to be realized, R&D targets set must be put forward by the wind energy industry, with the main directions and actions to be taken including the following:

- New wind turbines need to reduce their overall costs
  - Large scale turbines of 10-20 MW going offshore (R&D programs for prototypes already initiated)
  - Improved design and reliability of components (Testing facilities to assess efficiency and reliability of wind turbines)

  - Development of innovative logistics (Cross industrial programs)

- Deeper waters and larger turbines for offshore

  - Development and industrialization of support structures for sea installations, both fixed and floating (Structure concepts to be developed and tested at different depths and under different conditions)

- Achieve grid integration for even greater wind energy penetration

  - Introduction of large-scale energy storage systems and high voltage[13] alternative and direct current (HVAC-HVDC) interconnections (Offshore farms connected with more than one grid, long distance HVDC, R&D of energy storage systems)

- Resource assessment and spatial planning

  - More sophisticated assessment of wind resources (High quality measurements and databases for wind data as well as short-term wind speed forecasting with the use of neural networks)

  - Spatial planning through social and environmental considerations (Development of planning tools and methodologies)

It is necessary to clarify the energy sector, in others words, wind energy industry is a technology cluster. Another aspect of importance is the concept of technology clusters. This is based on the fact that a technology does not develop alone but is related to and depends on other technologies as well as infrastructures, institutions, networks of actors, etc. Multiple interrelated diffusion processes contribute to the evolution. Adoption and diffusion of technology occurs as a collective evolutionary process∴The complex interactions where technologies mutually reinforce and cross-enhance each other drive to the conformation of technological clusters, that is, families of technologies evolving and diffusing together, and the constitution of associated networks of economic and social actors. The members of a cluster are related by multiple links that contribute to magnify their economic, social and environmental impacts. These multiple relations contribute to make progress in one of them relevant, directly or indirectly, to other members of the cluster, as it helps to reinforce their own position in the marketplace (Barreto & Kemp, 2008).

3.2.4 ANALYTICAL FRAMEWORK FOR WIND POWER BUSINESS

In a business that aims to create value, the diffusion of a technology may be the key to its success. To that end, one should increase the availability through technological innovation, to ensure use by many people and create economic value for the business owners, who are the principal actors.

[13] The power supply system is divided into: a) low voltage (LV) system (nominal voltage up to 1kV); b) medium voltage (MV) system (nominal voltage above 1kV up to 35kV) and c) high voltage (HV) system (nominal voltage above 35kV). For more details, please see at (European Commission, 2001)

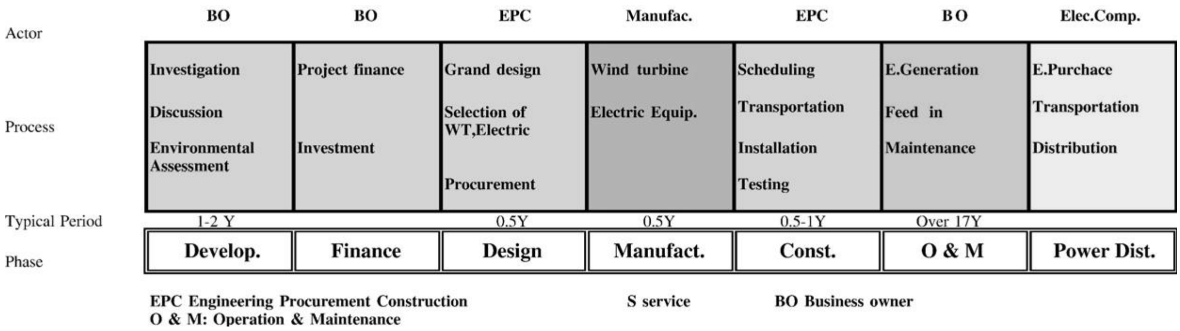


Figure 3.9 Structure of wind power business process. Source: Inoue and Miyazaki (2008)

As shown in Figure 3.9 the initial verification of the business process of wind power production might be worthwhile. The business process of wind power production can be broken down into the development phase, involving 1) wind survey and an environmental evaluation at the point of wind power production, 2) financing phase in which construction funds are raised, 3) system design and procurement phase in which wind turbines and system interface for electrical facilities are designed and constructors are selected, 4) equipment manufacturing phase in which wind turbines and system interface for electrical facilities are built, 5) testing phase in which transportation, installation and testing are carried out, 6) operation and maintenance phase and power distribution phase.

No problem can be envisaged because the business process of wind power is designed to allow economic value to be obtained by the competitive strategies of the electric companies, wind power proprietors, EPC (Engineering Procurement Construction) builders, and equipment manufacturers, all of whom participate. This business process seems free of any potential obstacle to the successful acquisition of economic value for four reasons∴Firstly, the power company would gain from the margin between the prices paid by the power company to purchase power from the wind power producer and the power charges paid by consumers. Secondly, the wind power owner would benefit from saving on its costs of power production with wind turbines located under good wind conditions. Thirdly, the EPC builder would benefit from savings made by man-hours, derived from a reduced procurement cost and efficient construction scheduling. Fourthly, the equipment manufacturer would benefit from saving costs from the experience effect.

For Lund (2007, 2009) the commercialization process of new technologies can analytically be explained through so-called learning curves that effectively integrate policies and associated learning investments into a unit cost curve that decrease with cumulative volume. At the breakeven point, the new energy technology becomes cost-effective over the traditional energy. The policy measures supporting commercialization can be split into two main categories namely *technology push* such as R&D that improve the innovations and *market pull* measures such as market deployment support that increase demand for the new technology. These main categories are further elaborated in Figure 3.10 into more specific measures. A market breakthrough often requires optimal mastering of the whole process and a right balance of different measures over time. In addition to the traditional energy policy measures, more renewable energy technology/product specific support may be very important to enhance industry growth. An important market pull policy measure in several countries is induced demand, such as feed-in-tariffs, green certificates, investment grants, RES quotas, etc. (Arentsen et al., 2007).

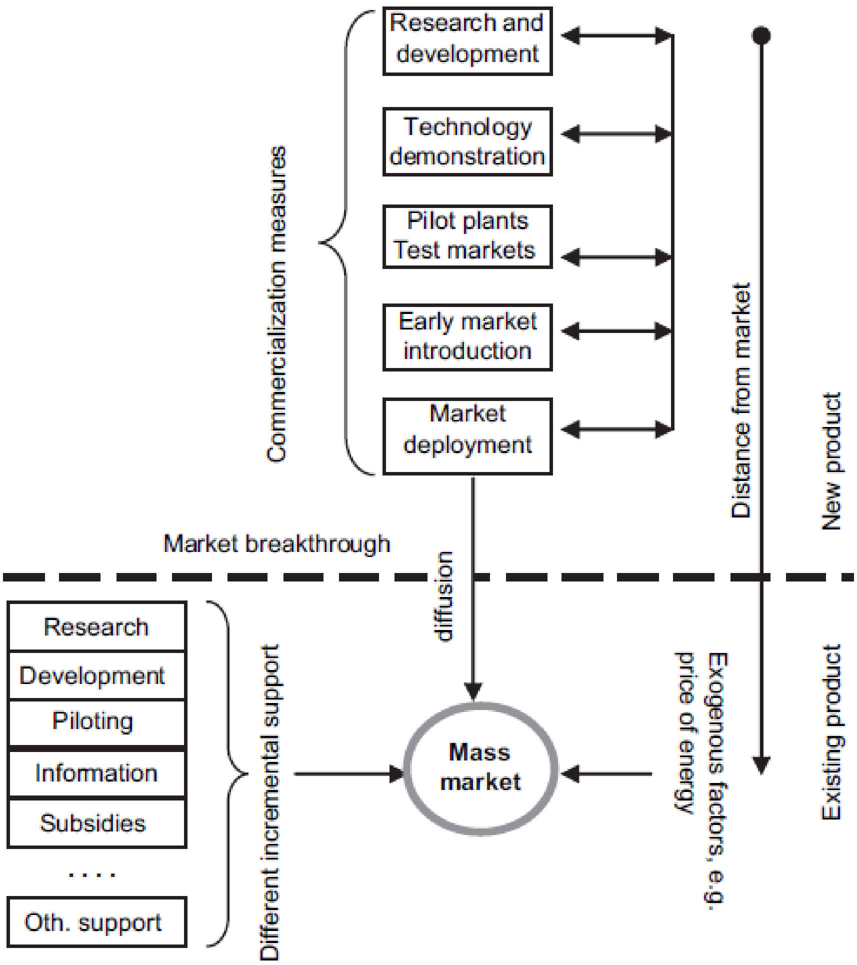


Figure 3.10 Commercialization process of new energy technologies. Source: Lund (2009, p. 54)

Hence, in order to interact, enterprises and other actors need to identify themselves as part of a system, see the common problems and opportunities they face and the value of collective action for framework of wind power business work as a perfect chain. In essence, therefore, network formation reflects the consciousness and practical realization of parts of the collective dimension of the innovation and diffusion process for wind energy business. Without such a consciousness, user–supplier relationships will be arms-length, university–industry relationships may not develop and political networks will not be formed (Bergek, Jacobsson, & Sandén, 2008).

3.3 WIND RESOURCES WORLDWIDE

The development of wind energy in many regions of the world faces the lack of reliable and detailed wind resource data in that site. Availability of these data is necessary for public authorities and other economic agents involved to identify wind power production potential and to promote rightly actions on that information. To overcome this difficulty, the National Renewable Energy Laboratory (NREL) and other organizations have, since the last five years developed new methods and approaches to more accurately assess the wind resource and produce detailed high-resolution (l-km) wind maps for essentially anywhere in the globe∴The NREL methodology for creating large-area wind resource maps is force-task for unifying global terrain and climatic data sets, Geographical Information Systems (GIS) technology, and analytical and computational techniques (Elliott, 2002). The modeling and wind resource predictions that do not need to rely on country-supplied data were permitted by the global data sets and analytical tools at NREL. In many regions of the globe, reliable surface wind data are sparse and often not available for areas of interest for producing electricity by wind technology. However, the use of weather balloon and satellite-derived wind data with computer mapping system enables NREL to create wind resource maps with reliable information even if high-quality surface wind data are not available yet. Wherever available, reliable surface wind data are useful in providing field truth verification of the model predictions.

When we analyze different technologies of power production including fossil fuel or renewable energies the main concern the fuel consumed or avoided. What is the best technology of power production (of electricity or heating)? Are the power plants in the right places? How much is it available for electricity demand? What is the production cost for each kWh of electricity produced? What emissions does it have for each kWh of electricity produced? How much residue does it leave? For wind power technology, the wind resource is "*free of fuel*" and *"free of charge"* and these questions are as relevant as they are for any other source. As wind is *"free"* and *"green"* so the concern about fuel makes no sense∴Questions about wind resources, however, are very important and essential for wind technology development. When we talk on a global scale, it is not difficult to find many studies about the enormity of the wind resource, and how it could be theoretically used for facing the global electricity demand in several times over. For example the collaboration by researchers at Harvard University in the United States and VTT in Finland that concluded that *"a network of land-based, 2.5 MW turbines, restricted to non-forested, ice-free and nonurban areas, operating at as little as 20% of their rated capacity could supply more than 40 times current worldwide consumption of electricity"* (Lu, McElroy, & Kiviluoma, 2008).

A comprehensive study by researchers from Stanford University's Global Climate and Energy Project focuses its conclusions on five years of data from the US National Climatic Data Center. Using an extensive set of surface and balloon measurements, they concluded that 13% of the sites tested had a good wind resource (Class[14] 3) at 80 meters off the ground, and using one in five of these sites for power production would allow wind energy to meet the world's electricity demand

[14] Wind classes determine which turbine is suitable for the normal wind conditions of a particular site. They are mainly defined by the average annual wind speed (measured at the turbine's hub height), the speed of extreme gusts that could occur over 50 years, and how much turbulence there is at the wind site. The three wind classes for wind turbines are defined by an *International Electrotechnical Commission* standard (IEC), and correspond to high, medium and low wind. For more information, please see http://www.iec.ch/.

(considering the data of year 2000) seven times over (Archer & Jacobson, 2005). In the same objective, an earlier study in 2003 by the German Advisory Council on Global Change calculated that the global technical potential for electricity production from both onshore and offshore wind technologies was 270,000 TWh per year. Considering 10% to 15% of this was executable in a sustainable manner, the resulting 39,000 TWh would meet more than double the current global electricity demand. A literature search shows up numerous similar studies with broadly similar conclusions (GACGC, 2004). According to Rosa (2009, p. 5) "*30% of the 173,000 TW of solar radiation incident on Earth is reflected back into space as the planetary albedo*[15]*. Of the 121,000TW that reach the surface, 3% (3600TW) are converted into wind energy, and 35% of this is dissipated in the lower 1km of the atmosphere. This corresponds to 1200TW. Since humanity at present uses only some 15TW, it would appear that wind energy alone would be ample to satisfy all of our energy needs".*

The studies have different results, because it depends on its assumptions used. For estimation of wind power potential is necessary to make assumptions about the size, capacity factor and rated power of the turbines used, which varies from study to study. We must highlight the higher the wind turbine is working, the better the wind resource is. Further, higher wind turbines or wind farms are less to be affected by turbulence caused by natural topography, surface roughness or other effects of *orography*[16]. Even more, the technology evolution can not only increase the capacity factor of wind turbines, but also the range of wind speeds in which they can work, thus broadening the range of sites at which they can be installed.

Another variable concerns assumptions about the land areas on which wind turbines can be deployed. While most studies will focus on conservation areas, forests and urban sites, some types of agricultural land such are easily compatible with wind farms installations without constraining the overall wind potential of a region∴In the case of offshore wind resources the methodologies for evaluation of its availability also differ in terms of assumptions used. An assumption needs to made concerning the areas in which wind farms can be built, both for technical reasons (maximum technical/economical distance to shore, water depth etc.), as well as taking into account environmental and regulatory limitations (nature reserve areas, shipping lanes, minimum distance to shore, etc.). Some new configurations that deploy turbines on floating structures and are thus suitable for use in deep water are at a preliminary stage of test deployment (Bilgili, Yasar, & Simsek, 2011). These could dramatically increase the technically usable fraction of the offshore wind potential. Evidence from a large number of studies into the world's wind resources suggests that there is no shortage of suitable sites for wind power development. However, it is worth noting that the rate of deployment of wind power in each county has largely been dependent on political will rather than resource criteria. Germany has a lower wind potential than many other European countries, yet its favorable political climate has led to fast and large-scale deployment of wind power. On the other hand, there are several parts of the globe with a good wind resource – places such as Argentina, Russia and South Africa – where development of wind power has barely started (GWEC, 2011a).

[15] The amount of energy reflected by a surface is called *albedo*. Albedo is measured on a scale from zero to one (or sometimes as a percent). For more explanation, please see Goode et al. (2001).
[16] It is the study of the formation and relief of mountains and can more broadly include hills, and any part of a region's elevated terrain. For more information, please see Petersen, Mortensen, Landberg, Højstrup, and Frank (1998).

The wind resources are spread globally, as we know the wind is fundamentally a form of solar energy. Wind is the result of simple air motion. It is caused by the unequal heating of the earth surface by the sun heat. Since the earth surface is made of different kinds of continents and oceans, it absorbs the sun heat at different rates, and the different temperature could cause the different pressure. The heat is distributed to the poles by ocean currents and atmospheric circulation (Maddaloni, 2005). As we can see in Figure 3.11, world wind map at 80m high, into a wind speed scale from 3-9 m/s, there are some regions on the globe (RETScreen® International Clean Energy Decision Support Centre, 2009). When it is necessary take into account the wind resources as an initial input or datum for wind farms economic evaluation, researchers as Marafia and Ashour (2003), Archer and Jacobson (2005), Arslan (2010), Ahmed (2011), Oliveira (2010), Gökçek and Genç (2009) show that a wind speed range starting from 3m/s as a minimum wind speed for wind power project gives economic returns to the investor. Wind energy projects are generally as more as financially viable in *"windy"* sites. This is due to the fact that the theoretical power output in the current wind technology is equal to the cube of the wind speed. However, the power production profile of a wind turbine is typically more proportional to the square of the average wind speed (Manwell, McGowan, & Rogers, 2002).

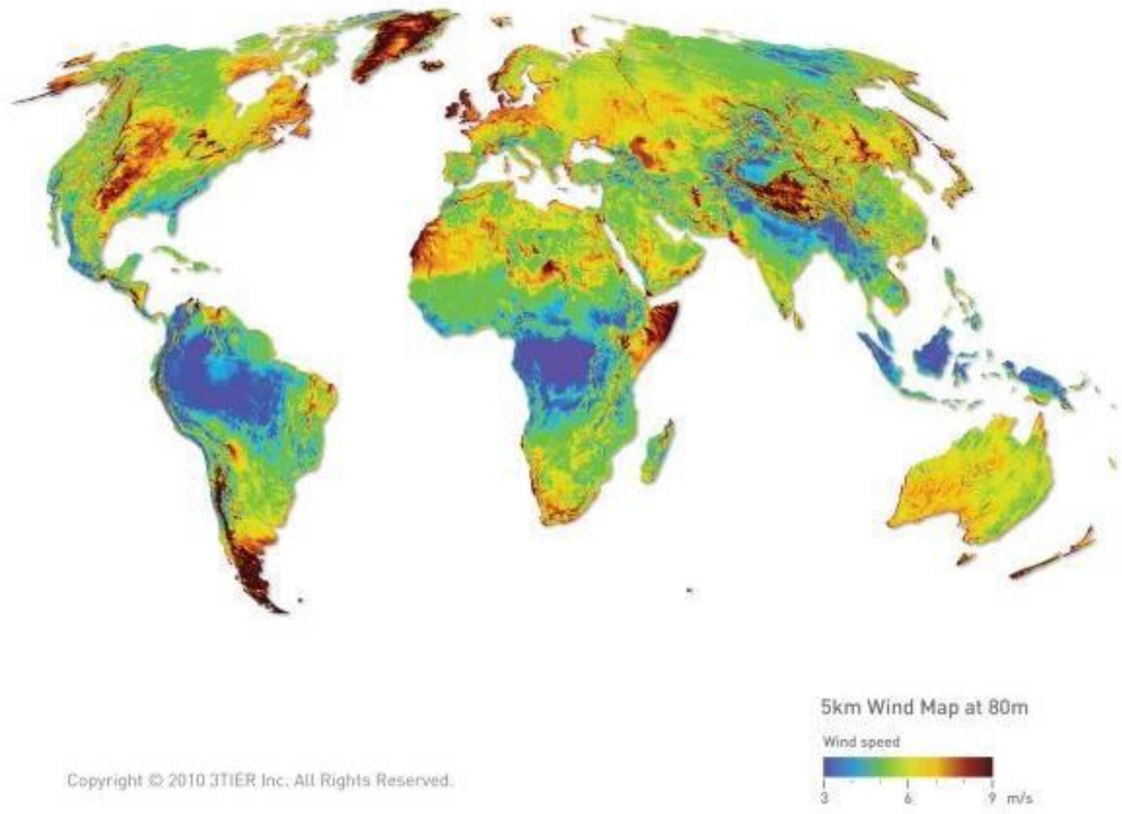


Figure 3.11 World wind map at 80m. Source: 3TIER, Inc/REmapping the World Initiative/ RETScreen® International Clean Energy Decision Support Centre (2009)

North America and Antarctica are the best locations for electricity production by wind energy technology. But they are also very favorable to electricity production by wind energy technology in the northern Europe, especially along the North Sea, the southern tip of South America (*Tierra del*

Fuego or Fireland) and Tasmania, in Oceania∴According to Herbert, Iniyan, Sreevalsan, and Rajapandian (2007) the theoretical potential of wind energy onshore is very large — $20{,}000\text{x}10^9$ to $50{,}000\text{x}10^9$ kWh per year in comparison with the current total annual global electricity consumption of approximately $15{,}000\text{x}10^9$ kWh, in 2005. Archer and Jacobson (2005) concludes that:

1. About 13% of all stations worldwide belong to class 3 or greater (i.e., annual mean wind speed ≥ 6.9 m/s at 80m) and they are indicated for electricity production by wind energy technology. In addition, wind power potential in these areas studied was underestimated in comparison to other studies.
2. The wind speed average calculated at 80m was 4.59 m/s (class 1) when including all stations; if only stations in class 3 or higher are considered, the average was 8.44 m/s (class 5). For comparison, the wind speed average observed at 10m from all stations was 3.31 m/s (class1) and from class ≥ 3 stations was 6.53 m/s (class 6).
3. The greatest numbers of stations in class ≥ 3 are in Europe and North America, whereas the greatest percentages are Oceania and Antarctica, 21% and 60%, respectively. Northern Europe along the North Sea, the southern tip of the South American Continent, the island of Tasmania in Australia, the Great Lakes region, the northeastern and western coasts of Canada and the United State have a strong wind power potential.
4. The wind speed was global-averaged at 80m was higher during the day (4.96 m/s) than night (4.85 m/s). The average nocturnal wind speed at above ~120 m was higher than the diurnal average.

The European Wind Energy Association (EWEA) and Greenpeace with their action for evaluation of global wind resources called *"Wind Force 12"* has concluded that the world´s electricity production by wind energy technology considering only 10% of the Earth's land area would be available for development, which figures the double of projected world electricity demand in 2020. Addition, a larger share of the land area could be used for electricity production by wind energy technology in sparsely populated and wind-rich regions in the globe as e.g. the Great Plains of North America, northwest China, eastern Siberia, and the Patagonian region of Argentina (Brown, 2003).

For a successful application of wind turbines is necessary the study of geographical distribution of wind resources, speeds profiles, topography and local wind flow and measurement of the wind speed are very essential in a complete and robust wind resource evaluation. The main and most direct mechanism by which global climate change could impact directly in the wind energy industry is by changing the geographic distribution due to its inter-and intra-annual variability of the wind resource available∴For Pryor and Barthelmie (2010) the global climate change may change the geographic distribution of wind resources in order to the variability of wind resource in a inter or intra yearly basis and it could change as result other the conditions for wind developments. As in a traditional industry sitting, the production and distribution of its process depending on the place where the vital resources can be found, in the case of the wind energy industry, the wind resources.

3.4 WORLD WIND ENERGY MARKET OUTLOOK

3.4.1 GLOBAL WIND ENERGY MARKET

For Wiser and Hand (2010) the global wind power capacity is growing fast in the last ten year, as a result, wind power has quickly become part of the mainstream in the global electricity industry. In 2007, roughly 20 GW of new wind capacity was increased globally, yielding a cumulative total of 94 GW (see Figure 3.12). Since 2000, cumulative wind capacity has grown at an average annual rhythm of 27%. The vast majority of this capacity has been located on land; offshore wind capacity surpassed 1 GW at the end of 2007, with accelerated growth expected in the future, especially in Europe. The expectations for wind power market growth in 2011 were mixed, as the low level of orders seen during the financial crisis worked their way through the system. The results of this were felt much more strongly in 2010 than in the previous year, and the overall annual market shrunk by 7% to 35.8 GW, down from 38.6 GW in 2009. The new capacity added in 2011 is equivalent in direct investments worth EUR 47.3 billion (USD 65 billion) (GWEC, 2011b, 2012).

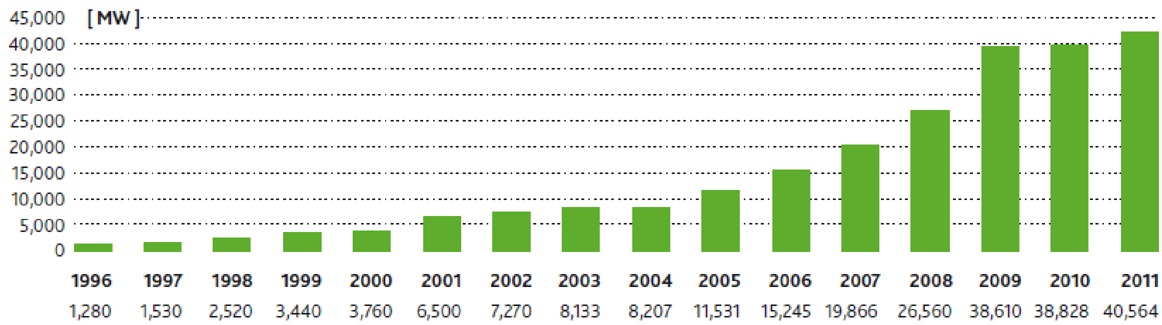
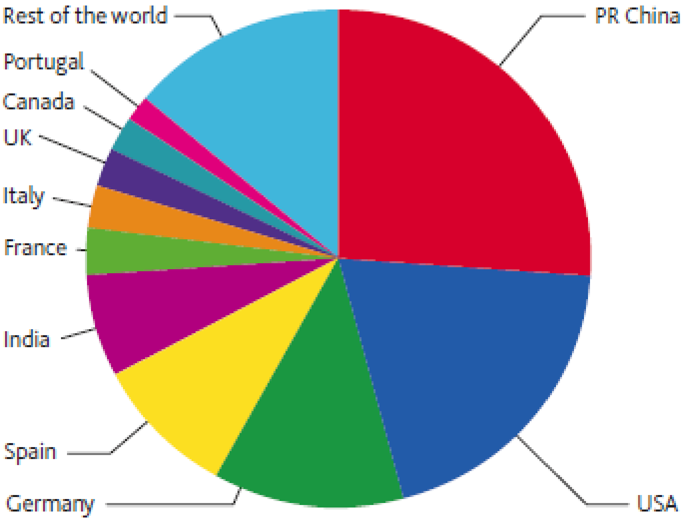


Figure 3.12 Global annual installed wind capacity 1996-2011. Source: GWEC (2012)

As shown in Figure 6.1 the global cumulative installed wind capacity in 1996-2011, in the year 2011, the wind capacity reached worldwide 237,669 MW, after 197,637 MW in 2010, 158,738 MW in 2009, 120,291 MW in 2008, and 93,820 MW in 2007. New wind turbines investment has declined in many parts of the globe. For the first time in more than twenty years, the market for new wind turbines was smaller in comparison with the last year and totalized an overall size of 40,564 MW in 2011, 38,828 MW in 2010 and after 38,610 MW in 2009∴The recovering of the wind industry worldwide totalized 40 billion (55 billion US$) in 2010, after 50 billion (70 billion US$) in the year 2009. The decrease is impact of lower prices for wind turbines and a shift towards China. The US market installed almost 50% less than in 2009. In the European market, new installed capacity in 2010 was 7.5% down on 2009, despite a 50% growth of the offshore market in countries like the UK, Denmark and Belgium, otherwise Romania, Bulgaria and Poland had a fast growth (WWEA, 2011). In December 2011, the ten biggest countries in cumulative capacity installed of wind power were distributed as shown in Figure 3.13.

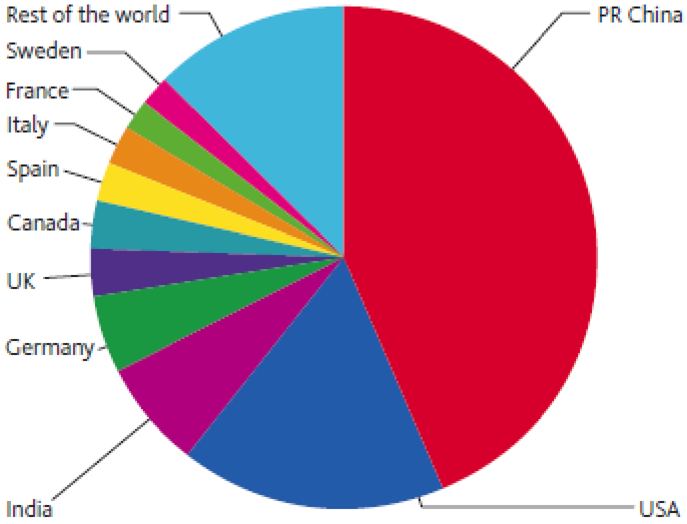


Country	MW	% SHARE
PR China	62,364	26.2
USA	46,919	19.7
Germany	29,060	12.2
Spain	21,674	9.1
India	16,084	6.8
France**	6,800	2.9
Italy	6,737	2.8
UK	6,540	2.7
Canada	5,265	2.2
Portugal	4,083	1.7
Rest of the world	32,143	13.5
Total TOP 10	205,526	86.5
World Total	**237,669**	**100.0**

Figure 3.13 Top 10 cumulative capacity Dec 2011. Source: GWEC (2012)

(**) *Provisional figure*

The main markets driving growth are Europe and Asia, which installed 96.6 GW and 82 GW respectively in the end of 2011. However, emerging markets in Latin America are beginning more competitive, led by Argentina and Brazil. In cumulative terms, the Latin America and Caribbean market grew by more than 58% in 2011. China, USA, Germany and Spain lead the global wind market with a share of 67.2% which has a great impact in the global energy matrix and in their domestic economies. We could see that 50% of all new wind power was increased outside of the traditional markets of Europe and North America in 2011(GWEC, 2012). In the case of Asia, what pushes this continent forward is the continuing boom in China, with 17.6 GW of new installations in 2011∴China had at the end of 2010 42.3 GW of wind power, which represents an increase of 39% in relation to the end of the year 2010 and has surpassed the USA in wind power capacity (see Table 3.2).



Country	MW	% SHARE
PR China	17,631	43
USA	6,810	17
India	3,019	7
Germany	2,086	5
UK	1,293	3.2
Canada	1,267	3.1
Spain	1,050	2.6
Italy	950	2.3
France**	830	2.0
Sweden	763	1.9
Rest of the world	4,865	12.0
Total TOP 10	35,699	88
World Total	**40,564**	**100.0**

Figure 3.14 Top 10 new installed capacity Jan-Dec 2011. Source: GWEC (2012)

The growing Chinese wind power market has pushed forward domestic production of wind turbines and components, because of this the Chinese manufacturing industry has been increasingly mature and this fact reflects over the whole supply chain. China has become the world's largest producer of wind energy equipment and components made inside the country (see Figures 3.16 and 3.17). China started to not only satisfy domestic demand, but also meet international market. Sinovel and Goldwind have given a step ahead for entering into international markets, which is justified the world's top five wind turbine manufacturers in 2009 (GWEC, 2011c).

Table 3.2 Global installed wind power capacity (MW) – Regional Distribution

		End 2010	New 2011	End 2011
Africa & Middle East	Cabo Verde	2	23	24
	Morocco	286	5	291
	Iran	90	3	91
	Egypt	550	-	550
	Other[1]	137	-	137
	Total	1,065	31	1,093
Asia	PR China	44,733	17,631	62,364
	India	13,065	3,019	16,084
	Japan	2,334	168	2,501
	Taiwan	519	45	564
	South Korea	379	28	407
	Vietnam	8	29	30
	Other[2]	69	9	79
	Total	61,106	20,929	82,029
Europe	Germany	27,191	2,089	29,060
	Spain	20,623	1,050	21,674
	France**	5,970	830	6,800
	Italy	5,797	950	6,737
	UK	5,248	1,293	6,540
	Portugal	3,706	377	4,083
	Denmark	3,749	178	3,871
	Sweden	2,163	763	2,970
	Netherlands	2,269	68	2,328
	Turkey	1,329	470	1,799
	Ireland	1,392	239	1,631
	Greece	1,323	311	1,629
	Poland	1,180	436	1,616
	Austria	1,014	73	1,084
	Belgium	886	192	1,078
	Rest of Europe[3]	2,807	966	3,708
	Total	86,647	10,281	96,606
	of which EU-27[4]	84,650	9,616	93,947
Latin America & Caribbean	Brazil	927	583	1,509
	Chile	172	33	205
	Argentina	50	79	130
	Costa Rica	119	13	132
	Honduras	-	102	102
	Dominician Republic	-	33	33
	Carribean[5]	91	-	91
	Other[6]	118	10	128
	Total	1,478	852	2,330
North America	USA	40,298	6,810	46,919
	Canada	4,008	1,267	5,265
	Mexico	519	50	569
	Total	44,825	8,127	52,753
Pacific Region	Australia	1,990	234	2,224
	New Zealand	514	109	623
	Pacific Islands	12	-	12
	Total	2,516	343	2,859
	World total	197,637	40,564	237,669

1) South Africa, Israel, Lebanon, Nigeria, Jordan, Kenya and Libya

2) Bangladesh, Indonesia, Philippines,Sri Lanka, Thailand

3) Romania, Norway, Bulgaria, Hungary, Czech Republic, Finland, Lithuania, Estonia, Croatia, Ukraine, Cyprus, Luxembourg, Switzerland, Latvia, Russia, Faroe Islands, Slovakia, Slovenia, FYROM, Iceland, Liechtenstein, Malta

4) Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, UK

5) Carribean: Jamaica, Cuba, Dominica, Guadalupe, Curacao, Aruba, Martinica, Bonaire

6) Colombia, Ecuador, Nicaragua, Peru, Uruguay

** Provisional Figure

Please note:
Project decommissioning of approximately 528 MW and rounding affect the final sums

Source: GWEC (2012)

Africa & Middle East

Wind energy could help African continent to face the lack of electricity. About a quarter of the world's population has no access to electricity, and the problem is especially acute in peri-urban and rural areas in Sub-Saharan Africa. Although Africa and Middle East has shown a great development of wind power technology, especially in wind power capacity in MW. We highlight Cabo Verde and Morocco∴When it is considered the end of 2010 and the end of 2011, these countries has an increase in wind power capacity of 1,100%, 2% respectively. At the end of 2011 Cabo Verde had installed 24 MW and Morocco 291 MW (GWEC, 2012). Africa and Middle East have increased 3%, in the same period and had as wind power capacity installed about 1 GW.

Asia

Asia in terms of wind energy has been surprising globally. According to the Global Wind Energy Council (GWEC) (GWEC, 2012). Asia at the end of 2011 had installed almost 82 GW (82,029 MW). China was the world's largest market in 2011 with 17.6 GW of new capacity installed and goes ahead of the USA and India and became the global leading wind power country (see Figure 3.14). However, there are indications that only about half of the turbines in China are really in operation. Many of the wind farms are not connected to the grid because of quality problems or grid weakness, and appear to have been constructed to allow large utility companies to gain incentives in order to expand their coal-fired operations. The whole market is still heavily dominated by onshore projects. Of the total cumulative capacity only 2.1 GW is offshore of which about 689 MW was installed last year. Of special significance are the 209 MW wind farm project Horns Rev II and Germany's first offshore wind farm Alpha Ventus, with a capacity of 60 MW (Markard & Petersen, 2009). The Chinese market had increased its capacity from 44.7 GW in 2010 to 62.3 GW at the end of 2011; it is an increase of 39% in the same period. In the case of India, the Indian wind power market awaked and increased its capacity from 13 GW in 2010 to 16.0 GW at the end of 2011; it is an increase of 23% in the same period. In terms of new installed capacity during 2011 and comes in third position behind China and the USA (see Figure 2.14). Wind power accounts for 70% of this renewable installed capacity. In 2010 the official wind power potential estimates for India were revised upwards from 45 GW to 49.1 GW by the Centre for Wind Energy Technology (C-WET). Other Asian countries with new capacity additions in 2011 include Japan (2,3 GW, for a total of 2.5 GW), Taiwan (519 MW for a total of 564 MW) and South Korea (379 MW for a total of 407 MW). The Chinese market, in particular, now has three manufacturers among the top 10 global players and has shown potential for more new businesses. The acceptance of new wind turbines on the market depends on their suitability for international trade and the successful operation of their first projects∴Most of the new players still have to prove this, particularly regarding the quality and long-term stability of turbine operations. In mid-2009, the South Korean firm Daewoo Shipbuilding & Marine Engineering (DSME), the world's second largest shipbuilder, announced its entry into the wind energy market by acquiring DeWind for around US$50 million. DeWind is a medium-sized wind turbine manufacturer that has installed around 570 wind turbines in the 500 kW to 2 MW range (Wiese, Kleineidam, Schallenberg, Ulrich, & Kaltschmitt, 2010). Asia has increased 34, in the same period and had as wind power capacity installed about 82 GW.

Europe

The Europe continent has been facing serious economics and financial problems in its EU Members States. The EU Member States have tried to reduce unemployment situation, low productivity, in other words, come back to growth road and stop economic recession. Related to wind power, reflected investment in RE technologies since decades ago, the wind power installed across Europe in the end of 2011 reached 96.6 GW. This represents an increase only of 11% compared to 2010. According to EWEA (2012) the annual onshore market increased by over 13% compared to 2009, while the annual offshore market grew by 51%, and accounted for 9.5% of all capacity additions. In terms of total capacity installed, we must highlight Germany and Spain, at the end of 2011, with 29 GW and 21.6 GW, respectively. In terms of new installations German was the largest market in 2011, installing 2 GW followed by UK with 1.2 GW and Spain. For Spain 2010 was a good year for wind power, and the country's wind farms produced 42.7 TWh of electricity, which figures 16.6% of total Spanish power consumption. Five out of Spain's 17 regions now host 1 GW or more of wind power (AEE, 2006, 2011).

France, Italy and Portugal had a total wind power capacity installed by the end of 2011 with 6.8 GW, 6.7 GW and 4 GW, respectively. This same European country has increased their wind power capacity in 20%, 24% and 23% compared with the end of 2010. The French government set a target to achieve 25 GW of installed wind energy capacity by 2020, including 6 GW of offshore wind. The Italian wind power sector now employs more than 28,000 people, of which some 10,000 directly. For Portugal the total wind power capacity installed by the end of 2011 was 4 GW∴An interesting situation happened — Portugal went ahead of Denmark with wind power capacity installed, 4,083 MW and Denmark with 3,871 MW at the end of 2011. According to GWEC (2011b, p. 11) Turkey, Belgium, Poland and Sweden had presented in 2010 the biggest rates of growth in wind power capacity installed, with 66%, 62%, 53% and 39%, respectively. In the United Kingdom, around 40 new wind farms were opened in 2010, totaling 962 MW of additional capacity and taking the country's total installed wind power capacity to 5.2 GW. With 1.3 GW of installed capacity, the UK continues to be the world's leading offshore wind market. The majority of wind farms in the UK are located in Scotland (2.3 GW), in the North West (1 GW) and in Wales (0.5 GW). Only Scotland installed a third of all new wind power capacity in 2010 (0.4 GW) (GWEC, 2011c). Europe has increased 11%, in the same period and had as wind power capacity installed more than 96.6 GW.

Latin America & Caribbean

Latin America and Caribbean is a region of the globe with best wind resources (see Figure 3.11). The rest of the world has putted the eyes in Latin America because it is considered prime territory for the deployment of wind power. In the beginning the development of RE technologies have been modest, but nowadays there are no doubts that the region is an opportunity for an exponential developing of wind power industry to complement its rich hydro and biomass (and potential solar) resources, most notably in Brazil and Mexico. Brazil is the country where wind power is making the most progress; it is also the largest economy of the region. This country has many areas with tremendous potential for wind energy technology, combined with a growing electricity demand and solid industrial and grid infrastructure (GWEC, 2011c). We must highlight Argentina and Brazil. These main latin countries have increased the wind power capacity installed by 160% and 60%

respectively. Brazil had 1.5 GW and Argentina had 0.13 GW at the end of 2011. Brazil and Argentina are in top positions in terms of wind power capacity installed at Latin America. Chile, Costa Rica and Caribbean these countries almost reach 0.4 GW of wind power capacity installed. An interesting country is Chile, which had nearly 0.2 GW (205 MW) of wind power in operation at the end of 2011. The total wind power capacity installed in the Latin America and Caribbean grew by 58% during 2011, and more than 2 GW of wind power capacity were installed.

North America

The USA wind energy market installed 6.8 GW in 2011, only about half of the 2010 market. The country now has 46.9 GW of wind power capacity (up from 40.2 GW at the end of 2011), thereby conceding its global leadership to China. By 76% of the American states now have utility-scale wind installations and 28% of those had more than 1 GW installed. The leading state was Texas with more than 10 GW of total installed capacity and wind power now generates 7.8% of the state's electricity demands. Iowa is in second place with 3.6 GW, and now receives close to 20% of its electricity from wind power, followed by California, Minnesota and Washington State (AWEA, 2011). The American manufacturing sector, meanwhile, appears to view 2010's slowdown as short-term. New component suppliers continued to enter the wind energy industry last year, and over 400 US manufacturing plants now serve the industry∴Around half of the wind production equipment deployed in the USA is now manufactured domestically. In addition, the construction pipeline for wind power is healthy, with 5.6 GW currently under construction. Given such indicators, the industry finished 2011 well ahead of 2010 numbers (GWEC, 2011c). Canada's wind energy industry took a step ahead in 2011 with the addition of 1,267 MW of installed wind energy capacity, ranking Canada in 9th position globally in terms of new installed capacity and 6th for overall cumulative installed capacity (see Figure 3.13 and 3.14). Canadian wind energy industry had done a record year in 2011 with approximately 1.2 GW of new wind energy capacity; reflect of an investment of $3.1 billion and creating 13,000 person-years of employment in the Canadian wind energy industry. Canada has increased the wind power capacity installed by 11% and 5.2 GW of wind energy installed capacity. For the end of 2011, Canada had shown a total of wind energy installed capacity around 5.2 GW. In 2011, new wind energy projects were built and commissioned in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, and Nova Scotia (CanWEA, 2012; GWEC, 2011b). The total wind power capacity installed in the North America grew by 18% during 2011, and more than 52.7 GW of wind power capacity were installed.

Pacific Region

Australia wind power market at the end of 2011 had installed 2.2 GW, an increase of 12% in relation to the end of 2010. There were 52 operating wind farms in the country, mostly located in South Australia (907 MW) and Victoria (428 MW). Australia's expanded Renewable Energy Target (RET) Scheme, which entered into force in January 2010, mandates that 45 TWh or 20% of Australia's electricity supply will be sourced from renewable energy in 2020 (CEC, 2012; GWEC, 2011c). The initial goal was 12.5 TWh, and this could be gradually increased until 2020. After a good year in 2009, the rate of development in New Zealand dropped with just 8.8 MW of new wind capacity added, taking the total up to close to 506 MW, representing an increase by 2% at the end of 2010. Wind energy currently supplies just over 3% of New Zealand's annual electricity demand.

The world energy scenario has changed and it is important to highlight some its aspects. First of all, wind energy technology is more nature than ten years ago due to heavily R&D investments and renewable energies penetration has increased (NZWEA, 2012). For the Pacific Islands had only 12 MW as total wind power capacity installed at the end of 2011, and no increase was register in the period. The total wind power capacity installed in the Pacific Region grew by 14% during 2011, and more than 2.8 GW of wind power capacity were installed.

The total wind power capacity installed worldwide grew by 20% during 2011, and more than 237 GW of wind power capacity were installed. In global terms, we can say that wind market is continuing to attract new players and a significant number of new companies in Europe and Asia are developing new wind turbines to enter the market in the coming years. It is necessary to give emphasis the increasing trend of professionalism in the market. One example of this is continuous flow production; it is the need of increase output and quality and to reduce costs. Many manufacturers, including GE, REpower, Vestas and Enercon, began this process between 2003 and 2006 but had little success due to the many different wind turbine types needed to satisfy customer demands∴Currently the products of the wind energy industry are more standardized; this kind of production is becoming more effective; examples of successful factories include Siemens and GE. Apart from Europe, the USA and Asia, other markets for wind energy they are still with a small market share. We must highlight, there are notable wind farm projects being planned and starting-up in the developing world. In South America, the growing markets are specially concentrated in Brazil, Chile and Argentina, while the African market is still dominated by Egypt and Morocco.

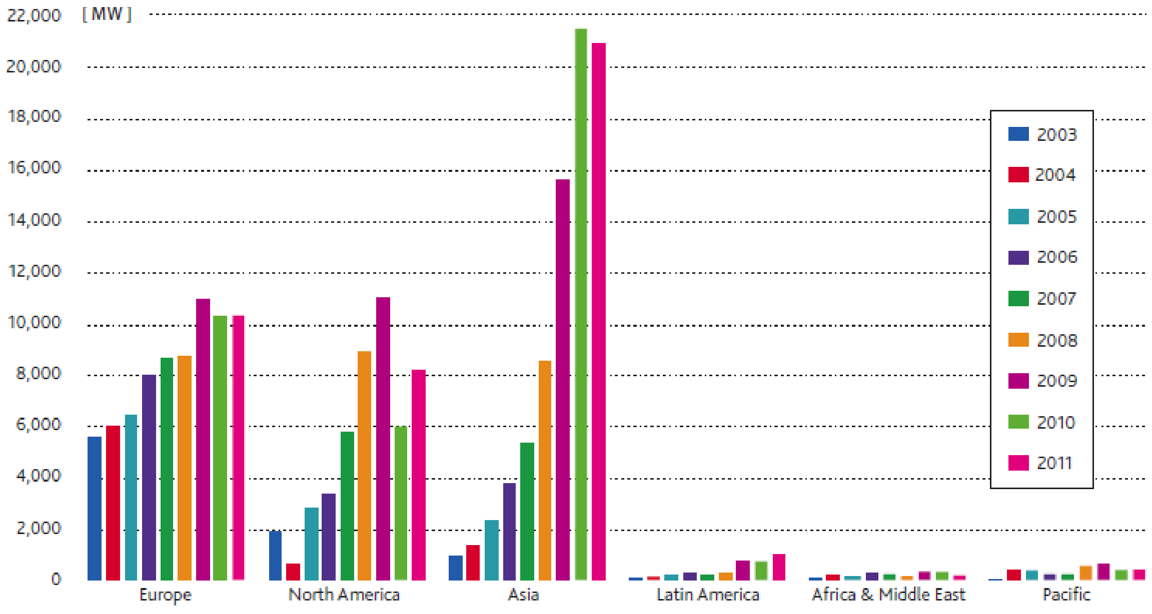


Figure 3.15 Annual installed capacity by region 2003-2011. Source: GWEC (2012)

According to GWEC (2012) the six regions worldwide has shown as annual installed capacity an interesting behavior (see Figure 3.15). In Latin America & Caribbean, Asia and North America had demonstrated highest growth with, 58% of increase and 2.3 GW (2011), 34% of increase and 82

GW (2011) and 18% of increase and 52.7 GW (2011), respectively. Also in Figure 3.15 we could conclude that the lowest growth was represented by Pacific Region, Latin America & Caribbean and Africa & Middle East with 2.8 GW (2011), 2.3 GW (2011) and 1 GW (2011), respectively. For Saidur, Islam, Rahim, and Solangi (2010) there have been a remarkable increase in any type of energy demand due to the economic and technological developments worldwide. The global economy has grown 3.3% per year over the last 30 years and in the same period energy demand has increased 3.6%. It is noticed that energy policy could help increasing wind energy industry. Oliveira and Fernandes (2011) conclude that human evolution is closely linked to energy, since the beginning of time man has to know it and seeking it ever more on the environment.

3.4.2 WIND ENERGY CONVERTERS MANUFACTURERS

In the wind energy industry, there is intense competition between the wind energy converters (WECs). Vestas and GE Energy have the largest market shares but no company controls more than 20% of the market (see Figure 3.16)∴However, there are distinct regional differences. Enercon, for example, dominates the German market with a share of 60%, but at the same time the company might have difficulties maintaining its global market share if the German market slows down. The situation for GE Energy in the US and Gamesa in Spain is similar. At any rate, since there is a trend towards ever-larger models that is accompanied by increasing capital requirements, larger companies will benefit on long-term (Green Rhino Energy, 2009).

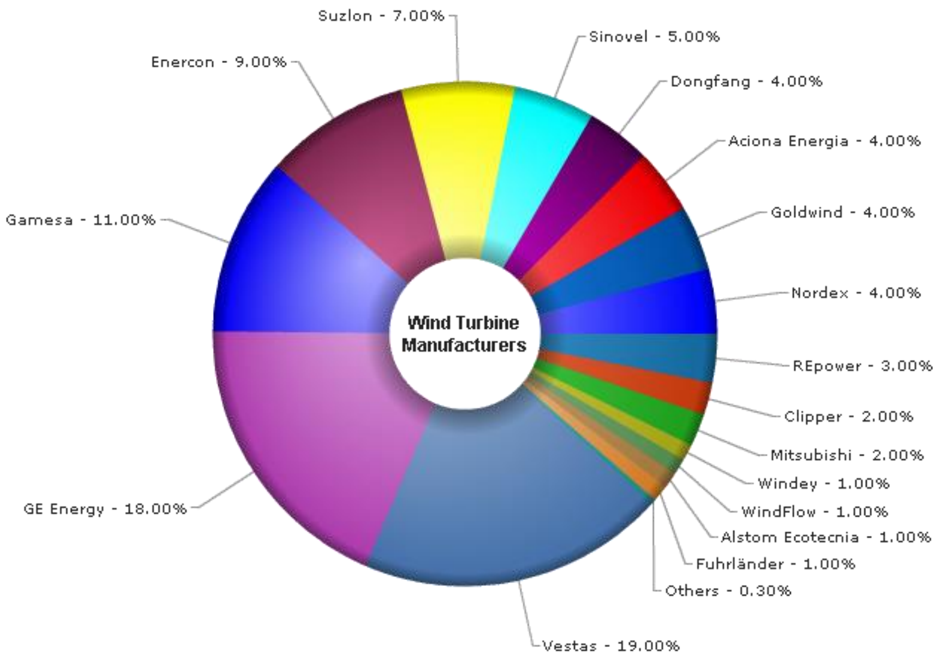


Figure 3.16 Wind turbine manufacturers' share. Source: Green Rhino Energy (2009)

When we take a look at turbine manufacturing features, Vestas one more time got the largest share (19.0%) of the global wind market, with approximately 37 GW (see Table 3.3). However, the enterprise has lost market share since 2008 and is near followed by GE Wind, whose market share was almost 18.0% in 2010. Amazingly for the first time there are also two Chinese enterprises in the top five suppliers list: Sinovel ranks sixth with 5.0% and Goldwind is seventh with 4.0% (see Figure 3.16). Although the wind power industry saw manufacturing volumes remain constant at their 2009 levels, manufacturing capacity increased substantially during 2010[17]. Project developers were challenged by competition with natural gas prices at three-year lows (leading to reduced sales), the continued challenge of obtaining project finance, and access to transmission. Industry leaders Vestas, Gamesa, Hansen Transmissions, and GE Wind all lowered sales forecasts during 2010∴Growth opportunities were focused mainly on China and other emerging markets as GE Wind supplied turbines to Brazil; Gamesa planned to triple investments in China by 2012; and Repower and Suzlon signed contracts in Turkey and Bulgaria[18]. Among the top 10 global manufacturing enterprises, Vestas of Denmark easily retained its number-one ranking, but Sinovel of China edged ahead of GE Wind in 2010 to take second place[19] (see Figure 3.17).

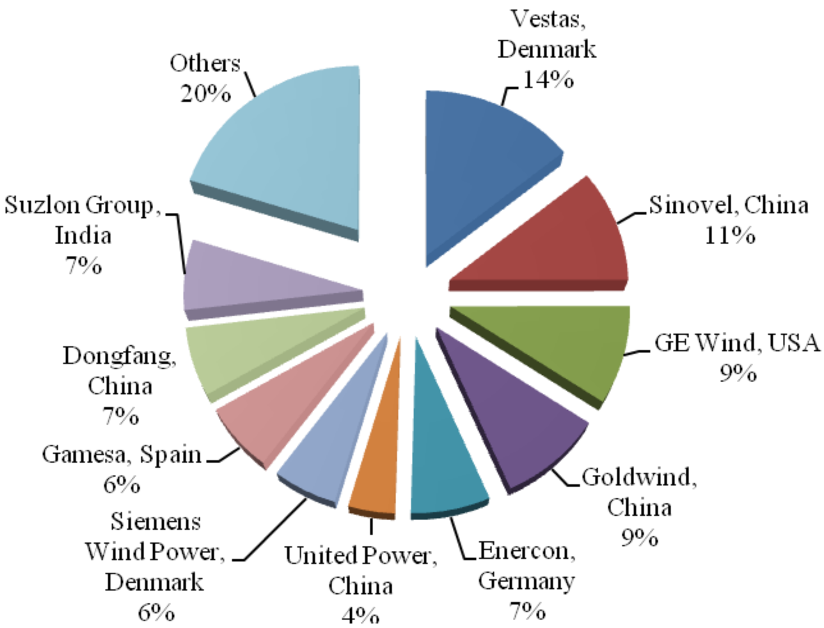


Figure 3.17 Market shares of top 10 wind turbine manufacturers in 2010. Source: REN21 (2011)

In China, enterprises Sinovel, Goldwind, Dongfang, and United Power saw strong growth driven by continued political and regulatory support and lower labor and manufacturing costs. Continued technology development at these enterprises also meant a smaller and closing gap in technological

[17] For more details, please see Steve Sawyer, Global Wind Energy Council (GWEC), personal communication with REN21, 19 April 2011.

[18] According to Rikki Stancich, *"2010 in Review: Peaks and Troughs for the International Wind Energy Sector,"* WindEnergyUpdate.com, 6 December 2010.

[19] Note that Suzlon Energy (IND) and Repower (GE) are listed as a Suzlon Group for the first time in BTM Consult's *World Market Update*. Rankings and data in Figure 13 from BTM Consult – A Part of Navigant Consulting, *World Market Update 2010* (Ringkøbing, Denmark: 2011), provided by Birger Madsen, BTM Consult, personal communication with REN21, March and June 2011. Note that the total quantity of capacity supplied exceeds 100% of the global market because some capacity was in transit or under construction and not yet commissioned at year-end. Data were adjusted for Figure 3.17 such that the sum of shares supplied totals 100%.

parity with overseas enterprises. Sinovel, for example, launched a 5 MW turbine model in 2010[20]. It appeared that industry consolidation might be on the horizon in China as a draft government policy called for narrowing the industry to far fewer than the existing 100-plus enterprises. The major developers of wind projects in China remained predominately state-owned enterprises: Longyuan, Datang, Huaneng, Huadian, CPI, and Guohua[21]. In Europe, industry activity focused increasingly on offshore technologies and on project development in Eastern Europe. The largest turbine to be financed so far, RePower's 6 MW model, was deployed in C-Power's 300 MW Thornton Bank project in Belgium, one of nine offshore wind farms developed in 2010.[22] And Transpower's high-voltage cable transmission infrastructure is being installed in the North Sea, laying the base for German offshore connectivity by 2013. Project developers became more aggressive in Eastern Europe, for example in Ukraine, where at least 10 project developers were active in 2010 due to a new feed-in tariff.[23]

In the United States, 14 new turbine manufacturing plants were established in 2010.[24] The U.S. industry was hampered, however, by late extension by the U.S. Congress of the Investment Tax Credit (ITC), low natural gas and electricity prices, and transmission access issues; so that project developers managed only half the number of projects they did in 2009∴Leading owners of wind power projects in the United States include NextEra, Iberdrola Renewables, Horizon-EDPR, MidAmerican/PacifiCorp, and E.ON Climate & Renewables.[25]

According to Markard and Petersen (2009) it is possible to differentiate the value chain of wind energy industry into five distinct parts. The first one is the *turbine manufacturing* which might include the development and production of wind turbines and auxiliary equipment. The second one is the *project development* with its sub-tasks such as planning, licensing, leasing of the land (onshore) and wind farm construction. The third is the *investment operation* that is about the provision of funds for a wind farm and forth is *operation* that concerns about managing the business including metering and billing of electricity production and maintenance of the technical components. And finally the fifth is *load management and power distribution* that is always combined tasks related to balance the intermittent power supply of wind farms and distributing and selling the electricity to end consumers. It is easy to notice when the sectorial value chain is simplified as there are further tasks (e.g. environmental impact evaluation, wind farm insurance or provision of meteorological services) that also need to be taken care of.

Direct-drive turbine designs captured 18% of the global market, led by Enercon (Germany), Goldwind (China), and Hara XEMC (China). Preferred turbine sizes were 2.5 MW in the U.K., 1.4 MW in China, and 1.2 MW in India. Globally, the average turbine size increased to 1.6 MW, up from 1.4 MW in 2007. Vestas launched the largest commercial turbine thus far, the dedicated

[20] Sinovel, "SL5000," www.sinovel.com/en/procducts.aspx?ID=148, viewed 19 April 2011.
[21] Shi Pengfei, Chinese Wind Energy Association and GWEC, personal communication with REN21, April 2011.
[22] Repower Corporation, *"REpower: 295 MW Contract Signed for Thornton Bank Offshore Wind Farm,"* press release (Hamburg/Antwerp: 25 November 2010).
[23] Vanya Drogomanovich, *"Can Wind Turn Ukraine's Orange Revolution Green?"* Bloomberg New Energy Finance Monthly Briefing, October 2010, p.12.
[24] American Wind Energy Association (AWEA), *Wind Energy Weekly*, 8 April 2011.
[25] Emerging Energy Research, *North America Wind Plant Ownership Rankings 2010: Trends and Review* (Cambridge, MA: 31 March 2011).

offshore V164 7 MW turbine, targeting North Sea opportunities.[26] Li and Chen (2008) made a comparison with geared-drive wind generator systems and concluded that most important advantages of direct-drive wind generator systems were the higher overall efficiency, reliability and availability due to no gearbox is necessary. The direct-drive generators usually have larger size, but it could not be disadvantage for the offshore wind energy applications.

Table 3.3 Track record by turbine type

	Installed in 2010		Accumulated installed	
	Number	MW	Number	MW
V52-850 kW	340	289	3,764	3,199
V60-850 kW	15	13	15	13
V80-1.8 MW	0	0	1,016	1,829
V80-2.0 MW	267	534	2,981	5,962
V82-1.5 MW	0	0	213	320
V82-1.65 MW	273	450	2,883	4,757
V90-1.8 MW	269	484	572	1,029
V90-2.0 MW	763	1,527	3,286	6,544
V90-3.0 MW	834	2,502	2,170	6,510
V100-1.8 MW	20	36	20	36
V112-3.0 MW	2	6	2	6
Other	1	1	26,511	6,729
Total	2,784	5,842	43,433	36,934

Source: Vestas (2011)

The search for more productivity in the power output what forward trends for larger wind turbines, about 82% of all wind turbines installed in 2009 falling into the range of 1.5 MW to 2.5 MW, but the growth is still slow. Wind turbines in onshore wind farms generally have a range between 2 MW to 3 MW in countries with a good infrastructure∴Although, larger wind farms with smaller turbines (up to 1.5 MW) are under development or have been installed in areas with poorer infrastructure. The REpower 6M and the Enercon E-126 are particularly well-known. The 6M has a rated capacity of 6.15 MW while the Enercon E-126 is available with 6 MW of rated capacity (Wiese et al., 2010).

The power output of a wind turbine is roughly proportional to the rotor area, so fewer larger rotors at higher towers use the wind resources more efficiently than more numerous, smaller wind turbines. The biggest commercial wind turbines today are 5–6 MW units with a rotor diameter of up to 126 m. Every five years wind turbines have doubled in size approximately, but this rate seems to be slow for onshore turbines, due to operational and installation constraints. The expected lifetime of a commercial wind turbine currently is 20–25 years. Lifetime spans may stretch as the technology continues to mature. However, due to the youth of the industry, as we know today, and the re-powering of wind farms with the updated turbine technology, few turbines have been around long enough to test this consideration. Due to extensive testing and certification, the reliability of

[26] See Chris Red, *"Wind Turbine Blades: Getting Bigger and Bigger"*, CompositesWorld.com, viewed 20 June 2011.

wind turbines — the proportion of the time they are technically available for operation — is approximately 99% (Furkan, 2011). During the last ten years power electronics have represented a key factor in the evolution of wind turbines towards more efficient wind energy capture, better quality of voltage output, better grid integration, etc. Efficiency is an important issue for wind turbines when comparing different systems because losses reduce the average power produced by the wind energy converter and, so on, they reduce incomes (Amirat & Benbouzid, 2007, p. 28). The Table 3.4, it is shown a list of top 10 globally wind turbine manufacturers in 2009 with its currently used generator concepts and power ranges.

Table 3.4 Top 10 globally wind turbine manufacturers of 2009, currently used generator concepts and power ranges

Manufacturer	Concept	Rotor diameter	Power range
Vestas (Denmark)	DFIG	52 – 90 m	850 kW – 3 MW
	GFC PM	112m	3 MW
General Electric (US)	DFIG	70.5 – 82.5 m	1.5 MW
	GFC PM	100 m	2.5 MW
	DD PM	110 m	4.0 MW
Sinovel (China)	DFIG	60 – 113 m	1.5 – 3 MW
Enercon (Germany)	DD EE	33 – 126 m	300 kW – 7.5 MW
Goldwind (China)	DD PM	70 – 100 m	1.5 MW – 2.5 MW
Gamesa (Spain)	DFIG	52 – 97 m	850 kW – 2 MW
	GFC PM	128 m	4.5 MW
Dongfang (China)	DFIG	-	1 – 2.5 MW
Suzlon (India)	CS	52 – 88 m	600 kW – 2.1 MW
Siemens (Germany)	GFC IG	82 – 107 m	2.3 – 3.6 MW
	DD	101 m	3 MW
Repower (Germany)	DFIG	82 – 126 m	2 – 6 MW

Source: Polinder (2011). CS: constant speed with gearbox and induction generator, possibly with extended slip or two speeds; DFIG: variable speed with gearbox, doubly-fed induction generator and partly rated converter; DD EE: variable speed direct-drive synchronous generator with electrical excitation and full converter; DD PM: variable speed direct-drive permanent-magnet generator and full converter; GFC PM: variable speed with gearbox, permanent-magnet generator and full converter; GFC IG: variable speed with gearbox, induction generator and full converter.

Table 3.4 starts with describing the most commonly used generator systems in wind turbines manufacturers' leader worldwide. Each manufacturer is market-oriented and size and concept differ during the period of time∴The most important trend in the marketplace is the progressive increase in the size of commercial wind turbines as a result of a bigger power output search. The average wind turbine size has thus increased by about 12% per year over the last decade (Hansen & Hansen, 2007). In chapter 4, it is discussed technical aspects of each concept and other important issues about wind energy conversion systems. Subsequently, some of the most important developments in wind turbine generator systems are discussed. Finally, some conclusions are drawn.

3.4.3 ECONOMIC IMPACTS FROM WIND ENERGY INDUSTRY

Wind power plants installations can create jobs in a country where local economies are often dependent on local business activities. Local jobs refer to construction-related activities; operation and maintenance of the facility after it is constructed, and jobs induced by the money addition in the local economy by the temporary workers. Lantz and Tegen (2008) made some studies about the variables affecting in an economic development process by wind energy activities. Lantz and Tegen (2008) state that *"creating policies to ensure maintenance materials are supplied by in-state business and that the local labor force is trained to perform wind turbine maintenance is also likely to have a large impact for wind power plants operating for 20 or more years"*. The maximization of economic benefits by wind energy development is linked to the improvement of related in-state businesses and trained labor force.

Greater energy independence, improved environmental benefits from reduced greenhouse gas emissions and positive economic impacts have been appointed as the main three main reasons for investing on wind energy industry. When we have to face our climate responsibilities and the opportunity to build a low-carbon economic base, job creation is an especially question to discuss about. The development of indigenous sources of renewable energy technology, as wind power, will forward the creation of more jobs locally than *'business as usual'* fossil-fuel economies of the last century (Engel & Kammen, 2009). The focus on finding solutions for mitigating global warming has resulted in renewable energy technologies gaining importance. Improvements accomplished in technology resulted in a fast growth in wind power worldwide∴Among the renewable energy technologies, wind power is one of the fastest growing technologies globally at an average annual growth rate of more than 26% since 1990 (Resch et al., 2008).

According to WWEA (2011) by the end of the year 2010, about 670,000 people were employed worldwide directly and indirectly in the many areas in the wind industry. During the last five years, the number of jobs almost tripled, from 235,000 in 2005. There is an increasing demand for a very broad range of jobs, from engineers, skilled workers to managers, financial, environmental and legal experts. One of the positive aspects of the wind energy industry is the impact on employs, but few studies have systematically dealt with this matter (Blanco & Rodrigues, 2009). The development of renewable energy industry has become a way to accomplish environmental objectives and a long way of increasing energy self-sufficiency and employment in general (Connor, 2003; Dincer, 2000; Hillebrand, Buttermann, Behringer, & Bleuel, 2006; Laitner, Bernow, & DeCicco, 1998; Moreno & López, 2008; Thothathri, 1999). The adoption of renewable energies technologies represent an opportunity to reduce energy dependence, reduce the emission of CO_2 and create new employs and revenues. The engagement of local economic agents is extreme necessary for the future development of RE technologies, especially in regions whose industrial activity mix was based on traditional energy sources. Wind energy industry in Europe is a predominantly male business with 78% employment, where men represent the majority of the labor force in fields of construction, production and engineering (Moreno & López, 2008).

The development of wind power can create new opportunities for more domestic jobs per currency invested and/or per kilowatt-hour produced than fossil fuel power production. *Manufacturing of wind power utilities and equipment*, *constructing and installing* the wind projects, and *operating* *and maintaining* the projects over their lifetime usually create direct jobs (Lewis & Wiser, 2007). The wind energy industry has become a major job generator globally: within only three years, the wind industry worldwide almost doubled the number of jobs from 235,000 in 2005 to 440,000 in the year 2008 (see Figure 3.18). These 440,000 employees in the wind energy industry worldwide, most of them highly skilled jobs, have been contributing to the production of 260 TWh of electricity (WWEA, 2011).

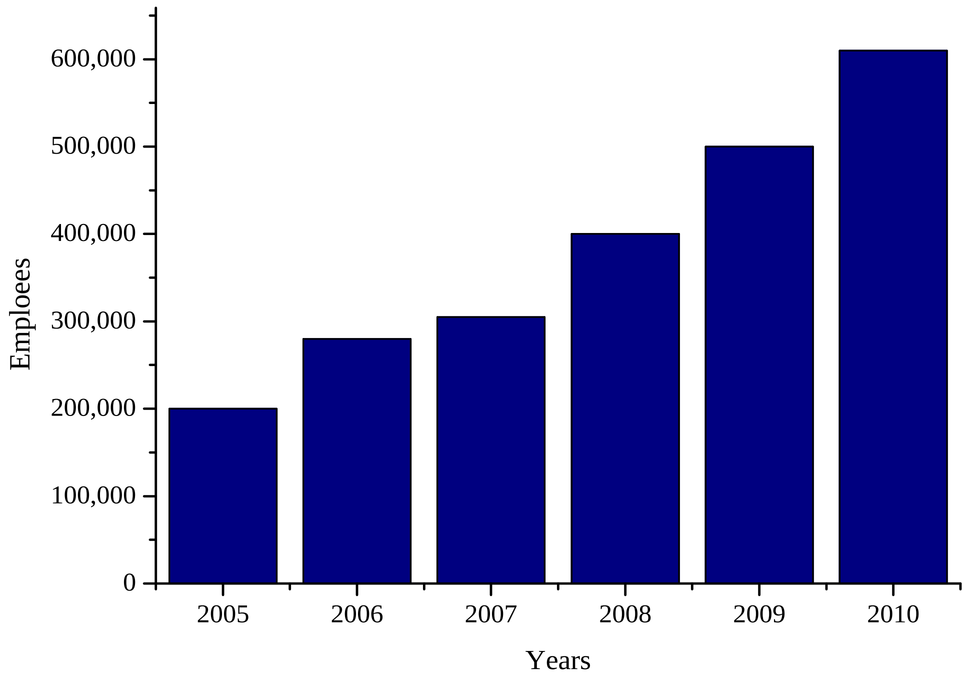


Figure 3.18 Green jobs on wind energy sector worldwide. Source: WWEA (2011)

Wind energy industry represents an attractive source of employment worldwide. Activities as construction, O&M, legal and environmental studies are best driven at local level; we can notice a positive correlation between the location of the wind farm and the number of jobs it creates. The location of a wind farm determine where can be located large manufacturing centers, however, microeconomic factors such as, skilled labor force, easy access roads, grids infrastructure and regional and municipal authorities have a role to play∴Another relevant issue is that wind energy employment is following the opposite trend to the general energy industry, particularly coal extraction and electricity production, and measures that encourage the transfer of workers from general energy industry to wind energy activities could be highly beneficial from both social and economic aspects (Blanco & Rodrigues, 2009; Thothathri, 1999).

According Hamilton and Liming (2010) the process of getting energy from the wind into the home is so complex, in business terms, that is why it involves many players simultaneously. A modern and commercial wind turbine consists of an estimated 8,000 parts. Turbines must be designed, built, transported, and erected before they can start producing energy∴As we have said the chain of wind industry can be classified into three major phases: *manufacturing*, *project development*, and *operation and maintenance*. A wind energy successful project, each of these phases overlap and there is substantial communication among players in all these three phases. The manufacturing sector hosts most of the jobs, followed by construction, and operation and maintenance. However, in the case of new wind farms forward the repower process, for manufacturers can take advantage of returns to scale. Figure 3.19 shows the distribution of jobs in American wind power industry in 2010.

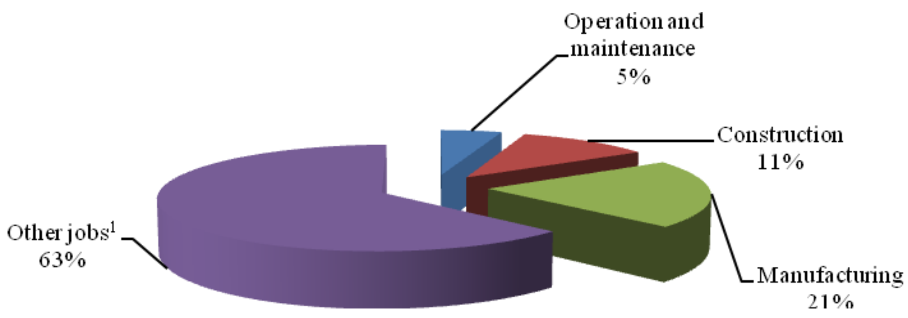


Figure 3.19 Jobs in wind power, 2009. Source: Hamilton and Liming (2010)

(1) *"Other jobs"* includes the following: some manufacturing, parts-related services, financial and consultant services, developers and development services, contracting and engineering services, and transportation and logistics.

Large wind turbines are made of complex pieces of machinery designed and built by companies known as *Original Equipment Manufacturers* (OEMs). Most of OEMs are large transnational corporations for which wind turbine manufacturing phase is only a small piece of their global business. Wind farm development is a challenging process that usually takes several years from conception to construction. The beginning of this process is the *selection of an appropriate site*. This step involves a great number of factors, such as wind speed and frequency, availability of area, ground constitution for supporting the weight — often more than 1,000 t — of turbine structures, environmental concerns — such as local avian populations and the feasibility of transporting large turbine components to the site chosen. In the phase of *project development* also has many legal and financial issues such as contract development and financing. All of this work representing the pre-operational phase of the wind energy project∴The self-running of wind energy projects is a way it works by itself with little need for human supervision (remote controlling). Energy companies employ monitors, either locally or remotely, to observe energy flows and report technicians of any problems. All wind farms employ local workers, but remote monitoring of wind turbines can allow for a cost-effective way to ensure that the wind turbine (wind farm) is working most efficiently as possible and that local technicians are alerted to any potential problems advised (Ayee, Lowe, & Gereffi, 2009).

The initial spending on the *construction* and *operation* phases of the wind farm has a second and economic effect, usually referred as *"indirect impacts"*. Indirect impacts during the construction phase representing the changes on relations inter-industry from the direct final demand changes which includes construction spending on materials, wind farm equipment; other purchases of related-goods and offsite services∴And increase in some final product represent an also increase in its components to produce it as well as an increase in the economic activity at local site (Goldberg, Sinclair, & Milligan, 2005). Indirect impacts reflect on all supply chain component impacts/manufacturing-related activities; therefore, the final phase of turbine assembly process, which includes gearbox assembly, blade production, and steel rolling are all included under the construction period indirect impacts category. Also the manufacturers of turbine parts such as bearing producers, steel producers, and gear producers are also in this same category. Indirect impacts during operating years refer to the changes in inter-industry purchases resulting from the direct final demand changes (Lantz & Tegen, 2008).

Landowners who lease their land to wind developers benefit from having a stable source of revenues. This option is usually greater than that from ranching or farming if we compare on a per acre basis, the revenue receive from leasing their land by wind developers. Landowners can be compensated in a variety of ways: option payments, construction disturbance or installation payments, land leases, and/or royalties. While royalty is a percentage of gross revenues received by the wind farm owner from the sale of power (Pedden, 2006).

According to Goldberg et al. (2005) it is possible to classify the total effect of developing a wind power plant into three types of impacts. They can be defined as *direct effect*, *indirect effect*, and *induced effect*:

1. *Direct effect:* they are general on-site or immediate effects created by expenditures. In constructing a wind power plant, it refers to the on-site jobs of the contractors and crews hired to construct the plant. It also includes the jobs at the turbine manufacturing plants and the jobs at the tower and blade factories.

2. *Indirect effect:* It refers to the increase in local economic activity that happens when a contractor, vendor or manufacturer receives payment for goods or services and in turn is able to pay others who support their business — economy cycle. For instance, this impact includes the banker who finances the contractor; the accountant who keeps the contractor's books; and the steel mills and electrical manufacturers and other suppliers that provide the necessary materials on-site.

3. *Induced effect:* It is a reflect effect and usually refers to the change in wealth and income that is induced by the spending of those economic agents (workers, companies, public services, etc.) directly and indirectly employed by the wind project. This would include spending on food, clothing, or day care by those directly or indirectly employed by the project, retail services, public transit, utilities, cars, oil, property & income taxes, medical services, and insurance, for example.

3.5 SUMMARY AND CONCLUSIONS

Now is the time to reform the energy system, since it was created during the growth phase in a highly industrialized society. Our society is on the verge of an energy crisis and various global environmental problems. These are influences that our society presents great opportunities for technological innovation. To implement this effectively, it is important to conduct and promote energy conservation policies, recognizing the negative effects on the external economy. Wind power has advantages over current systems of high efficiency power production used today. The great advantage of wind power is the fact that energy can be produced from natural resources that are available and plentiful. However, the electrical energy produced wind power is influenced by natural conditions, which can disturb the stability and reliability. Any escape from this problem of root development cannot be expected. The relationship between the owners of independent wind energy business and its external environment is very difficult. Therefore, it is safe to assume that wind power cannot remain competitive in isolation, as individual business entity with less financial support from consumers of electricity at present. For this question, initially, the government policy and electricity consumers should share the additional costs associated with all aspects of wind energy. As wind production becomes more widespread, the cost will be reduced through *"learning by doing."* The more traders contribute to the production of wind energy that will reduce some of the main disadvantages of the interaction between technology and markets. The advantages that accrue to the consumer as a result of greater penetration of wind power far outweigh the disadvantages of the initial costs.

The analysis of diffusion in the wind energy industry in terms of efficiency, effectiveness and development criteria reveals the following:

1) Internal technological innovation has solved the technological imbalance between the subsystems that constitute a system, thus increasing the performance of wind turbines. These technologies were used in large equipment, improving the efficiency of wind turbines and ensuring economies of scale of this type of equipment in large scale wind farms or wind farms.

2) For the system of energy businesses, this analysis demonstrated that there is no balance between incentives and contributions from business owners of wind energy, electric energy companies, and consumers. The system is therefore not effective enough now.

3) The system began to evolve in order to complement each other, with systems of other technological products (solar, photovoltaic, etc.) as well as micro-networks.

To highlight these three aspects can be divided into technological trajectory and interaction between technology and markets∴Analysis of the criteria of efficiency and technological development shows the trajectory, as described below, in technological innovation. In the first phase, innovations occurred in the subsystems of a product system. Pitch control was adopted in the original draft of Denmark, who became the dominant design. An approach permits the performance of a generator with increasing conversion efficiency of the turbine blades in a complementary relationship. In other words, in a complex product system consisting of interrelated subsystems, it is necessary to increase the integrated action with the parties taking into account the interdependencies with the system, when there is an innovation in a product system. The internal logic of the technology itself defines technological innovation, as stated in the model of Rosenberg's technological imbalance. This case study indicates that not only increases the performance of technological equipment for the imbalance itself, but also creates new technological opportunities to make projects more wind turbines (Rosseger, 1996; TPWind, 2010b).

In the second stage, the innovation has occurred at the unit level of a modular product system by adopting a function of change of speed. When a product system has nonlinear characteristics with respect to the external environment, each party within the modular unit is quite capable of improving the technological imbalances in the face of nonlinear characteristics. For this reason, researchers have turned interference from the external environment in non-interference, which cannot be performed alone, but only through cooperation within the product system with which there was a mutual relationship. Near linear characteristics were obtained, resulting in an increase in the overall performance of the product. In other words, there was awareness of the range in which the imbalance was resolved technological expanded from working out in the modular unit, in search of mutual cooperation and integration has improved the performance of the whole technology (Hobday, 1998; Inoue & Miyazaki, 2008).

In the third stage, the innovation has occurred at the system level and micro-emerging networks. When a disturbance occurs as a frequency shift of power in the electrical system, there are limits that govern the performance improvement, improving the relationship because of the mutual dependence of modular units. For further performance improvement, an alternative means or other technology option is necessary (Heier, 1998). One such measure is to continue with the system decomposition approach in an attempt to stabilize the networks in small groups, ensuring a balance between supply and demand at connection points, and avoid disruptions that occur on the grid in general. It is interesting to note that the evolutionary trajectory of this technology tends to lead to higher levels of the hierarchy of the system for stability (Tidd, Bessant, & Pavitt, 2005). This is the reverse, and in contrast to the process by which cars in general and other industries are going to lower levels, apparently due to the fact that the wind carries the full burden of social charges, while production technologies existing power are not subject to external economic factors. Micro-grids can be expected to affect the diffusion of wind power∴If the demand for wind energy grows, the opportunities for technological innovation will emerge as well, which make it possible to eliminate factors that inhibit the rate of technological evolution of wind power (Clark, 1985).

Related to wind resources worldwide, many studies deal with wind speeds geographical distribution and most of them converge that characteristic parameters of the wind profile, orography, topography and local wind flow and measurement of the wind speed are very necessary in wind resource evaluation for a successful and safe application of wind turbines (de Castro, Mediavilla, Miguel, & Frechoso, 2011). The potential availability of wind power can change over time and among locations. This variation is not only caused by the resource characteristics (wind regime and profile, soil, humidity, etc.) but also by geographical (land use and land cover), techno-economic (scale, labor cost, inflation, time horizon, etc.) and institutional (policy regime, legislation specialized) factors. Some of these factors cannot or can only approximately be quantified or estimated.

In respect to global wind energy situation we can say about 2011 was a tough year for wind energy industry, and although cumulative market growth was around 20%, the annual market decreased for the first time in the last twenty year. The financial crisis in medium term brought some consequences and the global economy had to slowdown, and very low orders in OECD countries at the end of 2008 and the beginning of 2009 made themselves felt in the 2010 installation totals, particularly in the USA. Amazingly approximately 40.5 GW of new wind power capacity was added around the world last year, and for once the majority of that new capacity was in developing countries and emerging economies; driven mainly by the booming wind sectors in China and India, but also with strong growth in Latin America, where we believe that macroeconomic situation and wind resource-rich will make the wind energy industry jumps much forward in those regions which we have been waiting for and expecting for so many years (GWEC, 2012).

The growth of wind power outside of the OECD has been essential driven by the continuing boom in China, which is now the top country in installed wind power capacity in the world (see Figures 3.13, 3.14 and Table 3.2). There is also a great change of attitude by government towards wind power in many countries. First of all wind technology was considered too expensive by many developing country energy planners just a couple of years ago, the progressive success of the technology in much more countries have changed that attitude to one of dramatically increased knowledge about wind energy and how could wind energy technology improve the country's power mix.

Economic impacts from wind energy industry are clearly positive in a macroeconomic terms, because its impacts on employment, incomes and taxes and production of goods and services in general. First of all, it is necessary to emphasize that wind energy industry represent an important source of employment in many countries in the globe. There are some activities like operation and maintenance (O&M), research and development (R&D), manufacturing and construction which are able to create jobs in wind industries. The electric power industry is a strongly regulated industry and, in the case of RE technologies, the role of governments' incentive to bring these young technologies (related to fossil fuel technologies) to market adds to the importance of politics. Looking at the growth of wind turbine capacity over the past ten years, some conclusions can be taken. Among all renewable energies, wind energy is certainly the one that is closest to making the transition from niche to mass market. It is strongly linked with long-term prosperity. For Pablo (2008) *investment* explains the productive capacity of an economy. Investments made in the renewable energy industry have in addition a strong influence on the degree of dependence among economies, their competitiveness, sustainability, and on all kinds of environmental issues including climate change.

Wind power technology must be understood with its nature, working principle of WECS, innovation and technology trends, in summary, the Chapter 4 is made a compilation of WECS in order to establish a context for better understanding the current wind energy conversion systems, for a comprehensive cost production analyzes of a wind farm.

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God gave the wind its weight.
Job 28:25.

CHAPTER 4

WIND ENERGY CONVERSION SYSTEM

This chapter discusses about wind energy conversion system (WECS). It is discussed about wind energy history, technological aspects; types of wind energy converters are also presented. There is a summary of physics basics applied to WECS. Wind farms layouts with their own aspects are shown. Summary and conclusions are shown with respective references at the end.

4.1 INTRODUCTION

Wind energy systems have a multidisciplinary aspect and various perspectives to be analyzed. Any perspective approached, regardless of its background, will feel large gaps in its knowledge, areas where it does not even know what the question is, let alone where to go look for the answer. For Herbert, Iniyan, Sreevalsan, and Rajapandian (2007) wind energy system has a unique technical identity and unique demands in terms of the methods used for design. Remarkable advances in the wind power design have been achieved due to modern technological developments. Wind energy systems convert the kinetic energy[27] of moving air into electricity or mechanical power. Wind turbines are commercially available in a vast range of sizes. The kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world (see Figure 3.11).

The energy that can be captured by wind turbines is highly dependent on the local average wind speed. Regions that normally present the most attractive potential are located near coasts, inland areas with open terrain or on the edge of bodies of water. Some mountainous areas also have good potential. In spite of these geographical limitations for wind energy project sitting, there is ample terrain in most areas of the world to provide a significant portion of the local electricity needs with wind energy projects. Wind turbines are getting larger because of the desire to increase the power output and the associated economy of scale $\therefore$ The power output is directly proportional to the swept area of the rotor (larger blades equal larger swept area, which results in higher power output). Costs are also decreased when using larger turbines because fewer turbines are needed to make up the wind farm, which means that; less roads to the turbines are required, less cabling between wind turbines is required, less maintenance (fewer turbines) is required, and there is less interference with agriculture (when compared to having several smaller wind turbine units in the same area producing the same power).

This chapter makes a compilation of wind energy conversion systems (WECS) in order to establish a context for better understanding the current wind energy conversion systems. It begins with a bit of history about wind energy and its milestones and application by human civilization until nowadays time (section 4.2). Section 4.3 refers to the technological aspects of wind energy technology by describing system parts or elements (section 4.3.1) within its conversion processes and types of wind energy converters (section 4.3.2) and the design of converters (section 4.3.3) used in actual power energy market. Section 4.4 is related to physical basics applied to wind energy conversion system, especially emphasis on energy extracted from wind (section 4.4.1); power coefficients (section 4.4.2). It this particular issue, we discuss about *Betz'law* and the *power coefficient* (sub-section 4.4.2.1), *tip speed ratio* (sub-section 4.4.2.2) and *power efficiency* (sub-section 4.4.2.3). For a question of economy scale, wind power is more and more presented as an aggregated form, in a wind farm configuration, that is why we discuss about wind farms layout (section 4.5). Finally, the summary and conclusions of the whole chapter (section 4.6) and all references used are present at the end of this chapter.

[27] According to Rosa (2009) wind is a kind of simple air motion. It is caused by the unequal heating of the earth surface. Since the earth surface is made of different kinds of continents and oceans, it absorbs the sun heat at different rate, and the different temperature could cause the different pressure. The wind's kinetic energy can be converted into other forms of energy, either mechanical energy and/or electrical energy.

4.2 HISTORY OF WIND ENERGY

The power of the wind has been utilized for at least 3,000 years. Wind energy first used for boat navigation on the Nile River 5,000 BC. During the same period, windmills pumped water in China. The first written information on wind turbines is based on a simple structural horizontal axis wind turbine during the region of Alexander the Great. It is known that the Persians used vertical axis wind turbines during 700 BC. Windmills are introduced to the western world at the beginning of the 12th century from Islamic world. Until the early 20th century wind power is used to provide mechanical power to pump water or to grind cereals (Şahin, 2004). According to Kaldellis and Zafirakis (2011) it was centuries ago when the technology of wind energy made its first actual steps - although simpler wind devices date back thousands of years ago — with the vertical axis windmills found at the Persian-Afghan borders around 200 BC and the horizontal-axis windmills of the Netherlands and the Mediterranean following much later (1300-1875 AD).

The wind has been used to power sailing ships for many centuries. Many countries owed their prosperity to their skill in sailing. The New World was explored by wind powered ships. Indeed, wind was almost the only source of power for ships until Watt invented the steam engine in the 18th Century. On land, wind turbines date back many centuries. It has been reported that the Babylonian emperor Hammurabi planned to use wind turbines for irrigation in the seventeenth century B.C. Heron of Alexandria[28], who lived in the third century B.C., described a simple horizontal axis wind turbine with four sails which was used to blow an organ (see Figure 4.1). The Persians were using wind turbines extensively by the middle of the seventh century A.D. Theirs was a vertical axis machine with a number of radially-mounted sails (Johnson, 2001).

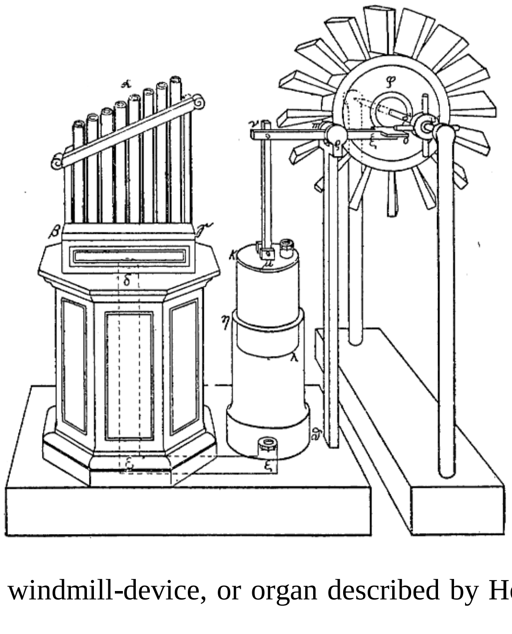


Figure 4.1 Concept of the windmill-device, or organ described by Heron of Alexandria. Source: Shepherd (1990, p. 5)

[28] *Heron of Alexandria* was a mathematician, a physicist and an engineer who wrote many books on Mathematics, Geometry and Engineering, in use till the medieval times. His devices were powered by single humans, water, steam or the wind, and contained many simple mechanisms (Papadopoulos, 2007, p. 23).

For Johnson (2001) these early machines were rightly simple and mechanically inefficient, but they served their purpose well for many centuries. Maintenance was probably a problem which served to keep many people at work. Their size was probably determined by the materials available. A need for more power was met by building more wind turbines rather than larger ones. The earliest recorded English wind turbine is dated at 1191. The first corn-grinding wind turbine was built in Holland in 1439. There were a number of technological developments through the centuries, and by 1600 the most common wind turbine was the tower mill. This application was so common that all wind turbines were often called *windmills*[29] even when they actually pumped water or performed some other function. The tower mill had a fixed supporting tower with a rotatable cap which carried the wind rotor. The tower was usually built of brick in a cylindrical shape, but was sometimes built of wood, and polygonal in cross section. In one style, the cap had a support or tail extending out and down to ground level. A circle of posts surrounded the tower where the support touched the ground. The miller would check the direction of the prevailing wind and rotate the cap and rotor into the wind with a winch attached between the tail and one of the posts. The tail would then be tied to a post to hold the rotor in the proper direction. This process would be repeated when the wind direction changed. Protection from high winds was accomplished by turning the rotor out of the wind or by removing the canvas covering the rotor latticework (Sorensen, 1995).

The optimization of the rotor shape probably took a long time to accomplish. It is interesting to note that the rotors on many of the Dutch mills are twisted and tapered in the same way as modern rotors and appear to have nearly optimized the aerodynamic parameters necessary for maximum efficiency. The rotors presently on the tower mills probably do not date back to the original construction of the tower, but still indicate high quality aerodynamic engineering of a period much earlier than the present. Dutch settlers brought this type of wind turbine to America in the mid-1700's. A number were built but not in the quantity seen in Europe. Then in the mid-1800's a need developed for a smaller wind turbine for pumping water. The American West was being settled and there were wide areas of good grazing lands with no surface water but with ample ground water only a few meters under the surface. With this in mind, a distinctive wind turbine was developed, called the American Multibladed wind turbine. It had high starting torque and adequate efficiency, and suited the desired water pumping objective very well. If the wind did not blow for several days, the pump would be operated by hand. Since this is a reasonably good wind regime, hand pumping was a relatively rare occurrence (Bellarmine & Urquhart, 1996).

An estimated 6.5 million units were built in the United States between 1880 and 1930 by a variety of companies. Many of these are still operating satisfactorily. By providing water for livestock, these machines played an important role in settling the American West (Kaldellis & Zafirakis, 2011). For Brown (2003) the energy future belongs to wind. The world energy economy became progressively more global during the twentieth century as the world turned to fossil fuels. It promises to reverse direction and become more local during the twenty-first century as the world turns to wind.

[29] The word *mill* refers to the operation of grinding or milling grain. The study of wind machines is called ***molinology***. It is related to several fields including Meteorology, Aerodynamics, Machine Design, Structural Design, Materials Technology, Power Engineering, Reliability Engineering, Instrumentation and Controls Engineering (Hills, 1996).

Wind power will shape not only the energy sector of the global economy but the global economy itself. Some milestones in the history of wind machines are summary up in Table 4.1.

Table 4.1 Historical development of wind energy conversion system

Period	Machine	Application
640 AD	Persian wind mills	Grinding, etc.
Before 1200 AD	Chinese sail type wind mill	Grinding, water pumping, etc.
12th century AD	Dutch wind mills	Grinding, water pumping, etc.
1700 AD	Dutch wind mill to America	
1850 to 1930 AD	American Multi-bladed	Water pumping, 35 VDC power
1888 AD	Brush wind turbine; dia.17m, Tower 18.3m	12 kW Electric power
1925 AD	Jacob's 3 bladed propeller; Dia.5m, 10-20m/h, 125 to 225 rpm	0.8 to 2.5 kW at 32 VDC
1931 AD	Yalta Propeller, Russia; 2 bladed, dia.100 ft.	100 kW
1941 AD	Smith-Putnam Propeller 2 bladed, dia.175ft, 30 m/h, 28 rpm	1250 kW
1925 AD	Savonius Machine	Mechanical or Electrical power
1931 AD	Darrius	Electrical power
1980s AD	2 bladed propeller (Commercially available)	225 kW
2000 AD	HAWT, VAWT	400-625kW, 1.2-3.2 MW

Source: adapted from Spera (1994) and Sorensen (1995)

Over more than 2,000 years, water and windmills powered the world's first industries with new technology and materials. Modern wind turbines are used to generate the clean electricity needed for lighting, heating, refrigeration and other uses. Wind energy is a rather young industry, but one which already makes good economic sense. It is a proven success and its use is increasing and the downward trend in its costs is expected to continue (Şahin, 2004). According to Leung and Yang (2012) currently, wind energy is a mature renewable energy source that has high potential to become a major primary source of energy in the future. Over the last decade, wind energy has developed by leaps and bounds∴ During this period, the world wind power producing capacity has grown rapidly, with an average annual growth of 29%. The history of wind energy has grown from humble sails and simple mills, to become one of the most important renewable energy sources in the energy markets. While the history of wind energy is already a long one, we believe the biggest part is not written yet! The history of wind energy is still in its childhood, and we will see many changes over the coming decades.

4.3 WIND ENERGY TECHNOLOGY

4.3.1 WIND ENERGY CONVERSION SYSTEM

The wind energy technology is a system (called “Wind Energy Conversion System” — WECS) developed to capture the power in the wind (see section 4.4.1). The working principle of a wind turbine involves two main conversion processes, which are carried out by its main components: the rotor, which extracts kinetic energy from the wind and converts it into a mechanical torque, and the producing system, which converts this torque into electricity. This general working principle is depicted in Figure 4.2. Although this sounds rather straightforward, a wind turbine is a complex system in which knowledge or expertise from the areas of aerodynamics, mechanical, civil, electrical and control engineering comes together. Depending on the focus given to the WECS it can be includes economics and management sciences (e.g. wind farm management, economic evaluation of wind farms, etc.).

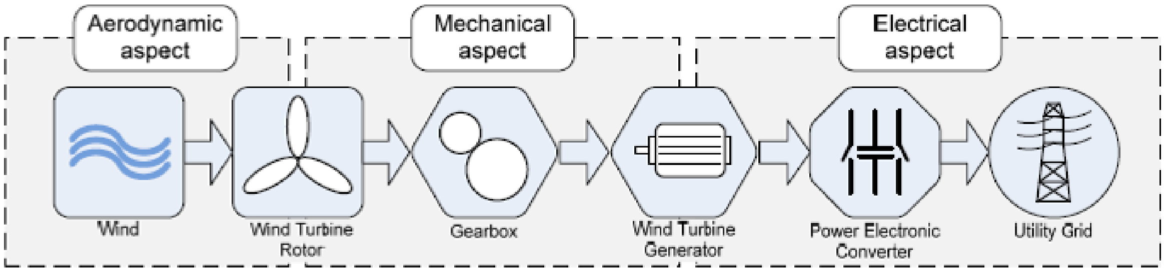


Figure 4.2 Wind energy conversion system (WECS). Source: Kim and Lu (2010, p. 120)

Susman and Glasmeier (2009) has divided wind energy systems into four major components. Each major component contains several sub-components, some of which are mentioned in the paragraphs below and in Figures 4.2 and 4.3.

1. ***Nacelles.*** The nacelle[30] is the external shell or structure that houses all of the producing components, i.e., gearbox, shaft, generator, etc. Turbine size ranges from 1 kW to 7 MW. A rotor aerodynamically converts wind energy into mechanical energy on a slowly turning shaft. A gearbox increases the rotor-shaft speed for the generator, which converts shaft speed into electrical energy. Most turbines have gearboxes, but generators can run at rotor-shaft speed and not require a gearbox (e.g., Enercon). The yaw drive[31] turns the turbine horizontally on its tower toward angles that maximize advantage of wind direction.

[30] Term derived from old French *nacelle* which means small boat or dinghy, which is derived from the Latin *navicella*. The term is used generally in aviation project, nautical and space. In the case of wind power, the nacelle is the part that houses the main components of the wind turbine, gear box, electric generator, gearbox, controllers, cooling system, among others (Jenkins, 2001).
[31] The yaw drive is a mechanism used to keep the rotor facing into the wind as the wind direction changes. The yaw system has a motor, which turns the wind turbine to align it with the wind, is nearly always included on large turbines, resulting in active yaw control (Hau, 2006, p. 146).

2. ***Rotors/Blades.*** Rotors typically have three blades that are secured to a hub by extenders. The dominant design for large wind turbines (above 100 kW) is variable speed and variable pitch[32] control. Also, the, rotor is located on the wind side (upwind) of the tower. In such systems, a pitch drive turns the blades to optimal angles for wind speed and desired rotation speed, e.g., perpendicular to the wind at low speeds and parallel at high speeds. Rotor diameter generally increases with turbine size for application in low and medium wind locations.

3. ***Towers***. For lighter wind power classes[33], turbines need to be raised to heights where the average wind speed is greater and the effects of local obstructions are fewer. Utility scale towers are 60-100 meters in height. Towers can be made of rolled tubular or lattice-structured steel or cement. Most towers in the current world are made of rolled steel tube sections that are bolted together (Paredes, Barbat, & Oller, 2011).

4. ***Balance of System Components.*** These components include transformers to step up voltage for transmission to electrical grids, underground cables, circuit breakers, power substations, supervisory control and data acquisition (SCADA[34]), fiber optic cables, a control station, crane pad, access roads, and maintenance buildings. It can also include *miscellaneous* items such as training, interest during construction and contingencies (Magoha, 2001).

According to Cheng, Lin, Bao, and Xue (2009) generally, a wind turbine producing system can be divided into two parts: mechanical section and electrical section (see Figure 4.3). Early development is focused on mechanical section with multistage gearbox; then it changed to more electrical part and less mechanical part, such as direct-drive and one-stage gearbox (see Figure 4.10). The trend is due to reduce the system mass and cost, mechanical loss and potential to wear out; increase the aerodynamic efficiency and control flexibility, then enhance the power quality. When we consider the WECS into these two main parts, it really makes sense to measure its working by the *electromechanical efficiency*, so it express a reduce way to analyze its electrical and mechanical power.

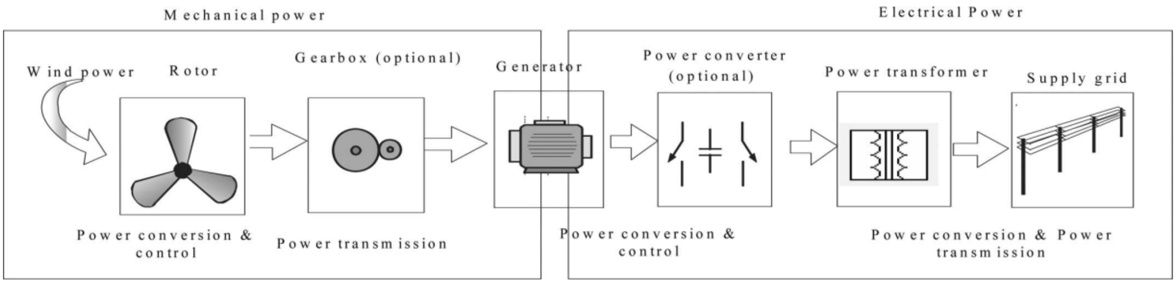


Figure 4.3 Main components of a wind turbine system. Source: Zhe, Guerrero, and Blaabjerg (2009, p. 1860)

[32] *Pitch control* is the active regulation of the rotor blades' angle by a machine control system (pitch control mechanism). Turbine blade pitch control has a significant impact on the dynamic behavior of the system. This type of control only exists in horizontal axis machines. Variable pitch turbines operate efficiently over a wider range of wind speeds than fixed pitch machines (Şahin, 2004).

[33] For more details, please see page 54, Chapter 3, footnote 14 of this Ph.D. research work.

[34] The SCADA system typically provides the ability to manage the wind plant remotely and locally. SCADA system also consists of databases to manage both real-time and historical information updated from the turbines typically done once every second, while the SCADA system aggregates and compiles the raw data into meaningful information (Badrzadeh et al., 2011).

The main components of a wind turbine system are illustrated in Figure 4.3, including a turbine rotor, a gearbox, a generator, a power electronic system, and a transformer for grid connection. Wind turbines capture the power from wind by means of turbine blades and convert it to mechanical power. It is important to be able to control and limit the converted mechanical power during higher wind speeds. The power limitation may be done either by stall control[35], active stall[36], or pitch control (Blaabjerg, Chen, & Kjaer, 2004).

For Hoffman and Molinski (2009) wind turbines are getting larger because of the desire to increase the power output and the associated economy of scale. The power output is directly proportional to the swept area of the rotor (larger blades equal larger swept area, which results in higher power output). Costs are also decreased when using larger turbines because fewer turbines are needed to make up the wind farm, which means that; less roads to the turbines are required, less cabling between wind turbines is required, less maintenance (fewer turbines) is required, and there is less interference with agriculture (when compared to having several smaller wind turbine units in the same area producing the same power).

Wind turbines are large structure and so weight is very important. Blade weight is especially important, as savings in rotor weights allow related reductions in the weight of the hub, nacelle and tower structure. A wide range of blade materials have been used for blade manufacture, including aluminum, steel, wood epoxy and glass-reinforced plastic (E-glass) (Griffin, 2002; Griffin & Ashwill, 2003). The two last materials are now most common as they have the best combination of strength, weight and cost. It is essential to keep weights to the minimum, as the weight of a wind turbine has a strong influence on its overall cost (Oliveira & Fernandes, 2012; Şahin, 2004). Dalili, Edrisy, and Carriveau (2009) studied about ice, insects, and erosion and conclude that these issues represent significant economic impact for commercial wind turbine operation, as they can decrease the aerodynamic efficiency of wind turbine blades, make happen shutdowns, and contribute to unscheduled maintenance requirements.

Towers are the other main component of WECS. They are as integral to the performance of the wind system as the wind turbine itself. The tower must be strong enough to withstand the thrust on the wind turbine and the thrust on the tower∴The tower must also support the weight of the wind turbine. Tall towers are preferred as they minimize the turbulence induced. Tall towers allow more flexibility in sitting. The most important factor is the ability of a tower to withstand the forces acting on it in high winds. Towers are rated by the thrust load they can endure without buckling. The thrust on the tower at high speeds depends on the rotor diameter of the wind turbine and its mode of operation under such conditions (Jenkins, 2001; Söder, 2001).

WECS can be classified is many aspects, so we consider broadly criteria used for wind energy conversion system technology (size of electrical power output; rotational speed of wind turbines and orientation of wind turbines). Table 4.2 presents the current classification of WECS.

[35] *Stall control* is a passive system that reacts to wind speed. The rotor blades are fixed in their pitch angle and cannot rotate around its longitudinal axis. The pitch angle is chosen so that wind speeds higher than the rated speed; the flow around the rotor blade profile takes off from the surface of the shovel (stall), reducing the support forces and increasing the drag forces. Under all conditions of winds in excess of rated speed, the disposal around the profiles of rotor blades is, at least partially, taken off the surface, producing a minors lift forces and high drag forces (Jenkins, 2001).

[36] According to Manwell, McGowan, and Rogers (2002) *active stall* is the combination of *stall* and *pitch control* options. This kind of control is being used on an increasing number of large wind turbines usually greater than 1 MW.

Table 4.2 General criteria, classification and some applications of WECS

Criteria	Classification	Application
1. Size of useful electrical power output	(1) Small size (up to 2 kW)	These may be used for remote applications, or at places requiring relatively low power.
	(2) Medium size (2–100 kW)	These turbines may be used to supply less than 100 kW rated capacity to several residences or local use.
	(3) Large size (100 kW and up)	They are used to generate power for distribution in central power grids.
2. Rotational speed of wind turbines	(1) Constant Speed Constant Frequency (CSCF)	For large scale electrical energy to feed-in directly into electrical grids with pitch and stall controls active with a simple design and low cost of capital; Frequency limitation by grids connection for power produced distribution.
	(2) Variable Speed Constant Frequency (VSCF)	When it is necessary to low the initial cost, leading to an overall reduction of 5–10% in total system capital cost, and are maintenance free and most reliable; Higher annual energy yields per rated installed capacity.
	(3) Variable Speed Variable Frequency (VSVF)	Stand-alone wind power applications; Off-grid applications.
3. Orientation of wind turbines	(1) Horizontal Axis Wind Turbines (HAWT)	Electricity production; Pumping water; Purifying and/or desalinating water by reverse osmosis; Heating and cooling using vapor compression heat pumps; Mixing and aerating water bodies; Heating water by fluid turbulence; Research, development, and demonstration (RD&D) initiatives.
	(2) Vertical Axis Wind Turbines (VAWT)	Research, development, and demonstration (RD&D) initiatives; Electricity production; Pumping water.
4. Location of wind turbines (cluster, e.g. wind farm)	(1) Onshore	When there is availability of lands without objections by the public or other stakeholders; Budget restrictions; RE policy. etc.
	(2) Nearshore	Few people live near the coast; when the distance out to sea, and a range of difficulties to do not overcome the difficulties of an offshore site for the wind farm; wind resources are better than off and on-shore sites available.
	(3) Offshore	When exist higher and more constant wind speeds and, consequently, higher efficiencies; The mobility of technicians and goods for O&M routines are not a problem.
5. Distribution of electrical power output	(1) Off-grid applications	Pumping water and providing smaller amounts of electricity for stand-alone battery; Charging applications; Research, development, and demonstration (RD&D) initiatives.
	(2) On-grid (grid-connected) applications	
	(2.1) Isolated-grid	Remote windy areas with high cost of transporting diesel fuel to these isolated sites; Research, development, and demonstration (RD&D) initiatives.
	(2.2) Central-grid	For windy areas, larger scale wind turbines clusters together (wind farm) for multi-megawatt output power

Source: based on Bansal, Bhatti, and Kothari (2002); Bansal, Zobaa, and Saket (2005), Haggett (2008) and RETScreen® International Clean Energy Decision Support Centre (2008, 2009)

As we could see in Table 4.2 it is possible to classify WECS into broadly criteria categories, so, that is, *(1) Size of useful electrical power output; (2) Rotational speed of wind turbines; (3) Orientation of wind turbines; (4) Location of wind turbines* and *(5) Distribution of electrical power output.* The first category, *size of useful electrical power output*, the *small, medium* and *large size*, there is a range from 2 kW to 100 kW per turbine. This classification is usually applied to wind turbine alone, not to wind turbine cluster together (wind farms)**.**

The second category, *rotational speed of wind turbines,* the wind turbines has developed since its first conception. The technological evolution has been pushing forward by nature of innovation process. The wind turbines typologies represent phases of wind industry evolution, in the beginning the CSCF machines were used for the implantation phase, after we can notice such a technological evolution in electronics aspects of wind turbines as VSCF and VSVF. These concepts have been improved in function, essentially, to avoid *harmonics*[37]and *flicker*[38] emissions on the grids (Chen & Blaabjerg, 2009; Georgilakis, 2008)∴It is important to say that each of these typologies depending on grids requirements or connection, in case of on-grids applications. Most of the current grid connections are still in constant frequency situations. According to Polinder (2011) wind turbines are mostly connected to a 50 or 60 Hz grid.

The third category is usually when it is considered the direction of the axis of wind turbines in relation to the air flow; they can be classified as *Horizontal Axis Wind Turbines (HAWT)* and *Vertical Axis Wind Turbines (VAWT)*. We must highlight into the history of wind energy technology the first steps were done with VAWT principle by the Persian people. During the technology evolution special emphasis was given to HAWT due to its applicability in different and better windy sites for this kind of technology.

The fourth category is related to the location of wind turbines, it is clear to understand the difference among onshore, nearshore and offshore. According to Mathew (2006) when a wind farm is about three kilometers away from the nearest shoreline it is regarded as an *onshore* wind farm. They are normally installed in the mountainous areas as the higher you go the faster the wind blows. The cliffs and mountains also contribute to speeding up the wind. Before setting up a wind farm much research has to be done because the smallest difference of placement could even double the turbines' output (Petersen, Mortensen, Landberg, Højstrup, & Frank, 1998). If a wind farm lies on land within three kilometers to the nearest shore line or staying on the water within ten kilometers from the shore it is considered as *nearshore* wind farm. Sea shores tend to be very windy as the land and sea heat up and cool down at different rates, creating strong winds. The wind from the sea is also denser and therefore carries more energy than the same speed wind in mountainous terrain (Söder, 2001). If a wind farm is more than ten kilometers into the sea form a shore then it is considered to be *offshore*. Offshore turbines are found in deep sea waters and are usually much larger than their land-based siblings. The wind over the open sea is considerably faster and stronger than that of land because they have no obstacles in their way such as trees and

[37] Harmonic emission is another crucial issue for grid connected wind turbines cause it may result in voltage distortion and torque pulsations, which consequently causes overheating in the generator and other problems (Kim & Lu, 2010, p. 127).
[38] Fluctuations in the system voltage (in terms of rms value) may cause perceptible light flicker depending on the magnitude and frequency of the fluctuation. Fast variations in the power output from a wind turbine, such as generator switching and capacitor switching, can also result in variations in the rms value of the voltage. At certain rate and magnitude, the variations cause flickering of the electric light. Thus, this type of disturbance is called *voltage flicker* (Zhe et al., 2009).

buildings to affect the wind speed. Their distance from land allows companies to create larger ones and they do not need to worry about any noise factors as they are a considerable distance from the shore (Haggett, 2008). The offshore wind farms are the most expensive to build as they need to be set in the open ocean where they are subjected to all the earth's elements, therefore raising the maintenance cost of offshore wind farms∴The cost involved in transferring the electricity from the turbine to the land could be large as there is a large distance to be covered (Beurskens, Andersen, Petersen, & Garrad, 1996). Offshore wind farms are much larger than the onshore counterparts as there is much more space in the open sea as opposed to land.

The fifth category, *distribution of electrical power output*, it is related to the distribution of the electrical production by wind turbine or wind farm. The main criterion is the grid connection of the power system. If the WECS is not connected to any grid, it is named *off-grid* applications. This has been applied to remote sites when the connection to an electrical grid is too much expensive to the whole system, considering the power output of this same power system. But if the wind power system must be connected into a grid for power distribution, it can be classified into *isolated-grid* and *central-grid*. The main differences between isolated-grid and central-grid applications

We must clarify that these categories of WECS classification can be expanded due to its evolutive nature and applications. It is not a rigid classification and it is far of being concluded. More categories can be added, it depends on the way we want to analyze the power system as a whole or as its parts. So what it is shown in Table 4.2 is the most common and useful classification of current WECS, as we know it. Some aspects of WECS configuration must be known as essential technical aspects of the power system, as *swept area of blades*, *rotor diameter*, *rotor blade (2 or 3 blades)* and *hub height* (see Figure 4.4).

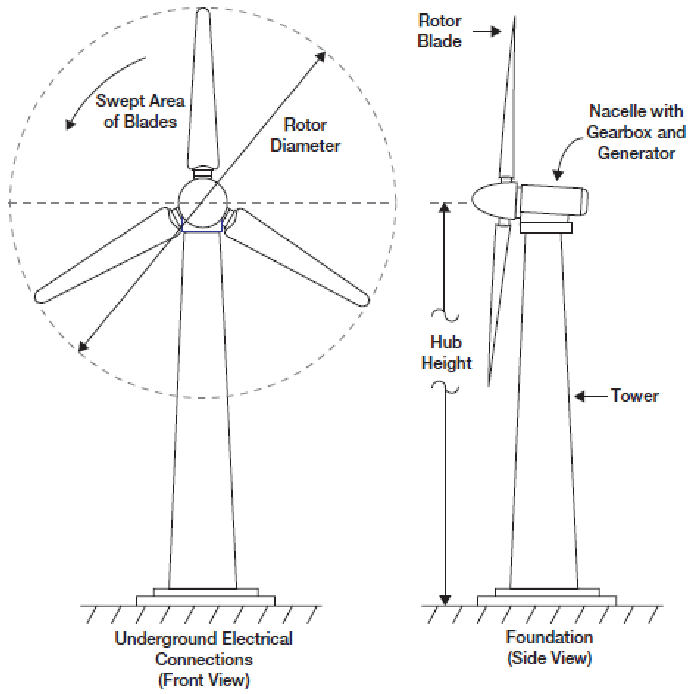


Figure 4.4 HAWT system schematic. Source: RETScreen® International Clean Energy Decision Support Centre (2009, p. 8)

4.3.2 WIND ENERGY CONVERTERS

A wind turbine is a rotating machine which converts the kinetic energy in wind into mechanical energy. If the mechanical energy is then converted to electricity, the machine is called a *wind generator, wind turbine, wind power unit (WPU), wind energy converter (WEC), or aerogenerator*. Today there are various types of wind energy converters in operation as shown in Figure 4.5. The most common device is the horizontal axis wind energy converter, also named as Horizontal Axis Wind Turbine (HAWT). The main aspect of this type of system is the rotor blades optimized by few aerodynamics controls, which its function is primary make the regulation of the position of their long axis (pitch-regulation). Another less expensive way to control and regulate it is related to the design of the blades in such manner that the air streaming along the blades surface will go into turbulence at a certain speed (stall-regulation). Therefore, it is only applied for electricity production projects purpose which needs *"high speed engines"* to keep the gear transmission and the generator small and cheap (Hau, 2006, p. 102; Mathew, 2006, p. 34).

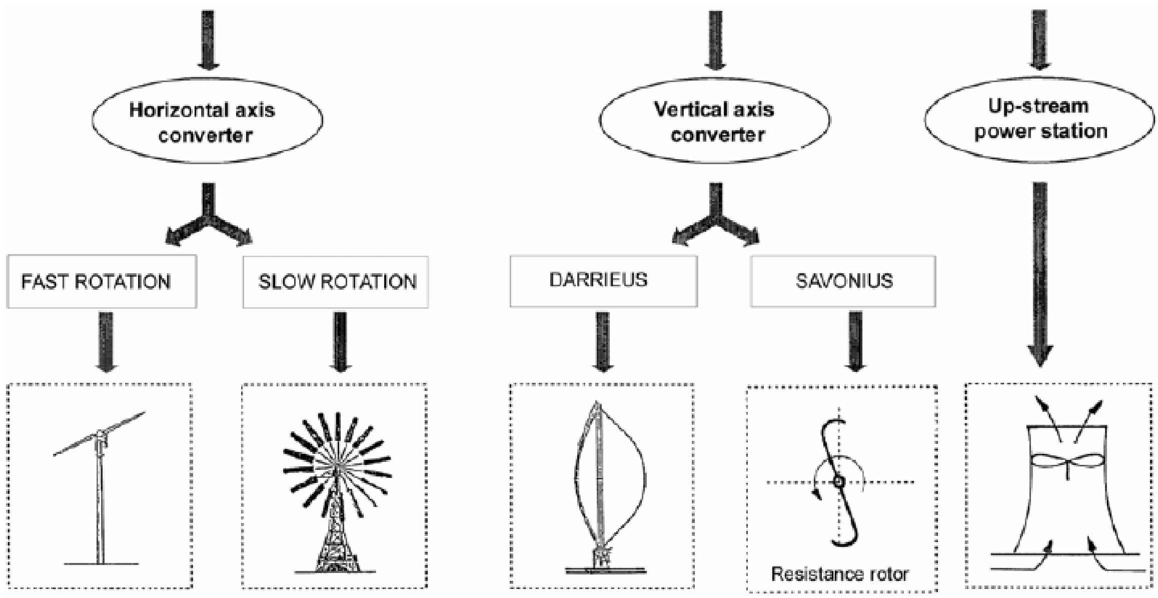


Figure 4.5 Different types of WECS. Source: Wagner and Tryfonidou (2005, p. 192)

The multiblade wind energy converter is another type of horizontal axis rotor. As windmills in the beginning of wind power history utilization have a high starting torque which makes them suitable for driving mechanical water pumps. The number of rotations is low, and the blades are made from simple sheets with an easy geometry. For pumping water, a rotation regulating system is not necessary, but there is a mechanical safety system installed to protect the converter against storm damage. In order to increase the number of rotations, this type of converter had been equipped with aerodynamically more efficient blades facilitating the production of electricity, where the area of a blade is smaller. The mechanical stability of such *"slow speed converters"* is very high; some have had operation periods of more than fifty years (Shepherd, 1990).

A third type of converter is known as Darrieus, they are a type of vertical axis rotor engines. Their main advantage is that they do not depend on the direction of the wind. To start working, they need the help of a generator working as a motor or the help of a Savonius rotor installed on top of the vertical axis. In the 80`s and 90´s years, a reasonable number of Darrieus-converters had been installed in US, especially in California, but in the rest of the world does not happen the same. One possible reason could be the noise produced when they were working in comparison with horizontal axis converters. It is important to highlight the disadvantage about the increasing nature of wind speed with height, which possible makes horizontal axis rotors on towers more attractive at economical point of view. Amazingly this type of rotor is extensively applied for R&D activities, pumping water, and other related purpose for conversion of kinetic power into mechanical ones (Eriksson, Bernhoff, & Leijon, 2008).

The Savonius rotor is used only for research activities, e.g. as a measurement device especially for wind speed, it is not used for power production. In fact, the Savonius rotors can be said to be high productivity and low technicality wind machines∴It is probably the reason why they are often used for water pumping, especially in poor countries and in isolated sites (Menet, 2004). Therefore it will not be discussed in detail here. There have been many designs of vertical axis windmills over the centuries and currently the vertical axis wind turbines can be broadly divided into three basic types, namely *(1) Savonius type*, *(2) Darrieus type*, and *(3) H-Rotor type*. Take a look in Figure 4.6 below.

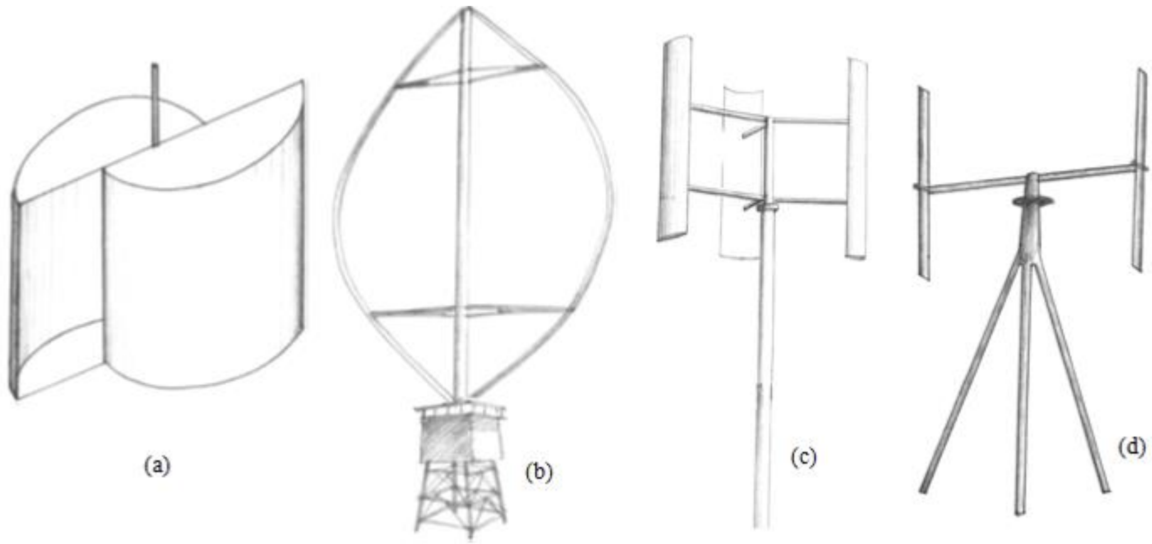


Figure 4.6 Modern VAWT types. Source: Islam, Ting, and Fartaj (2008, pp. 1091-1095) (a) Savonius-type VAWT; (b) Curved-blade (or ‘‘Egg-beater’’ type) Darrieus VAWT; (c) Straight-bladed Darrieus VAWT; (d) H-Rotor-type VAWT.

The last technique is known as *up-stream power station*. The up-stream power station’s principle working is a scheme of sequential power conversion inter-connected. The air is heated by solar radiation under a low circular transparent or translucent roof open at the periphery; the roof and the natural ground below it form a solar air collector. In the middle of the roof is a vertical tower with large air inlets at its base. The joint between the roof and the tower base is airtight. As hot air is lighter than cold air it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter. Continuous 24 hours-operation can be achieved by placing tight water-filled tubes or bags under the roof. The water heats up during day-time and releases its heat at night. These tubes are filled only once, no further water is needed. Thus solar radiation causes a constant updraft in the tower. The energy contained in the updraft is converted into mechanical energy by pressure-staged turbines at the base of the tower, and into electrical conventional generators (Schlaich, Bergermann, Schiel, & Weinrebe, 2003).

Two major technological developments have recently occurred in the field of wind energy. First, a substantial extension which in turn made further reducing the cost of wind energy turbine: individually become bigger and so has typical dimensions. For modern wind turbines of multi-MW class, both the height of the rotor diameter and nacelle are on the order of 100 m. Hence, upright, the tip of the blade can reach heights of up to 150 m. development of scale of individual wind turbines placed on the market is represented in Figure 4.7.

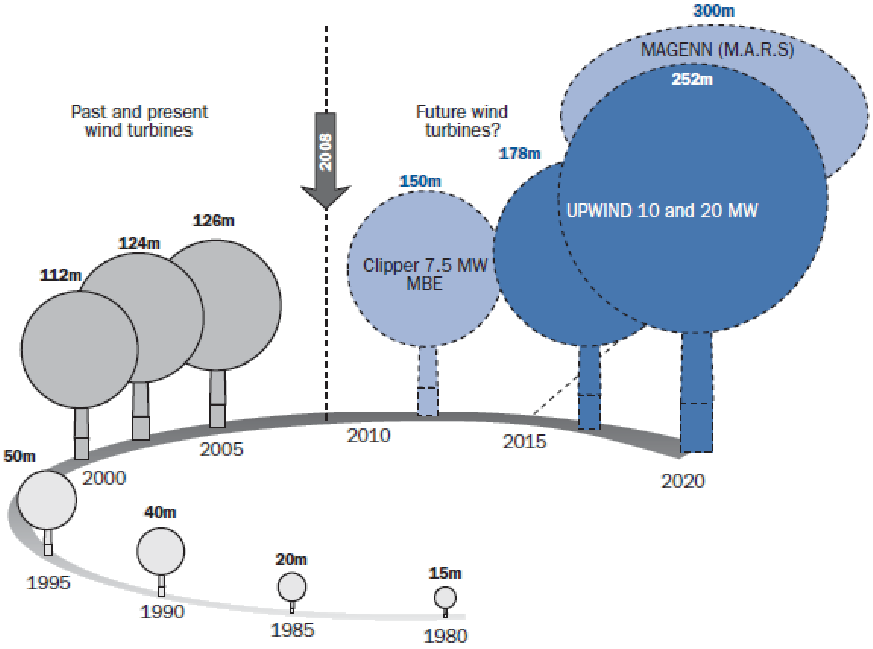


Figure 4.7 Growth in size of commercial wind turbine designs. Source: Morthorst and Shimon Awerbuch (2009, p. 39)

The second important development in wind turbine technology is the change of production constant speed for a variable speed system of production. Of course, the difference in wind speed constant turbine, the rotor rotates at a constant speed while in a variable speed wind turbine; the rotor rotation speed can vary and be controlled, of course within a certain limit projected. In recent years, many manufacturers have the concept of conventional speed constant to the variable speed concept. Variable speed systems are technically more advanced than the constant-speed systems. Consist of more components require additional control systems and, therefore, a higher cost. However, also have several advantages compared to systems of constant speed, as greater energy efficiency, a reduction in noise emission and mechanical loads and better controllability of active and reactive power (Jenkins, 2001; Manwell et al., 2002).

According to Amirat and Benbouzid (2007) the fixed and variable speed for WECS has its own peculiarities. In a fixed speed WECS, the turbine speed is determined by the grid frequency, the *generator pole pairs number*, the *machine slip*, and the *gearbox ratio*. A change in wind speed will not affect the turbine speed to a large extent, but has effects on the electromagnetic torque and hence, also on the electrical output power. With a fixed speed WECS, it may be necessary to use aerodynamic control of the blades to optimize the whole system performance, thus introducing additional control systems, complexities, and costs∴As for the producing system, nearly all wind turbines installed at present use either one of the following systems: *squirrel-cage induction generator*[39] *(SCIG)*, *doubly-fed* (wound rotor) *induction generator*[40] *(DFIG)*, *direct-drive synchronous generator*[41] *(DDSG)*. The variable speed production system is able to store the varying incoming wind power as rotational energy, by changing the speed of the wind turbine, in this way the stress on the mechanical structure is reduced, which also leads to that the delivered electrical power becomes smoother. The control system maintains the mechanical power at its rated value by using the Maximum Power Point Tracking Technique[42] (MPPT). These WECS are generally divided into two categories: systems with partially rated power electronics and systems with full-scale power electronics interfacing wind turbines.

For Li and Chen (2008) WECS can be classified considering the rotation speed, into *fixed speed*, *limited variable speed* and *variable speed*. For variable speed wind turbines, based on the rating of power converter related to the generator capacity, they can be further classified into wind generator systems with a partial-scale and a full-scale power electronic converter. In addition, considering the drive train components, the wind turbine concepts can be classified into *geared-drive* and *direct-drive* wind turbines. In geared-drive wind turbines, one conventional configuration is a multiple-stage gear with a high-speed generator; the other one is the multibrid concept which has a single-stage gear and a low-speed generator. In the last decade, many power converter techniques have been developed for integrating with the electric grid. The use of power electronic converters allows for variable speed operation of the wind turbine, and enhanced power extraction. In variable speed operation, a control method designed to extract maximum power from the turbine and provide constant grid voltage and frequency is required. A wide range of control schemes, varying in cost

[39] According to Solyali and Redfern (2009) a squirrel-cage rotor is the rotating part used in the most common form of AC induction motor. In overall shape, it is a cylinder mounted on a shaft. Internally it contains longitudinal conductive bars (usually made of aluminum or copper) set into grooves and connected at both ends by shorting rings forming a cage-like shape.

[40] Doubly fed electric generators are electric motors that have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and electrical system. Doubly fed machines are used in applications that require varying speed of the machine's shaft for a fixed power system frequency (Baroudi, Dinavahi, & Knight, 2007).

[41] The rotor of direct-drive generator for wind turbine is directly connected to the rotor hub. The synchronous machines have as a work principle to operate at synchronous speed (speed of rotor always matches supply frequency). One of the most important types of electrical rotating machines is the *synchronous generator*, this machine is capable of converting mechanical energy into electricity when operated as a generator and power mechanics when operated as a motor (Bang, Polinder, Shrestha, & Ferreira, 2008; Cheng et al., 2009).

and complexity, have been investigated for all the previously considered conversion systems. All control schemes integrated with the power electronic converter are designed to maximize power output at all possible wind speeds (El-helw, Tennakon, & Shammas, 2006). The wind speeds range from the *cut-in speed*[43] to the *rated wind speed*[44], both of which are specific to the size and type of generator used in the WECS. There is a continuing effort to make converter and control schemes more efficient and cost effective in hopes of an economically viable solution to increasing environmental issues (Hau, 2006; Li & Chen, 2008).

The wind turbine generators can be classified into four categories well known by the electronics market. These categories are: Induction Generators (IG), Doubly-Fed Induction Generators (DFIG), Field-Excited Synchronous Generators (FESG) and Permanent Magnet Synchronous Generators (PMSG). It is not the focus of this thesis explains each one in details, but we try to explain broadly the main differences of each category. We start with the Induction Generator. It can be called Asynchronous Generator (AG), is a type of alternating current electrical generator. The generator's rotor is placed within a rotating magnetic field, and the rotor is then spun by an external source of mechanical energy so that it rotates more rapidly than the magnetic field. Induction generators are less complex and more rugged than other types of generators and can continue effectively producing power if their rotor speed changes. An induction generator needs an external supply of electricity to create its rotating magnetic field and start operating, but once it has started producing power it can continue running on its own provided it has a source of mechanical energy (Cheng et al., 2009; de Freitas, Menegaz, & Simonetti, 2011).

Meanwhile, the DFIG are electric motors that have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and electrical system. Doubly-fed machines are used in applications that require varying speed of the machine's shaft for a fixed power system frequency. The DFIG producing principle is widely used in wind turbines. It is based on an induction generator with a multiphase wound-rotor and a multiphase slip-ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip-ring assembly (e.g. with brushless doubly-fed electric machines), but there are problems with efficiency, cost and size∴A better alternative is a brushless wound-rotor doubly fed electric machine (Muller, Deicke, & De Doncker, 2002).

The FESG are able to effectively convert mechanical energy applied to its axis, but it is necessary that the field winding located in the rotor of the machine is powered by a voltage source so that by rotating the magnetic field produced by the rotor poles can move on to the drivers of the stator windings. The electric current used to power the field is called the *excitation current*. When the generator is operating in isolation from an electrical system (i.e., off-grid applications), the excitement of the field will control the voltage produced.

[42] This technique is encountered in the literature under its acronym, MPPT. Its goal is to operate the WECS around the maximum power (within safety limits), using information from the static power characteristic and a minimum of information from the system (Munteanu, Cutululis, Bratcu, & CeangĂ, 2008, p. 110).

[43] *Cut-in speed* is the minimum wind speed at which the wind turbine will generate usable power. For more information, please see Johnson (2001, p. 155).

[44] The *rated (nominal) wind speed* is the lowest wind speed at which a wind turbine can generate its nominal output power. The rated wind speed usually corresponds to the point at which the conversion efficiency is near its maximum. At wind speeds between *cut-in* and *rated*, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called *"power curves"*, showing how their wind turbine output varies with wind speed. Please see Manwell et al. (2002) and/or Rosa (2009).

In the case of PMSG, they are electrical generators where the excitation field is provided by a permanent magnet instead of a coil[45]. In a PMSG, the magnetic field of the rotor is produced by permanent magnets. Other types of generators use electromagnets to generate a magnetic field in a rotor winding. The direct current in the rotor field winding is fed through a slip-ring assembly or provided by a brushless exciter on the same shaft.

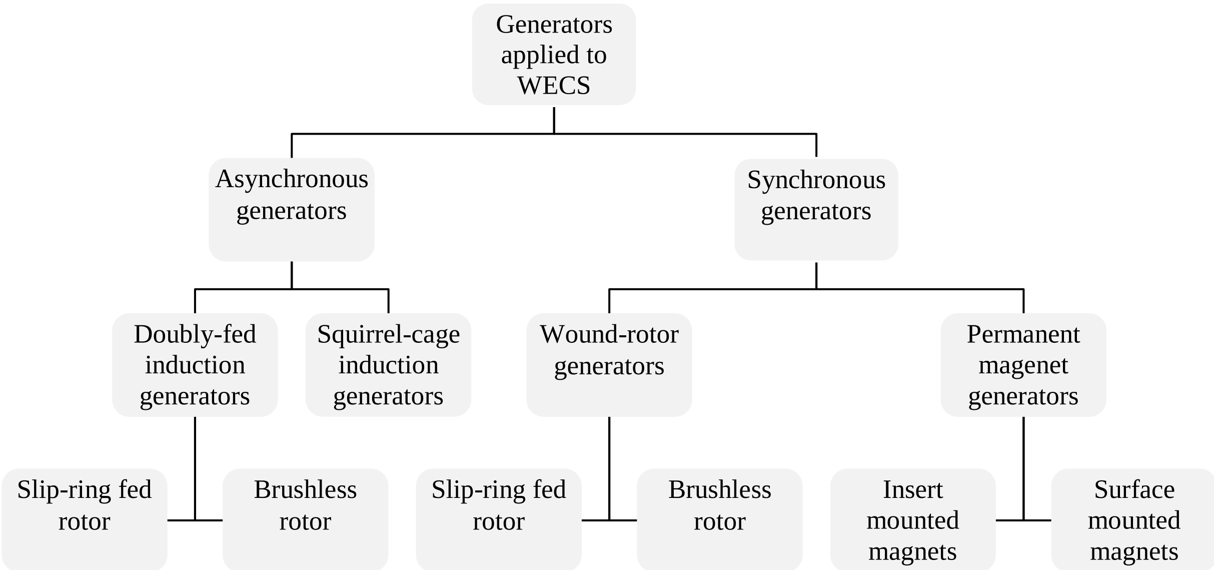


Figure 4.8 Categorization of electrical generators applied to WECS. Source: based on Hansen, Helle, et al. (2001); Hansen, Madsen, et al. (2001) and Yao and Harley (2009)

Due to the nature of technology`s evolution, the future is difficult to predict. However, one issue is certain; the demand of renewable energy technologies keep growing vertically and WECS is an important RETS in any energy portfolio. Innovations are the results of market needs, push demand nature∴Many concepts and protypes will be considered and even applied but only those that fulfill market demand and show significant performance will survive. There have been great developments in WECS, but this has not finished yet.

Many WECS with different generators and power electronic converters have to be analyzed in function of the lowest cost of energy produced and best electromechanical efficiency reached. Different types of WECS have quite different performances and controllability, which theoretically results into different costs per kWh produced, which is the main priority. Table 4.3 shows the advantages and disadvantages of generator types studied.

[45] The simplest coil is an electrical wire wrapped in. As usual in electricity the wire has to be the electrical conductor, but must have an electrical insulation to clothe it (for example, an insulating varnish or a plastic coating). If not, it won't work as expected and may even burn. A *coin* (or an *"electromagnetic coil"*) is formed when a conductor (usually an insulated solid copper wire) is wound around a core or form to create an inductor or electromagnet (Ohsaki, Terao, & Sekino, 2010).

Table 4.3 Advantages and disadvantages of generator types

Types	Advantages	Disadvantages
Permanent magnet synchronous generator	✡ Eliminates the need for separate excitation or cooling systems. ✡ Flexibility in design allows for smaller and lighter designs. ✡ Generator speed can be regulated without the need for gears or gearbox. ✡ Higher output level may be achieved without the need to increase generator size ✡ Lower maintenance cost and operating costs, bearings last longer. ✡ No significant losses produced in the rotor ✡ Very high torque can be achieved at low speeds.	✡ High temperatures and sever overloading and short circuit conditions can demagnetize permanent magnets. ✡ Higher initial cost due to high price of magnets used. ✡ Permanent magnet costs restrict production of such generators for large scale grid connected turbine designs. ✡ Use of diode rectifier in initial stage of power conversion reduces the controllability of overall system.
Asynchronous generator	✡ Excellent damping of torque pulsation caused by sudden wind gusts. ✡ Higher availability especially for large scale grid connected designs. ✡ Known as rugged machines that have a very simple design. ✡ Lower capital cost for construction of the generator. ✡ Relatively low contribution to system fault levels.	✡ Generator requires reactive power and therefore increases cost of initial AC–DC conversion stage of converter. ✡ Increased control complexity due to increased number of switches in converter. ✡ Increased converter cost since converter must be rated at the full system power. ✡ May experience a large in-rush current when first connected to the grid. ✡ Results in increased losses through converter due to large converter size needed for IG.
Doubly fed induction generator	✡ Allows converter to generator or absorb reactive power due to DFIG used. ✡ Control may be applied at a lower cost due to reduced converter power rating. ✡ Improved efficiency due to reduced losses in the power electronic converter. ✡ Reduced converter cost, converter rating is typically 25% of total system power. ✡ Suitable for high power applications including recent advances in offshore installation.	✡ Increased capital cost and need for periodic slip ring maintenance. ✡ Increased control complexity due to increased number of switches in converter ✡ Increased slip ring sensitivity and maintenance in offshore installations. ✡ Is not direct drive and therefore requires a maintenance intensive gearbox for connection to wind turbine. ✡ Stator winding is directly connected to the grid and susceptible to grid disturbances.
Wound field synchronous generator	✡ Allow for independent control of both real and reactive power. ✡ Allow for reactive power control as they are self-excited machines that do not require reactive power injection. ✡ Direct drive applicable further reducing cost since gearbox not needed. ✡ Minimum mechanical wear due to slow machine rotation. ✡ Readily accepted by electrically isolated systems for grid connection.	✡ Magnet tends to become demagnetized while working in the powerful magnetic fields inside the generator. ✡ Magnet used which is necessary for synchronization is expensive. ✡ Requires synchronizing relay in order to properly synchronize with the grid. ✡ Typically have higher maintenance costs again in comparison to that of an IG.

Source: adapted from Baroudi et al. (2007, p. 2382)

Hansen and Hansen (2007) the wind turbine technology has matured during the last ten years. Wind turbine technology objectives have changed the drives philosophy from convention to optimization issues, and taking into consideration the operating regime and market environment. In addition to wind turbines are increasing their sizes (see Figure 4.7). Wind turbine design concepts are progressing from fixed speed, stall control and drive trains with gearboxes to variable speed, pitch control and drive trains with or without gearboxes∴The present general availability of low-cost power electronics increasingly supports the trend towards variable speed wind turbines. Table 4.4 is a list of some technology improvements and the implementation of best practices from related products and industry sectors that have helped to reduce the cost of wind energy during the last decade.

Table 4.4 Examples of technological improvements in the wind industry in the last decade

Feature	Comments
Advanced airfoils	Driven by the wind industry to meet its special needs. A key accomplishment for the industry.
Direct electrical drive	Adapted initially from the hydro electric industry (large low speed multi-pole generators) and advanced electric rail technology (linear inductive) with significant wind industry innovation and commercialization to meet large and small turbine requirements.
Fiber glass RTM methods	Advances driven by wind power needs.
Full span pitch control	Adapted from the helicopter industry.
Large diameter pitch bearings	Adaptation of commercial bearings driven by specific wind turbine needs.
Large scale manufacture	Large HAWTs are a multi-billion $ industry and must use modern manufacturing techniques.
Numerical simulation techniques	Significant wind industry advances and adaptations of commercial software for other rotating structures.
Power electronics	Adapted from the variable speed drive product sector with some wind industry innovation. The power electronics sector is a vital industry sector and the wind industry continues to benefit from technology improvements and cost reductions.
Spherical cast hubs	Adopted for all large HAWT rotors.
Steel welding quality control	Adoption of high quality steel fabricating industry *“best practices”*. Important for fatigue strength.
Tower feedback in controls	Part of a system approach to controls. Software and hardware costs for sophisticated controls are now more affordable.
Variable speed	Wind industry driven. Reliable operation of turbines at variable speed with full-span pitch control to limit power output is a major accomplishment for the industry.

Source: adapted from Malcolm (2003) and Oliveira and Fernandes (2011a)

The wind turbine generators can be also distinguished by whether there is a gear box between the turbine and the generator. These aspects are present at section related to technical design of converters.

4.3.3 TECHNICAL DESIGN OF CONVERTERS

4.3.3.1 THE DESIGN WITH GEARBOX

The wind energy conversion systems have changed so much since the beginning of the utilization on wind power as a way to substitute man power in humankind activities. So gearbox had to walk together its (r)evolution. The design was adapted according to its necessity. The efficiency and safety are the main drive of converter`s design. The first to be shown in general aspects is the design with gearbox (see Figure 4.9), also called the *Danish* design as this is where the history most developed.

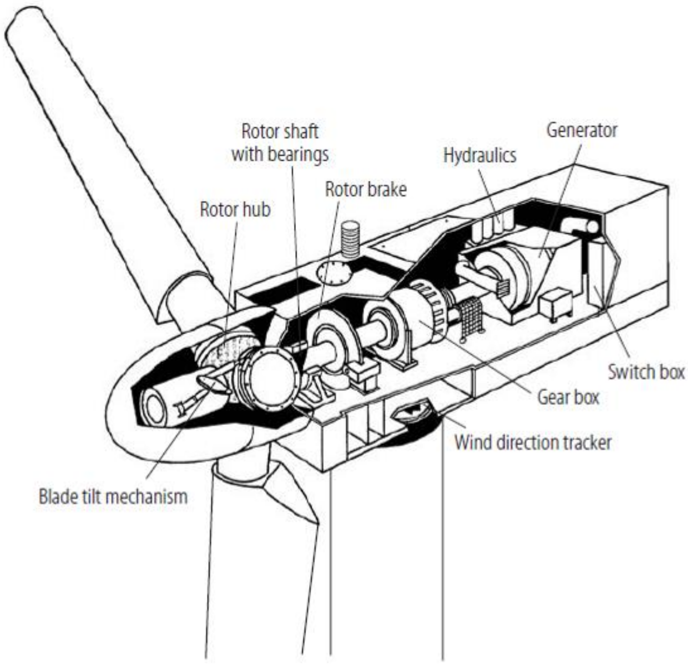


Figure 4.9 The classic design. Source: Wagner and Tryfonidou (2005, p. 197)

This design is characterized by the split shaft system. A wind turbine gearbox must be robust enough to handle the frequent changes in torque caused by changes in the wind speed. The gearbox requires a lubrication system to minimize wear. The gearbox converts slow rotating into high torque power which gets from the wind turbine rotor — and high speed, low torque power, which is use for the electric generator (Ragheb & Ragheb, 2010). The transmission of torque to the generator is shut off by means of a large disk brake on the main shaft. A mechanical system controls the pitch of the blades which can also be used to stop the operation of the wind turbine. There is a hydraulic system for pitch mechanism control∴This system requires a yearly basis maintenance and constant pressure monitoring, along with the gearbox which is lubricated with oil (Arabian-Hoseynabadi, Tavner, & Oraee, 2010). A small electric motor is used for each blade pitch angle controlled in the case of applications without a main brake disk. Wind speed and direction measuring devices are located at the back of the hub head. The Danish concept is well-known design in the wind power industry worldwide (Tavner, Xiang, & Spinato, 2007).

4.3.3.2 THE DESIGN WITHOUT GEARBOX

In wind power industry is more and more necessary to reduce weight and cost for wind turbine components — so a right way is develop another working mechanism to WECS as a producing system. The design without gearbox, usually called *gearless* wind turbine. This design has just one stationary shaft. It is important to say that rotor blades and the electric generator are mounted on the same shaft. The electric generator is in the shape of a large spoked wheel with a certain number of *pole pairs*[46], around the outer circumference and stators fixed on a stationary arm around the wheel. The wheel is fixed to the blade support, so it rotates slowly with the blades (Gandy, 2009). So, it becomes unnecessary a gearbox, rotating shafts or a disk brake. These omissions of mechanical parts simplify and reduce the cost of the maintenance and production of the WECS as a whole. This design as a typical minimized converter system (compared to others) needs to be automated, in this exact case; a central computer controls the pitch control and hub direction, which operates the small directional motors∴DD wind turbine is an answer by Enercon manufacturer, which adopts an annular multiple poles generator. This type of generator significantly reduces the number of moving parts, lowering the amount of maintenance work/cost and associated turbine downtime, which increases the availability in general (Hansen, Helle, et al., 2001; Ragheb & Ragheb, 2010).

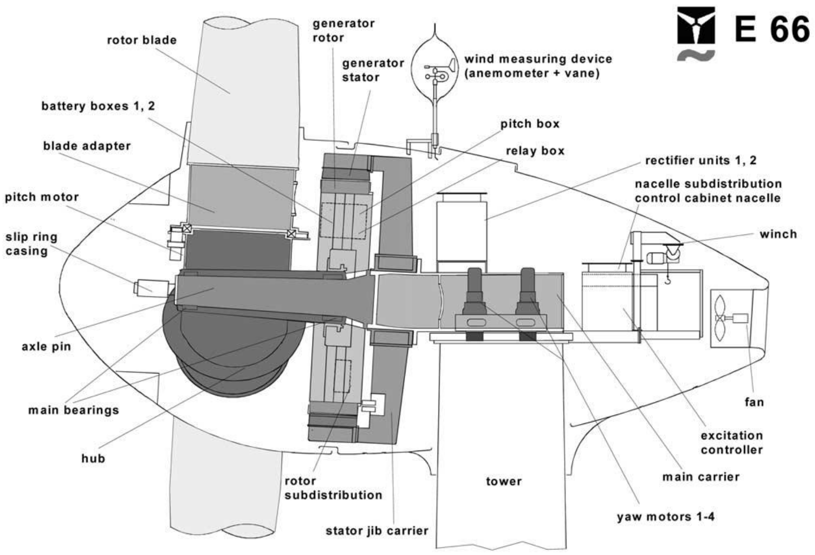


Figure 4.10 Scheme of a nacelle without gearbox (Model Enercon 1.5 MW). Source: Ackermann and Söder (2002, p. 93)

As we can see in Figure 4.10 the rotor shaft is directly connected to the generator stator, which can reduce the electromechanical losses, or in other words, increases the overall efficiency of the WECS.

[46] The number of pole pairs determines the synchronous speed of the three phases motor.

4.4 PHYSICAL BASICS APPLIED TO WECS

4.4.1 ENERGY EXTRACTED FROM WIND

The quantity of power captured from a wind turbine is specific to each technical features of wind energy conversion system but we can generalize by:

$$P_w = \frac{1}{2}\rho \mathrm{A} v_w^3 \qquad [\mathrm{W/m^2}] \qquad \text{Eqn (4.1)}$$

Where P_w is the turbine power, ρ[47] is the air density, A is the swept turbine area and v_w is the wind speed. The air density (ρ) is calculated by the formula (Rehman & Al-Abbadi, 2005):

$$\rho = \frac{P}{R \times T} \qquad [\mathrm{kg/m^3}] \qquad \text{Eqn (4.2)}$$

Where P is the air pressure (Pa or N/m^2); R is the specific gas constant for air (287 J/kg K); and T is the air temperature in Kelvin (ºC +273).

As we can notice in Eqn 4.1 the output power is directly proportional swept area by rotor and the air density. Regarding to wind speed, the output power is just the cube of it!!! So we can sure highlight the importance of wind resource. Currently, to be cost-competitive, wind farms must be sited in high quality wind regimes, normally a wind power class of 4 or higher, preferably 5 or higher. Figure 4.11 shows a graph with the comparison of wind speed/power classes to capacity factor.

The capacity factor of a wind power plant is the percentage of a year it would need to run at rated power to generate its annual output. As power output, and therefore production, is related to the cube of the wind speed, slightly higher average wind speeds, or wind regimes with a higher variability in the high speed range, can generate significantly more power. The very best wind sites tend to be class 6, according to Figure 3.11$\therefore$A class 4 site is considered marginal by economic point of view, especially when the wake effects of other wind turbines within a wind farm are taken into account. The cost of wind-produced electricity is driven by several factors. The cost of wind power changes as assumptions regarding to capacity factor, capital cost, financing terms, and operation and maintenance routines. Therefore, in today's market, a capacity factor of about 25% can be considered a lower bound, unless the combined capital and operating costs of wind turbines drop down (Khatib, 2003).

[47] It is important to know that *"P"* and *"T"* change according the site analyzed.

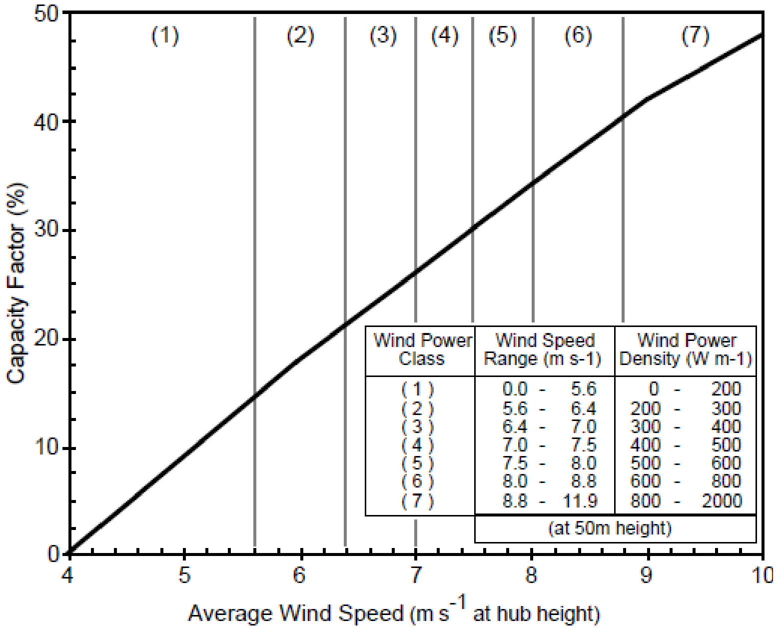


Figure 4.11 Comparison of average wind speed and wind power class to capacity factor. Source: McGowan and Conners (2000, p. 152)

Wind speed and power class where the WECS is installed have a great influence on the system overall. That is why the wind resources analysis is so important for a better or lowest cost of energy produced by a wind power plant. According to Georgilakis (2008) wind power plants generate electricity when the wind is blowing, and the plant output depends on the wind speed. Wind speeds cannot be predicted with high accuracy over daily periods, and the wind often fluctuates from minute to minute and hour to hour∴Consequently, electric utility system planners and operators are concerned that variations in wind power plants output may increase the operating costs of the electrical system as a whole (taking into consideration on-grid applications). The energy production from WECS is highly dependent on the wind speed at hub height. Usually, the wind speed measurements are made at heights much lower than the hub heights of modern wind machines. For energy production from such machines, the wind speed at hub height is calculated using the $1/7^{th}$ wind power law that may underestimate or overestimate the wind speed, which ultimately will provide wrong estimates of energy production (Rehman & Al-Abbadi, 2005).

4.4.2 POWER COEFFICIENTS

As we understand, the WECS is a conversion chain processes by a wind mechanical and electrical parts. The power coefficients are so important in order to analyze the WECS performance as a whole. It is necessary for wind farms management and ensures a safety and profitable range for cost of energy produced by the power plant. So we easily can conclude that during this process we have to face its limitations (electromechanical and Physics` laws). The next sub-sections (4.4.2.1, 4.4.2.2 and 4.4.2.3) discuss about these key issues.

4.4.2.1 BETZ' LAW AND THE POWER COEFFICIENT (C_P)

A German physicist called Albert Betz concluded in 1919 that no WECS can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. Nowadays this is known as the *Betz Limit* or *Betz' Law*[48]. The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the *"maximum power coefficient"* and is defined as:

$$C_{p_{\max}} = \frac{16}{27} P_w \cong 0.593 P_w \qquad [\mathrm{W/m^2}] \qquad \text{Eqn (4.3)}$$

The power coefficient *(C_p)* is defined as the power extracted by rotor *($P_{w_{out}}$)* to power available in the wind *(P_w)* is given by:

$$C_p = \frac{P_{w_{out}}}{\frac{1}{2}\rho \mathrm{A} v_w^3} \qquad [\%] \qquad \text{Eqn (4.4)}$$

The power coefficient must consider the mechanical *(η_m)* and electrical *(η_e)* transmission efficiency. So the electrical power output is defined by Yao, Bansal, Dong, Saket, and Shakya (2011):

$$P_{w_{(e)}} = C_p \eta_m \eta_e P_w \qquad [\mathrm{W_{(e)}/m^2}] \qquad \text{Eqn (4.5)}$$

Also, wind turbines cannot operate at this maximum limit or nominate rated power in term aerodynamically. There is only one C_p value to each turbine type and it is a function of wind speed that the turbine is operating in. When are inputted many as often engineering requirements of a wind turbine — strength and durability in particular — the real world limit reached is much less than the Betz Limit with values in the range of 0.35–0.45 common even in the best designed wind turbines (Mathew, 2006). Whereas other factors in a complete WECS — e.g. the gearbox, bearings, generator and so on — only 10–30% of the power of the wind is ever actually converted into usable electricity. Hence, the power coefficient needs to be factored in Eqn 4.1 and the extractable power from the wind is given by:

$$P_{w_{avail}} = \frac{1}{2}\rho C_{p_{\max}} \mathrm{A} v_w^3 \eta_m \eta_e \qquad [\mathrm{W_{(e)}/m^2}] \qquad \text{Eqn (4.6)}$$

[48] The energy conversion systems in general are driven by the *First Law of Thermodynamics (Conservation)* which states that *"energy can be changed from one form to another, but it cannot be created or destroyed. The total amount of energy and matter in the Universe remains constant, merely changing from one form to another*. For more explanations related to Physics applied to WECS, please read the chapter about *Physical Principles of Wind Energy Conversion* in Hau (2006, p. 81).

If we consider the mechanical (η_m) and electrical (η_e) transmission efficiency into the overall efficiency of WECS (η_{wecs}) and rewriting the Eqn 4.6, we must have:

$$P_{w_{avail}} = \frac{1}{2}\rho C_{p\max} \mathrm{A} v_w^3 \eta_{wecs} \qquad [\mathrm{W_{(e)}}] \qquad \text{Eqn (4.7)}$$

Rosa (2009) explains the difference among power density (P_w), available power density (P_A) and power delivered (P_D). When it is necessary to analyze the performance of WECS these aspects must be well-defined (see Figure 4.12).

The symbol, P, in this chapter stands for both *power* and *power density*—that is, power per unit area, depending on the context. The lower case, p, is reserved for *pressure*.

The following subscripts are used:

$P_W = \frac{1}{2}\rho v^3$	"Power density in the wind." This is the amount of energy transported across a unit area in unit time.
$P_A = \frac{16}{27}\frac{1}{2}\rho v^3$	"Available power density." This is the theoretical maximum amount of power that can be extracted from the wind.
$P_D = \frac{16}{27}\frac{1}{2}\rho v^3 A\eta$	"Power delivered." This is the power that a wind turbine delivers to its load.

Figure 4.12 Principles of aerodynamics applied to WECS. Source: Rosa (2009, p. 730)

It is not the focus of this sub-section discusses about aerodynamics issues[49], but when we talk about wind energy conversion system it becomes impossible not to discuss about something related to. Wind is the air in motion and it is a type of energy (kinetic energy), and rotational movement is *Physics Applied*, which means *Aerodynamics*.

4.4.2.2 TIP SPEED RATIO

The rotor is a rotate part of WECS, so the rotor efficiency is a function of the rotor turning rate. The tip speed ratio *(TSR)* is given by dividing the speed of the tips of the turbine blades $(\pi D N_{rs})$ by

[49] For more details, please see Snel (2003). Review of Aerodynamics for Wind Turbines. *Wind Energy, 6*(3), 203-211. doi: 10.1002/we.97.

the speed of the wind *(v_w)*. If the rotor turns too slowly, the efficiency drops off because too much wind unaffected by the wind turbine blades. However, if the rotor turns too fast, efficiency will reduce as the turbulence caused by one blade increasingly affects the following blades. The TSR can be calculated by Yao et al. (2011):

$$TSR(\lambda) = \frac{\pi D N_{rs}}{60 v_w} \quad [-] \qquad \text{Eqn (4.8)}$$

Where *(N_{rs})* is rotor speed in rpm, *(D)* is the rotor diameter *(m)*; and *(v_w)* is the wind speed *(m/s)* upwind of the turbine.

4.4.2.3 POWER EFFICIENCY

In a power plant is an important factor to be analyzed is the power efficiency of the entire system. A classical way to take this measure is through the power input into comparison with power output. In WECS, obviously, the wind farm efficiency is a function of the turbine type employed, the wind farm configuration and wind speed∴Estimation of the overall efficiency of a wind farms of crucial importance to a wind farm design procedure since due to its explicit relation to total annual power converted; it is considered a vital trade-off between performance and cost analysis (Kiranoudis, Voros, & Maroulis, 2001).

According to Krokoszinski (2003) the efficiency and effectiveness of wind farms must be evaluated based on the losses which can be classified into *downtime losses, speed losses* and *quality losses*. Each of these losses affects the wind power plant in terms of power efficiency. In downtime is related to the availability of wind turbines' working or producing electricity. As much as downtime losses less electricity are produced. In the case of speed losses are linked to power curve of wind turbines and wind site profile. The quality losses are linked to electricity actual produced and useful. It is a relation of the valuable production time and net operation time. Grauers (1996) suggests a calculation method to find the power efficiency applied to wind power plants.

$$\eta_{wecs} = 1 - \frac{P_{w_{av}}}{L_{w_{av}}} \quad [-] \qquad \text{Eqn (4.9)}$$

where *($P_{w_{av}}$)* is average power production by WECS and *($L_{w_{av}}$)* is the average losses of WECS.

4.5 WIND FARM PLANNING

The wind farm planning is a long term process and involves several *economic agents*[50] during the lifetime of the power plant. The planning process can be classified into five phases. These phases are*: (1) Pilot study, (2) Site evaluation, (3) Planning, (4) Realization* and *(5) Operation* (see Figure 4.13). The phases 1 and 2 can happen simultaneously what makes wind farm developers save time in the planning process as a whole. In the *pilot study* phase begins with site selection. The most important issues for this step are wind resources and access to the right site chosen. Due to these two *drivers,* the legal aspects and initial economics analysis within WEC technology are performance. In this phase is also suggested to be done a pre-feasibility study for economic evaluation.

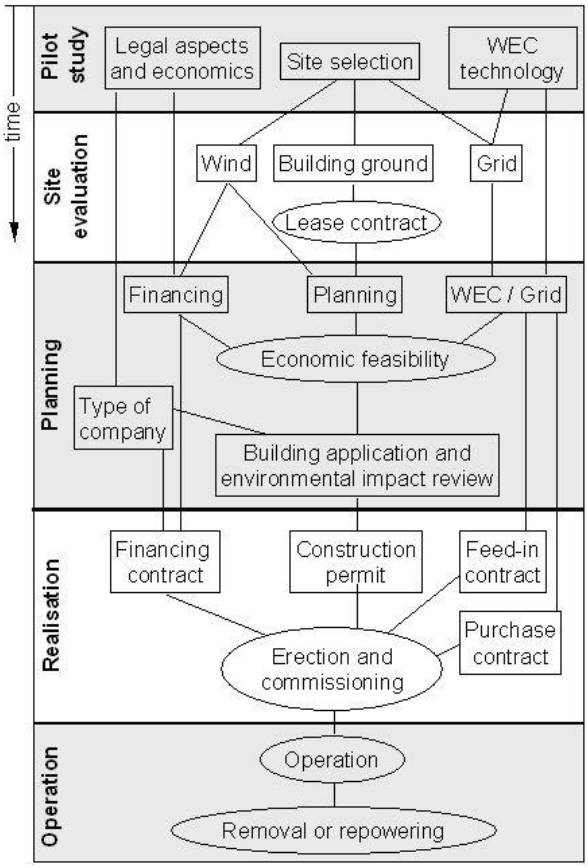


Figure 4.13 Flowchart of wind power during the project lifetime. Source: WWEA (2011)

In the *site evaluation* phase the estimation of local wind conditions are especially crucial in the selection of the site. In addition to an evaluation of the wind speed based on general meteorological data, wind prediction also requires an analysis of the orography of the site selected, i.e. the structure of the terrain, the roughness of the surface, and the type and size of the terrain's

[50] An institution, single person, company etc. that has an effect on the economy of a place (city, region and country), for example by buying, selling, or investing.

boundaries. Furthermore, any individual obstacles — *such as rows of trees, buildings, and any other wind turbines* — must be registered accurately (Meah & Ula, 2008). In this stage it is necessary to determine accurately the potential of local wind energy production. Several methods are commonly used to measure, simulate, and evaluate wind conditions∴Depending on local conditions and the quality of any wind and data available for the region — *such as from measuring stations* — a methodology will be chosen, and a decision will be made as to whether additional wind measurements are required to confirm the initial findings (Al-Yahyai, Charabi, & Gastli, 2010).

For the *planning phase* a more in-depth analysis of the project's prospects is done which is driven by the feasibility study. The *feasibility study* must provide information about the physical characteristics, financial viability, and environmental, social, or other impacts of the wind power project, such that the proponent can come to a decision about whether or not to proceed with the project. It is characterized by the collection of refined site, wind resources, costs and equipment's data. It typically involves site visits, resource monitoring, energy audits, more detailed computer simulations, and the solicitation of price information from equipment suppliers. Also in this phase is defined the type of company to run the wind project related about financing operations and grid access, in case of on-grid applications.

In the *realization phase* all administrative aspects are carried out. First of all, it is given emphasis to the *Financing contract*, *Construction permit* or *licenses*, *Feed-in*[51] *contracts* and *Purchase Contract*. The *Financing* and *Feed-in* contracts are directly influenced by *Financing* terms and *WEC/Grid* conditions. The erection and commissioning steps will only be done when the legal and economics items are concluded. This step usually requires another or additional studies for installing and testing the wind farm as a new power plant. If it is a *repowering*[52] action it is necessary to check the last years of operation of the wind farm in order to notice how *WEC/Grid* conditions and what are possible impacts on the economic feasibility of the project, so the modifications, if it is possible, in the *Financing* and *Purchase* contracts.

Finally in the *operation phase* is the last of planning stage but the first and longest phase in a wind power project, a wind farm. The operation objective for a wind power plant (WPP) is to ensure that the system achieves the best energy yield from the prevailing wind conditions at the respective location. In addition to these commercial requirements, the operation of the WPP must also ensure that dangerous operating conditions are recognized early enough and that the WPP control system acts appropriately to avoid dangers to the environment and the WECS that could arise from malfunctions. If necessary, the system behavior can be continuously monitored via remote data and on-site monitoring and interventions implemented in the WPP control system. A wind farm is usually designed for 20 to 25 years of operation, which is planned for 175,200 to 219,000 full hours, excluding the downtimes for maintenance or repairs. After 20-25 years-operation it is time to decide to *removal*[53]or repower the power plant.

[51] The central principle of *feed-in tariff* policies is to offer guaranteed prices for fixed periods of time for electricity produced from Renewable Energy Sources (RES) (Couture & Gagnon, 2010).
[52] The expression *"repowering"* refers to power plant in general and includes all measures which improve the efficiency and capacity by means of retrofit to the latest technology.
[53] The expression "*removal"* is used when a wind power plant shutdown the operation definitely.

4.5.1 WIND FARM LAYOUT

Lundberg (2003, 2006a) a wind farm is a set of elements, such as wind turbines (WT), local wind turbine grid, collecting point, transmission system and wind farm interface to the point of common connection (PCC). The energy is then transmitted to the wind farm grid interface over the transmission system. So to discuss about wind farms layout is a complex issue and exciting due to its nature and importance for a better performance of the whole power plant. The wind farm layout can be so different from wind farm to wind farm, from site to site and from type of wind turbine used.

As stated in the specialized literature *"rule of thumb"* is applied 10 ha/MW for land requirement of wind farms, including infrastructure (Bansal et al., 2002). The spacing of a cluster of wind turbines in a wind farm depends on the terrain, the predominant wind direction and speed, and the turbine size. According to Patel (1999), the optimal spacing is found in rows 8–12 rotor diameters apart in the windward direction, and 1.5–3 rotor diameters apart in the crosswind direction∴According to Ammara, Leclerc, and Masson (2002) and Grady, Hussaini, and Abdullah (2005) discussed about this intuitive spacing scheme resulted in sparse wind farms that were inefficiently using the wind energy potential of the site. A dense, staggered sitting scheme was proposed that would yield production similar to the sparse scheme, but would use less land. While this approach successfully reduced the land mass required for a given amount of wind turbines, the method of placement was still intuitive.

According to Samorani (2010) the way or criteria used to choose the number and the model of the wind turbines to install depends on a variety of factors. First, it is important to note that a more powerful wind turbine is usually preferred to a less powerful one since both the cost of a turbine and the energy it generates is usually proportional to its nominal power. So when we in the phase of project development there is a trend to choose a more powerful wind turbine in order to have a lowest cost per wind power installed and consequently a lowest cost of energy produced. But it is also such a *"trick"* because as bigger as the size of wind turbines as more expensive are the initial investment cost formed by civil works, electrical works and the rest of the installations and maintenance costs impacted by the size of the wind turbine.

The actual consultancy market practice is design a preliminary layout used for discussions with the relevant local economic agents and other affected parties. This process is iterative due to its nature because this preliminary layout is a tool for engineering, economics, environmental studies and common can be changed in function of the results reached. As many researcher states the most factors that usually affect wind turbines location are: *(1) optimization of energy production output; (2) turbines loads; (3) noise emissions* and *(4) visual impact* (Gonzalez, Rodriguez, Mora, Santos, & Payan, 2009; Payan, Gonzalez, Rodriguez, Mora, & Santos, 2011; Zhang, Chowdhury, Messac, & Castillo, 2012). In the wind power industry we frequently identify as *"Balance of Plant (BOP)"* the civil and electrical works and are generally have been done by a contractor or contractors separate from the wind turbine supplier. The major influence on the economic success of a wind farm is the energy production, which is principally determined by the wind regime at the chosen site, the wind farm layout and the choice of wind turbine technology applied.

4.5.2 REQUIREMENTS FOR LAND AREA

The utilization of the land depends on several aspects but one of most important is wind turbine model to be used in the power plant. If the wind power plant is the type of on-grid application, the area must be design to the access roads, buildings support and the power station. When we have useful (in terms of electricity production) wind resources and land enough, the wind farm design process begins. The central objective is to maximize energy production, minimize capital cost and operating costs, take into account the constraints imposed by the site. The constraints and costs are all subject to some level of uncertainty in terms of a project conception; the optimization process also seeks to minimize risk.

The land area required for wind power projects varies significantly from project to project. The goal of a project plan is to distribute the wind turbines in order to maximize power production. Wind turbines are usually distributed in lines perpendicular to the prevailing wind direction. The direction of the prevailing winds and the complexity of the terrain are two of the most important aspects that guide the placement of turbines in a project. The distance between the wind turbines (between lines and between the wind turbines in a same line) is commonly described in terms of the diameter of the rotor∴For example, if a plant is described as having a spacing 3x10, this means that the turbines are distributed with an equivalent spacing for three rotor diameters within the same row, and the lines have a spacing equivalent to 10 rotor diameters. For a project that uses a rotor with 60 meters in diameter, this means spacing between the turbines of a same line of 180 meters, and 600 meters between the rows. Figure 4.14 shows a typical wind farm layout and so the land area changes according to its layout defined.

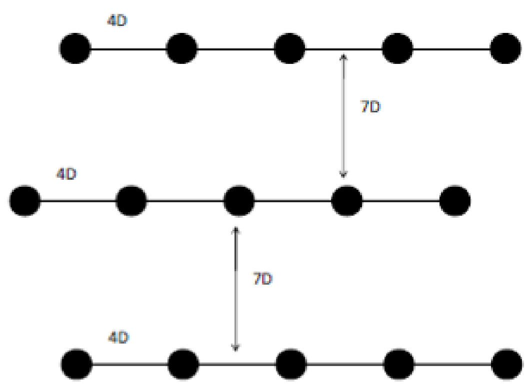


Figure 4.14 Wind farm layout according to the rule of thumb. Source: Samorani (2010, p. 12)

The interference of a turbine on another positioned towards the wind turbine is called *interference effect (wake effect or array effect)*[54]. The turbines are positioned too close to each other will suffer a loss of greater energy-induced effect of interference. As a large spacing between turbines usually

[54] Whereas a wind turbine generates electricity from wind energy, the wind flow after passing through the turbine must contain a lower potential energy than the wind flow reaching turbine first.

maximizes power production output, but increases the need for infrastructure (e.g., land area, network and roads), the cost must be parsed before defining the location of the turbines. For example, there is a replacement of the costs between the optimization of layout of turbines for power production (increasing the spacing) while trying to keep a compact design to have reasonable costs with network and roads, which tend to grow with increased spacing between turbines (Samorani, 2010). A wake effect of one wind turbine on another decides the spacing between the wind turbines in a wind farm. Typical spacing between the machines in a wind farm is shown in Figure 4.13 and effect of spacing on energy loss is shown in Figure 4.15. Grid connectivity, accessibility are important considerations in selection and design of wind turbines site. Other considerations are reducing noise, transmission disturbance and visual disturbance (Hau, 2006).

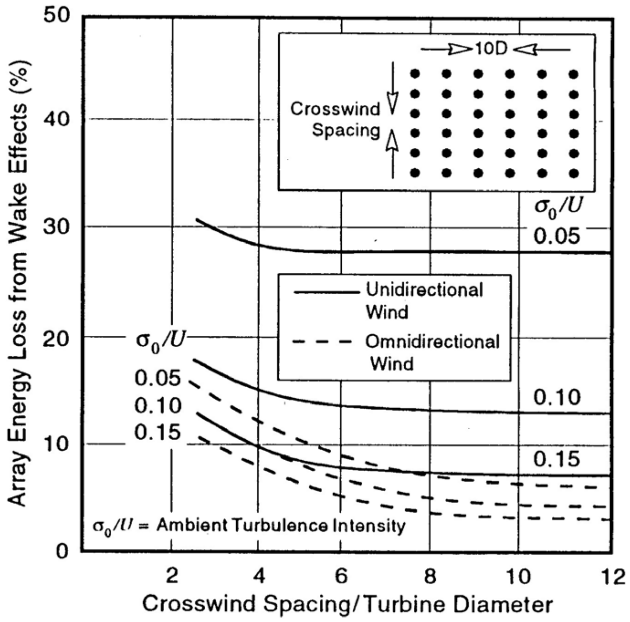
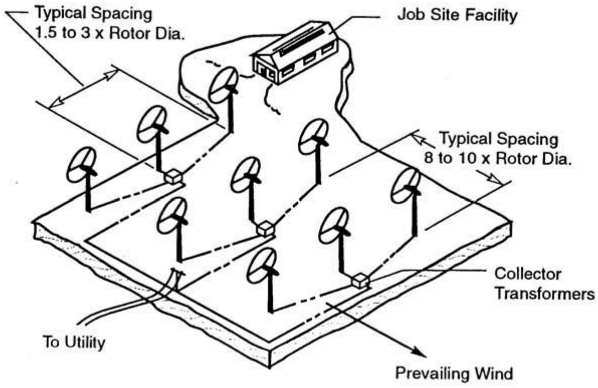


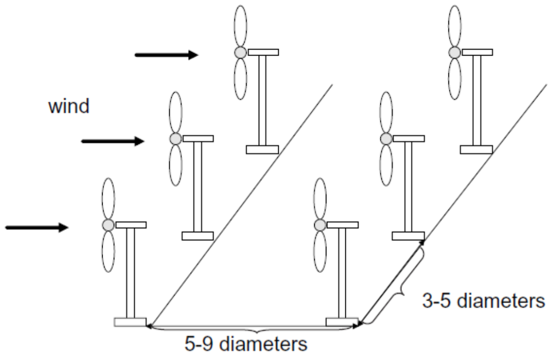
Figure 4.15 Effect of spacing on energy loss. Source: Hau (2006).

The distance between lines in a complex terrain is typically determined by the characteristics of the terrain (e.g., the turbines will be arranged linearly in a mountainous relief to take advantage of better exposure to the wind, and the layout is determined by the location of mountain ranges). In a relief plane, the rows are spaced turbines depending on the spacing between the turbines of a same line. The goal is to optimize the balance between the increased interference effect and the lower cost associated with a narrow spacing. Regard to the lines, the spacing is determined by the direction of the wind. Unidirectional environments (mostly wind power production comes from the same direction), the turbines can be placed closer together in a same line. In the case of multidirectional winds (ex., half the time it comes from the North and the other half he comes from East), you need a larger spacing (Ozturk & Norman, 2004; Petersen et al., 1998).

The typical spacing for wind uni-directional or a location with strong winds in two opposite directions predominant (180º) is three rotor diameters between the turbines in a same line and 10 diameters between rows. The typical spacing for omni-directional wind or wind with two predominant directions of 90º is five to six diameters between turbines and seven to eight diameters between the lines. The turbine manufacturer may require or allow a narrower spacing depending on the characteristics of the turbine and wind characteristics of local.



(a) Typical spacing for wind farms



(b) Optimum spacing of towers in wind farm

Figure 4.16 Comparison of suggested spacing for wind farms. Source: based on Hau (2006, p. 586) and Yao et al. (2011, p. 14)

As we can notice the distances change from author to author (see Figures 4.14 and 4.16), but all of them have as the main concern the optimization of the wind power plant, in other words, the wind farm electricity output production. For example, Emami and Noghreh (2010) have studied the optimum wind turbines distances in flat terrains. Hau (2006) and Yao et al. (2011) have studied the best positions for maximizing wind power capture by the wind farms reducing the wake effect. The great question is not what size are the precise distance among turbines and the rest of facilities in the power station because it is so variable. This variability is due the technical features of the wind farm in general. That is why it is necessary to analyze the wind farm array in terms of production, called the *array efficiency*, given by Pao and Johnson (2009):

$$\eta_A = \frac{E_A}{E_T N_{WT}} \qquad [\%] \qquad (4.10)$$

Where (E_A) is the annual energy of the array, (E_T) is the annual energy of one isolated turbine and (N_{WT}) is the number of turbines in the wind farm. Array efficiencies of greater than 90% have been shown to be achievable when downwind distances of 8-10 rotor diameters and crosswind distances of 5 rotor diameters are used (Lissaman, Zaday, & Gyatt, 1982).

4.5.3 TYPES OF WIND FARM LAYOUT

A wind farm is an industry in essence with special aspects related to its configuration. We called *"power plant"* because it is a unit that produces something, electricity, in this case. An industry only produces if there is *raw material*, in other words, *wind resources* available in economic terms. As an industry it must be the machinery to transform raw materials in products, similarly we mean, *electricity energy sold*. The arrangement of this power producer machinery in the wind power plant is the *layout of the wind farm*.

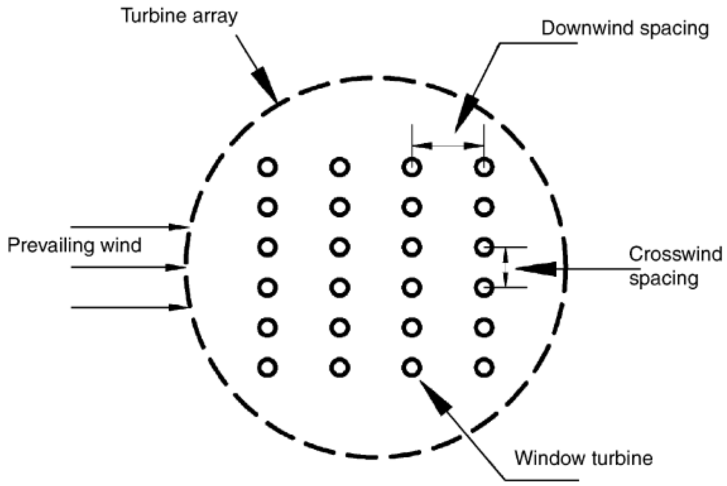


Figure 4.17 Wind farm array schematic. Source: Asif and Muneer (2007, p. 1411)

Figure 4.17 shows a general schematic of the layout of a wind power plant that may be situated either *onshore* or *offshore* applications related to the most important thing in a wind farm, the wind turbines sites. Many authors have shown that for turbines that have downward and crosswind spacing of up to 10- and 5-rotor diameters, respectively, the array losses are typically less than 10% (Manwell et al., 2002). According to Lundberg (2003, 2006a) a wind farm is usually composed by:

- Wind turbines
- Local wind turbine grid
- Collecting points
- Electrical transmission system and
- Wind farm interface to the point of common connection

All these elements reflects on the wind farm layout and performance, so it must be evaluated and optimized as we could notice in most of studied done in order to optimize the wind farms performance and cost of energy produced. We cannot forget the investment cost is impacted directly by the type of layout used, so it is necessary to run an economic analysis and always try to reduce the amount of capital invested in the wind farm. For a better visualization we can see Figure 4.18 and understand that we must face technical and economical challengers for optimizing a wind farm and get the most competitive cost of energy.

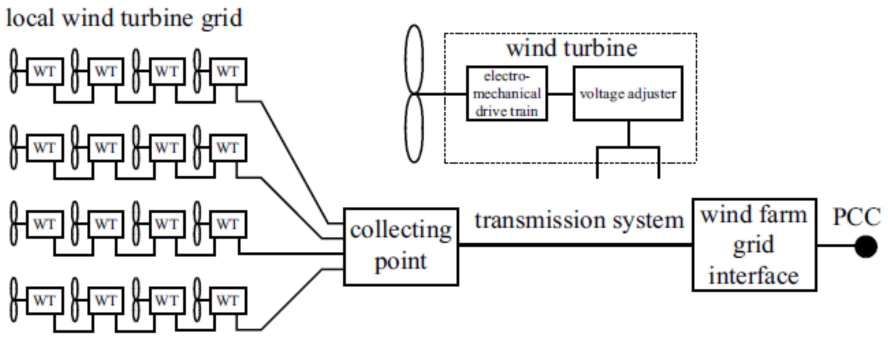


Figure 4.18 General wind farm layout. Source: Lundberg (2003, p. 5)

In Figure 4.18, the layout is formulated considering such aspects: (1) the wind turbines (WT) are in linear configuration, each row is composed by four WT inter-connected; (2) the collecting point is the same to all WT which can represent a risk for the wind farm, because if there is some problem with a single WT, it is necessary to stop the whole wind power plant. Although it has an advantage in initial investment, usually lower than other configurations which require more than one or central collecting point∴ According to Lundberg (2006b, p. 27) "*in the collecting point, the voltage is increased to a level suitable for transmission. The energy is then transmitted to the wind farm grid interface over the transmission system. The wind farm grid interface adapts the voltage, frequency and the reactive power of the transmission system to the voltage level, frequency and reactive power demand of the grid in the PCC".*

The distance to the nearest road access and the complexity of the terrain will substantially influence the capital cost of the project. It is important to say, the layout configuration of a wind farm must be analyzed considering each project is a *unique project*. It can change so much its analysis in function of the site, legal aspects, economic feasibility, WECS technology installed, and other aspects related to wind farm direct and indirectly, such as renewable energy policy.

When we discuss about wind farm layout, in other words, it is related to the position of wind turbines, providing the overall form or configuration of the wind energy development and its perceived density or complexity. In Figure 4.19 is shown some typical layout topologies applied in wind farms, both *onshore* and *offshore* applications, excepting the Figures 4.19 *(f)* and *(g)* because they are especially designed for *onshore* and *nearshore* applications. Generally, wind farm layout should be of a uniform type, whether a single line, staggered line, splayed line, random or grid, rather than a mixture. The creation of a *"visual stacking"* effect from a sensitive viewpoint should be avoided.

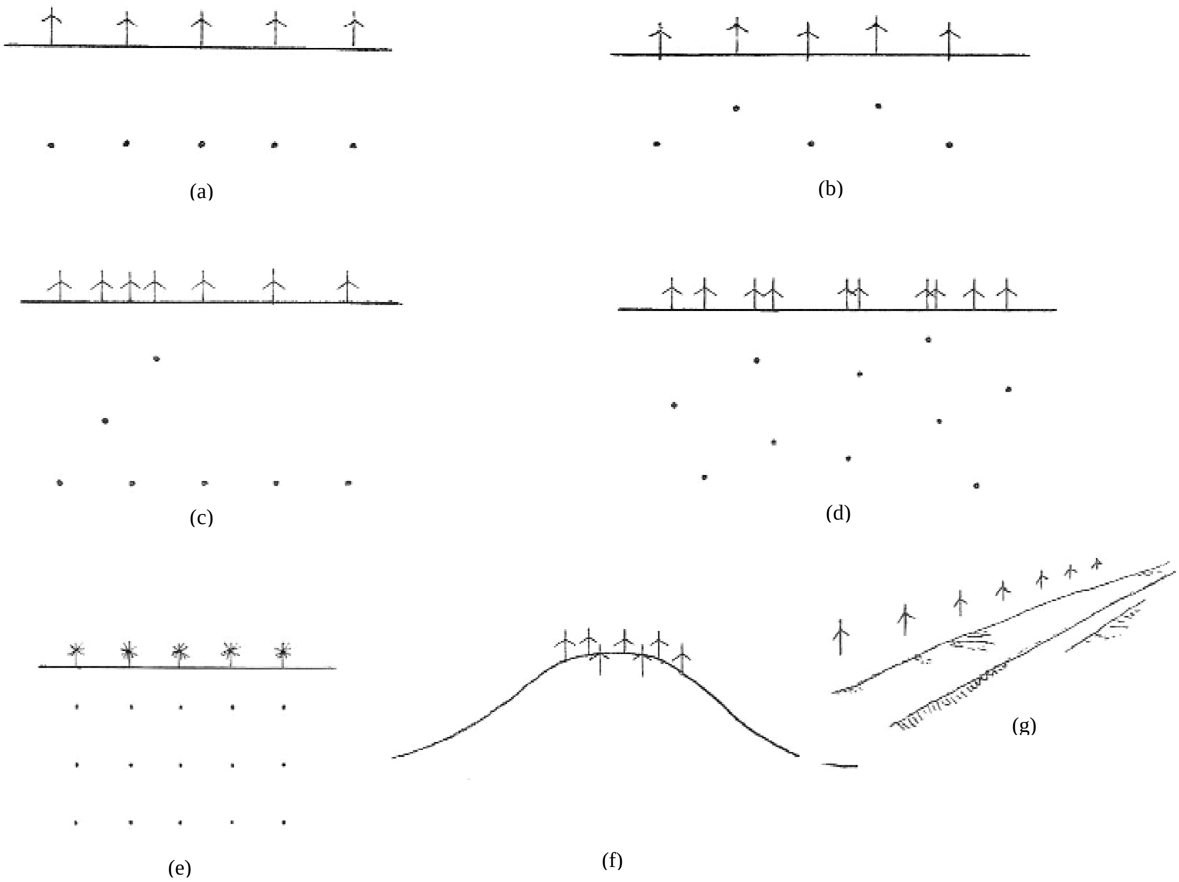


Figure 4.19 Typical layout topologies applied in wind farms. Source: adapted from Farrell Farrell (2006, p. 44). *(a) Plan and view of single line layout; (b) Plan and view of staggered line layout; (c) Plan and view of splayed linear layout; (d) Plan and view of random layout; (e) Plan and view of grid layout; (f) View of linear layout on a peak and (g) View of linear layout in response to a road, shoreline or cliff.*

All layout options are usually acceptable. However, the best solutions would either be a random layout, and clustered where located on hills and ridges (Figure 4.19 (f)), or a grid layout on sweeping and continuously even areas of moorland or plateau (Figure 4.19 (c) and (d)). Where a wind energy development is close to a linear element, such as a river, road or long escarpment, a corresponding linear layout (Figure 4.19 (a), (g)) or staggered line (Figure 4.19 (b)) might be most desirable.

It is important to empathize that terrain conditions, so the *topography*[55], impact directly on wind farm layout and performance in general, not only related to wind turbines, but in the rest of wind farm`s facilities and operation. That is the case of the access roads, supporting buildings, electricity collecting points, and so on. The final arrangement also impacts on costs of installations or capital costs, operation & maintenance costs, other costs and expenses which will reflect on the cost of energy produced by the power plant as a whole.

[55] The wind close to the earth's surface is strongly influenced by the nature of the terrain surface, the detailed description of which is called *topography* (Petersen et al., 1998).

4.6 SUMMARY AND CONCLUSIONS

Humankind evolution is closely linked to energy resources, since the beginning of time man has to know it and seeking it ever more on the environment. He began to enjoy and benefit from their potential. Thus obtained a better and continuing adaptation to the environment questions and needs, which was often hostile and consequently sparsely inhabited. Respecting the means and knowledge of each period of evolution, man became sovereign in the environment, acquired with so much more responsibility, while that on the environment imposed serious changes to meet its development. In general, wind power can provide an important contribution to reducing fossil fuel consumption and meet international environmental commitments. However, interconnection capacity, the combination of the existing capacity of production and characteristics of the wind power system to have a significant effect on how the variable production is assimilated by the system and on the extent of their contribution to meet the needs of modern society.

A WECS is a rotary system that extracts the energy from the wind. The mechanical energy from the wind turbine is converted to electricity (wind turbine generator)∴The wind turbine can rotate through a horizontal (HAWT) or vertical (VAWT) axis. Most of the modern wind turbines fall in these two basic groups: HAWT and VAWT. For the HAWT, the position of the turbine can be either upwind or downwind. For the horizontal upwind turbine, the wind hits the turbine blade before it hits the tower. Significant differences between wind turbines depending on the direction of their axis of rotation have been presented in this chapter. Many comparative studies have shown that VAWTs are advantageous to HAWTs in several aspects. Furthermore, common misjudgments about VAWTs have been discussed in the wind power literature.

The tower shadow has a great importance in HAWTs due to the tower interference. This problem is not as big for upwind turbines as for downwind turbines. The turbine dynamics is affected by the tower shadow gives power fluctuations and increases noise production. VAWTs do not experience tower interference as the distance between blades and tower is much larger in comparison to HAWT (Eriksson et al., 2008). It is important to say that these two types of WECS must be analyzed considering its application. Generally, the green investors try to maximize its return of capital invested, which is one of the reasons the HAWT has developed more than VAWT in the last decades. Table 4.5 makes a comparison between HAWT and VAWT.

Table 4.5 Comparison between HAWT and VAWT concept

Types	Advantages	Disadvantages
HAWT	✡ Variable blade pitch, which gives the turbine blades the optimum angle of attack. Allowing the angle of attack to be remotely adjusted gives greater control, which results in the maximum amount of wind energy collected during the period of operation. ✡ High efficiency, since blades always moves perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring aerofoil surfaces to backtrack against the wind for part of the cycle. Backtracking against the wind leads to inherently lower efficiency. ✡ The tall of the tower allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up, the wind speed can increase by 20% and the power output by 34%.	✡ The tall towers and blades up to 90 meters long are difficult to transport. Transportation can now cost 20% of equipment costs. ✡ Tall HAWTs are difficult to install, needing very tall and expensive cranes and skilled operators. ✡ Massive tower construction is required to support the heavy blades, gearbox, and generator. ✡ Downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower). ✡ HAWTs require an additional yaw control mechanism to turn the blades toward the wind. ✡ Reflections from tall HAWTs may affect side lobes of radar installations creating signal clutter, although filtering can suppress it.
VAWT	✡ A massive tower structure is less frequently used, as VAWTs are more frequently mounted with the lower bearing mounted near the ground. ✡ Designs without yaw mechanisms are possible with fixed pitch rotor designs, which low the initial investment. ✡ A VAWT can be located nearer the ground, making it easier to maintain the moving parts. ✡ VAWTs have lower wind start-up speeds than HAWTs. Typically, they start creating electricity about 3 m/s. ✡ VAWTs may have a lower noise signature.	✡ Most VAWTs generate energy at only 50% of the efficiency of HAWTs in large part because of the additional drag that they have as their blades rotate into the wind. ✡ While VAWTs' parts are located on the ground, they are also located under the weight of the structure above it, which can make changing out parts nearly impossible without dismantling the structure if not designed properly. ✡ Having rotors located close to the ground where wind speeds are lower due to wind shear, VAWTs may not generate as much energy at a given site as a HAWT with the same footprint or height.

Source: Malcolm (2003) and Dang (2009)

Because VAWTs are not commonly deployed due mainly to the serious disadvantages, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years. The development of a wind energy system requires the integration of many disciplines and resources. The necessary elements in the development of a wind power plant include wind resource evaluation and sitting, project development and financing, engineering, manufacturing and construction, and operations and maintenance. All these elements must be balanced in order to get the most competitive performance and cost of energy produced.

The wind power technology has achieved the maturity in 2000 years, as we could notice at Table 4.4, but this history and such evolution keep going forward, in function of new application and the improvement of efficiency and reliability of wind energy conversion systems. For McGowan and Conners (2000) the advances in wind energy system technology during the 1990s have produced major successes in the following three areas:

1. Cost of delivered energy. This success has occurred as a result of continued technology improvements, increased size and number of sales, and increased financial confidence.

2. Flexibility of wind technology. Because wind energy systems represent a modular technology, it can be added in relatively small steps, making it easier to speed up or slow down introductions to meet immediate economic circumstances. Also, wind technology is relatively easy to transfer, making it attractive to developers in expanding international markets.

3. Availability. The availability, or fraction of time that a wind turbine is available to generate power has increased to the point where values of 98% to 99% are typical for established wind farms. This high level of availability represents values that are higher than many conventional utility scale power production systems.

The working principle of a wind turbine encompasses two main conversion processes, which are carried out by its main components: the rotor that extracts kinetic energy from the wind and converts it into generator torque and the generator that converts this torque into electricity and feeds it into the electrical grids (Slootweg & Kling, 2003). The power in the wind is proportional to the air density (ρ), the intercepting or rotor swept area (A) and the wind speed (v_w) to the third power relation, as shown in Eqn 4.1. The air density is a function of air pressure and air temperature, which both are functions of the height above sea level (Ackermann & Söder, 2002).

The calculation of the annual theoretical production of electrical power from a wind farm is resulting from the product of electrical power installed, total hours of production for one year and capacity factor of the wind farm. The capacity factor is due to production losses, stops for maintenance and periods where the wind speed is not suitable for the production of electricity by wind turbines. The capacity factor is also referred to as system utilization factor of production (Kreith & West, 1997; NREL, 1995).

The wind farm planning is a long and complex process which each phase is remarkable for the whole wind power plant lifetime. A major issue in the planning of a wind farm is to identify the optimal rating and design of the installation. Several phenomena will limit the maximum possible capacity of wind farms. According to Oliveira and Fernandes (2011b) renewable energies have generally lower emissions than conventional power stations, making them strongly favored by the environmental regulations for the energy sector. However, renewable energy technologies are not free of negative impacts, although the public attitude in relation to renewable energy is generally positive, local people may react negatively to specific projects. In the particular case of wind energy impacts on the ecosystem, noise pollution (noise) and negative impacts on the landscape have been reported.

As we can see at Figure 4.13 the planning process of a wind farm has been made by four stages or phases: *(1) Pilot study*, *(2) Planning*, *(3) Realization or Execution* and *(4) Operation.* In the *Pilot study* are checked legal and economic aspects, site selection and type of WEC/grid technology will be used for the project. All the licenses necessary for the project goes are taken in this phase. This first step usually takes from 1 to 2 years to be concluded.

The *Planning* phase is longer than the first one. This stage can take from 2 to 3 years of duration. This phase several and important aspects related to the project economic feasibility are done such as financing planning and WEC chosen to be installed in the power plant∴A quick and initial examination by the pre-feasibility analysis determines whether the proposed project has a good chance of satisfying the proponent’s requirements for profitability or cost-effectiveness, and therefore merits the more serious investment of time and resources required by a feasibility analysis. It is also analyzed the type of company and building application and environmental impact review to complete a the final feasibility analysis that is a more in-depth analysis of the project’s prospects, the feasibility study must provide information about the physical characteristics, financial viability, and environmental, social, or other impacts of the project. The *Planning* phase is done in order to be used as decision tool about whether or not to proceed with the project by the developer.

In the *Realization or Execution* phase, the project get out from papers and computers and starts be materialized. This phase can take from 1 to 2 years to be done. The *Financing*, *Feed-in* and *Purchase* contracts are concluded. If the feasibility study is positive, then engineering and development will be the next step. Engineering includes the design and planning of the physical aspects of the wind power plant∴Development involves the contracts and other regulatory aspects of the project. Even following significant investments in engineering and development, the project may be halted prior to construction because financing cannot be arranged, environmental approvals cannot be obtained, the pre-feasibility and feasibility studies *“estimates”* important cost items, or for other reasons.

Finally, the project is built and put into service in the *Operation* phase. This phase represent the longest part of the project lifetime and start from the year 5^{th} to 25^{th} of the wind power project. This phase includes control, monitoring and maintenance activities that must be performed precisely to keep downtime to a minimum. The main objective for a wind farm is to ensure that the system achieves the best energy yield from the prevailing wind conditions at the respective location. In addition to these commercial requirements, the operation of the wind farm must also ensure that dangerous operating conditions are recognized early enough and that the wind farm control system acts appropriately to avoid dangers to the environment and the WECS that could arise from malfunctions.

At the end of the Operation phase a great decision must be taken: *removing* or *repowering* the wind power plant. *Removing* or *Decommissioning* is a process of inactivating a wind power plant and trying to remove the most the environmental impacts caused by the previous power plant existence. The purpose of the removing plan is to identify the methodology to be used to mitigate potential impacts resulting from the cessation of operation of the facility at the end of the project’s useful life. The removal action-plan identifies the specific project components that will be removed; the nature of the costs associated with the removal of the components and associated scrap value.

In the other hand, if the power plant will going on, improved its efficiency it is necessary to make a repowering process. Also known as replanting, *Repowering* is the process we go through to replace older first-production wind turbines with modern, more efficient wind turbines∴The process is carried out in a timeframe that allows us to replace an older wind farm, by the time it comes to end of its typical 20-25 year lifetime. Many wind farms have permission to operate for up to 25 years. If a site has proved to be a good and efficient site, we consider whether there is merit in continuing to operate a wind farm at this location.

It is important to say about WECS in relation to GHG emissions, especially CO_2 considering wind power be market-ready (mature technology), and the price of power is broadly competitive to other types of RETs production, depending on the location. In terms of energy and carbon balance, about 3–7 months of turbine operation are required to recover the energy spent in the full life cycle of the wind power plant (including removal and disposal), and the technology can avoid CO_2 emissions ranging from 391 to 828 g CO_2/kWh (GWEC, 2010).

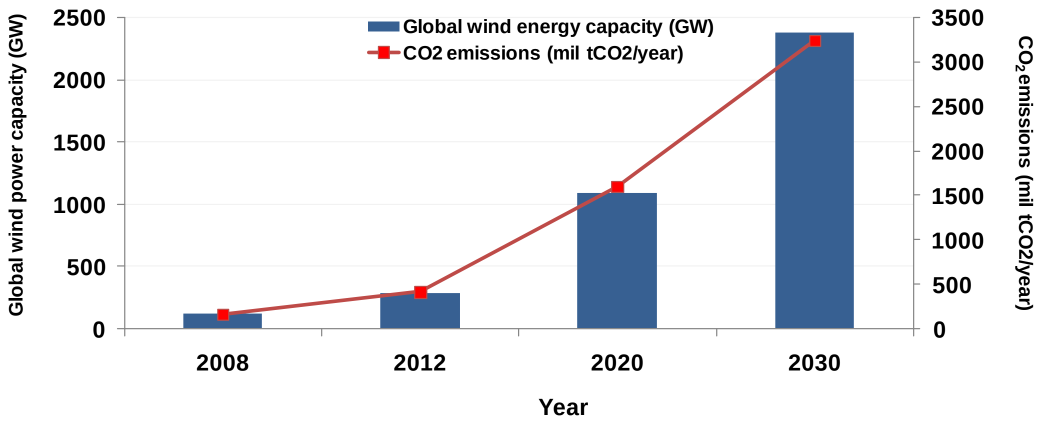


Figure 4.20 CO_2 emissions saved by WECS deployment from 2008–2030. Source: GWEC (2010)

The success of wind power as a renewable energy sources is obviously a direct function of the economics of production of WECS. In this regard, the role of improved power output through the development of better aerodynamic performance offers some potential return; however, the focus is on the cost of the entire system. For this reason in the Chapter 5 is discussed about *economic measures and optimization models* applied to renewable energy technology with emphasis on wind energy technology.

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If one of you is planning to build a tower, he sits down first and figures out what it will cost, to see if he has enough money to finish the job.

Luke 14:28.

CHAPTER 5

ECONOMIC MEASURES AND OPTIMIZATION MODELS

This chapter discusses about economic measures and optimization models applied to RETs, with focus on wind power technology in order to establish a framework for a better utilization in economic engineering evaluation at a microeconomic view. Summary and conclusions are presented at the end, with the respective references.

4.1 INTRODUCTION

The objective of economic measures is to provide the information needed to make a judgment or a decision in economic issues related to a certain project. The most complete analysis of an economic measure of a renewable technology project requires the analysis of each year of the lifetime of the same project, taking into account relevant aspects, such as direct costs, indirect and overhead costs, taxes, and returns on investment, plus related externalities, such as environmental impacts, that are relevant to the decision to be made∴However, it is important to consider the purpose and scope of the particular economic measures used in economic analyzes because this will drive the course to follow. The perspective of the analysis is important, often dictating the approach to be used. Also, the ultimate use of the results of an economic measure will influence the level of detail undertaken.

The modern world is moved by ways to generate and consume energy, especially into electricity form. Electricity is accepted as one of the driving forces of the economic development of all the nations. The challenge of continuously producing electricity and meeting the growing demands is great concern for both developed and developing countries. The high costs of delivered electricity can be attributed to strong dependence on centralized energy systems which operate mostly on fossil fuels basis and require huge investments for establishing transmission and distribution grids that can be available anywhere for everybody. Furthermore, the fossil fuel utilization results in the emission of greenhouses gases rising concerns about the climate change and other health hazards (Oliveira & Fernandes, 2011c).

In order to face these problems there is a strong need for renewable energy systems of power producing and distribution. Unlike the centralized energy systems, on the other hand, decentralized energy systems, the case of WECS, both in the presence and absence of grids, and easily accessible to remote locations because of production and consume of power can happen in the same place, considering the demand site. The Renewable Energy Technologies (RETs) must be optimized in function of its own nature capital-intensive and its production output is expectable not plannable due to the forces of nature, in terms of intensity, frequency, availability of the natural resources.

This chapter discusses about economic measures and optimization models applied to RETs, with focus on wind power technology in order to establish a framework for a much better utilization in economic engineering evaluation of a project in a microeconomic view. It starts presenting economic measures principles and costs categorization to be considering into analysis (section 5.2). Section 5.3 refers to the models of projects economic evaluation by describing the most used economic measures indicators (section 5.3.1) within its particularities and hurdles. Section 5.4 is related to models for costs evaluation applied to energy power projects, especially emphasis on monetary costs indicators for wind power projects (section 5.4.1); Peculiarities in the cost analysis of wind energy projects (section 5.4.2). Section 5.5 discusses about optimization models applied to REPs, in this particular issue, we show some algorithms applied to technical-economic analyses of power plant. It is important to say that our purposed model of optimization (Chapter 6) is built considering these models extensively studied. Finally, the summary and conclusions of this chapter (section 5.6) and all references (section 5.7) used are present at the end of this chapter.

5.2 ECONOMIC MEASURES

The success of a project finance transaction depends on the project's capacity to generate sufficient cash during its operating phase so that it matches the cash needed for debt service (interest and principal repayment) and dividends paid to the project sponsors. Project finance is usually associated with large capital-intensive ventures (for example, power plants, transportation infrastructure, telecom projects) with low ratability values and limited recovery values in case of project defaults (Borgonovo, Gatti, & Peccati, 2010). Under these circumstances, lenders pay particular attention to project performance on a going concern basis because the possibility to repay principal and interest depends on the project's ability to generate sufficient cash flows.

Opportunities to use sun, wind, water, wood as energy sources are numerous. Renewable energy sources are naturally replenished energy in a relatively short period and produced by natural processes. While conventional sources of energy are finite (in human dimensions of time). Each case must be evaluated is the project economically∴If the present high cost of energy produced compared to classical sources, the use of new technology is discredited by final consumers (and public opinion behind it). When there are different technical solutions, or when you offer multiple investment opportunities is necessary to evaluate the projects to decide what or who should be executed. This chapter focuses on the economic and financial evaluations for renewable energy projects (REPs). The REPs can be of different sizes and can extend over different time horizons. But always involve technical, financial and human resources that must be combined to create the expected result. The REPs share the typical characteristics of all other projects (Cleland, 1991):

1. The project begins and ends that determine the *"project´s life"* that differentiates it from other activities of a permanent nature in existing organizations or companies (who may be involved in the project).
2. The financial and human resources available for project implementation are limited (usually pre-determined at the beginning of the project).
3. The project is a set of tasks and activities that are separate from other activities undertaken by the parties involved in a repeating basis (*"the day-to-day"*).

When we use economic measures for cost analysis of the electricity supplied by wind energy conversion systems (WECS) is a rather difficult task requiring the estimation of output power production as well as the cost of the WECS, in addition to the analysis of the wind distribution parameters. Power production of the WECSs is closely related not only to the system's performance but also to operating conditions, which means the wind characteristics of the site, as well as (Gökçek & Genç, 2009). The economic-financial models comprise many more factors influencing these key variables, such as macro-economic variables (inflation rates, interest rates, economic growth rates, etc.), market variables (overall demand, development of input and output prices) or technology variables (price developments due to technological change). Setting up the economic and financial model is typically done by applying standard investment appraisal techniques (discounting future cash flows, computing net present value (NPV), etc.) (Oliveira & Fernandes, 2011a).

Efficient planning and resource management is the key to the success of an energy project. The REPs require a specific organization that unites all parties together, regardless of other (existing permanent) organizational ties or relational boundaries between the parties involved, as shown in Figure 5.1.

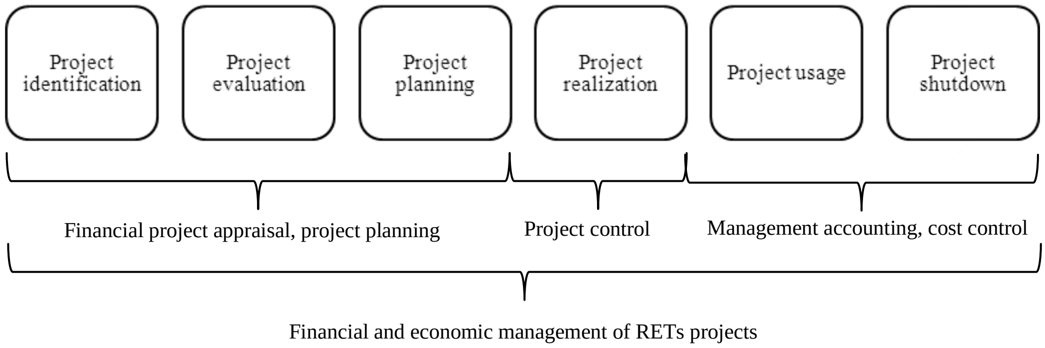

Figure 5.1 Evaluation process and financial management of REPs. Source: adapted from NREL (1995)

As we can see Figure 5.1, evaluation and economic management applied for RETs projects, is a process or a cycle. In order to differentiate the project and project management it is necessary to develop distinct definitions for the two terms. A project can be considered to be the achievement of a specific objective, which involves a series of activities and tasks which consume resources (*Project identification*, *Project evaluation* and *Project planning*). It has to be completed within a set specification, having definite start and end dates∴In the other hand, project management can be defined as the process of controlling the achievement of the project objectives (*Project control*). Utilizing the existing organizational structures and resources, it seeks to manage the project by applying a collection of tools and techniques (*Management accounting, cost control*), without adversely disturbing the routine operation of the company (Munns & Bjeirmi, 1996), in the case of wind power, the wind farm manager.

The evaluation measures the investment attractiveness of investment or potential project (here more specifically: a REP, wind onshore) for the investor and/or manager. A project is attractive, the consequences of that lead to the expected result of attractive economically, financially by the investor (Lapponi, 2000). This chapter discusses the main methods of economic evaluation applied to the energy industry with a discussion of the topics of greatest interest to economists, engineers and other professionals related to analysis of economic and financial viability of investments in power of decentralized production of electricity. However the issue is important: the economic and financial viability of the enterprises is a necessary condition for the gradual deployment of new energy technologies to do so solid and convincing.

5.2.1 CLASSIFICATION OF COSTS CATEGORIES

5.2.1.1 COST STRUCTURE OF WIND ENERGY PROJECTS

Although we have not made any distinction between different technologies in renewable energy, the cost structure of a REP is dependent on the technology used. The *"Renewable Energy"* covers a diverse set of technologies ranging from small photovoltaic solutions for roofs of individual houses to large wind farms onshore and offshore∴Most of the costs parameters and definitions used in this sub-section are characterized costs related to the onshore wind power made the analysis from production to the mains distribution.

The following are the major cost components for onshore wind power are presented and briefly described (see Table 5.1). The emphasis is on description of these elements are not in exact figures. The cost values are dependent on circumstances of individual projects and are altered at a rapid pace due to technological advances and economies of scale. The main cost elements are proving to be quite stable in the technological nature of particular projects to generate electricity from wind, so you should be familiar with them, to make a complete and consistent assessment of attractiveness of the project (Harrison & Jenkins, 1993; Kaltschmitt, Streicher, & Wiese, 2007).

Depending on the nature and reflects the behavior of the final cost of power produced by wind farm, the typical elements of cost are grouped by cost category. The listing does not tend to be exhaustive, as wind power, by experience and technological maturity has become easier to identify these costs. It is important that classification of the cost structure to facilitate financial and economic analysis of projects (EWEA, 2009)∴A plant for producing electricity from wind energy uses the principle of conversion of kinetic energy[56] contained in flowing air masses (wind) into electrical energy. The wind turbine consists of tower equipped with rotor blades and (the concept of *"windmill"*) connected to the electrical generator that converts rotational mechanical energy into electrical energy. Wind power can be used for both connected to the mains system (usually *"wind farms"*), as well as for applications independent of electrical grids (Heier, 1998).

According to IEA (1991), NREL (1995) and RETScreen® International Clean Energy Decision Support Centre (2008), the individual elements of project costs of wind power for electricity production can be grouped into four distinct categories of costs (investment costs, operational costs, maintenance cost and financial cost). This classification is used for monetary costs evaluation and excludes other types of cost, such as, the invisible costs usually present in sustainable renewable energy systems (wind energy conversion systems, wave energy, solar power systems, biomass, nuclear power, geothermal power systems, and others), like externalities costs, social costs and environmental costs.

[56] In *Physics*, the principle of converting kinetic energy is the amount of work that must make an object to change its speed (either from the rest - *zero speed* - either from an initial speed). For an object of mass m speed v kinetic energy in an instant of time, is calculated as $KE = \frac{mv^2}{2}$ (Rosa, 2009).

Table 5.1 Classification of costs into categories for wind energy projects

Investment cost	Also called the *"capital cost*" or *"initial investment"*, this group of costs reflect all cost elements that occur only once at the beginning of the project. Investment cost includes cost of purchase and installation of equipment, site preparation, acquisition of necessary licenses or permissions, planning and professional advice necessary to connect the wind farm system facilities or construction of public grids.
Operating cost	Refers to the cost elements that occur during regular operation mode of the system after being put into production. The operating cost can be cost of raw materials or operating personnel, as well tax payments and insurance, land lease, or cost to supply energy to the public network (access fee). Part of the cost of operations is independent of capacity utilization of the production system, so, they are fixed. Other operating costs vary with the load supplied to the grid. The split between fixed and variable operating costs differ among renewable energy technologies. The ratio of fixed operating costs to revenue (per period) is called *"project self-financed"*. In a system with self-finance the project uses a greater proportion of revenue on systems with low self-financing. The self-finance the project reduces the flexibility of the cost of the system during operation.
Cost of O&M	It includes all cost elements that occur in order to maintain or ensure the production capacity (system operational availability). Can be achieved through preventive maintenance (system check before being damaged) or repair (arranged in the system after it was damaged). Maintenance measures may be small and frequent (replacement of small parts such as lamps and air filters, periodic verification procedures), or large and infrequent (unscheduled repair of significant damage, change of principal components).
Financial cost	This category of costs is included in all financial expenditures caused by financing transactions within the lifetime of the project. The most important element of cost is the interest payment to lenders of the project. Other elements are typical costs resulting from banking to venture capital acquisition, construction consortium, the cost of financial guarantees. The financial cost can be cost elements related to a specific period during the life of the project (similar to the cost of capital) or elements of recurrent costs (similar to the operating cost). Different from the capital costs and operations, as are not due to technical or operational characteristics of the project, but are influenced by the nature of funding.

Source: IEA (1991)

It is important to differentiate the wind farm costs in terms of installed capacity (total capital costs and variable costs) and cost of wind energy per kWh produced. Fuel costs for wind farm cost is zero. This is the fundamental difference between electricity produced by wind power and other options of conventional power production. For example, in a power plant to natural gas has been 40 to 60% of the costs related to fuel and O&M, compared with about 10% for onshore wind farm. Moreover, the fact that wind energy projects require substantial capital investment affects the financial viability of projects∴Become essential to the investor or manager to have most of the funds needed at the time that the wind farm is built. To have access to the rest of the capital financed in good condition for a refund. Some projects cannot be executed due to the necessary funding process during this initial phase, although, over time, may become a less expensive option (Blanco, 2009).

The great advantage of wind power after the installation process and wind measurements calculated correctly, the production cost of this technology is predictable, which reduces the overall risk to the power company. The cost of capital projects for offshore wind power is higher than for onshore wind energy projects (Neij, 1999). The higher cost is due to increased investments (foundations of the tower under the sea) and transport costs, on the other hand the need for high reliability and low maintenance routine (accessibility of the wind farm). The additional protection to physical facilities more effectively against corrosion and accumulation of harmful materials is necessary for marine offshore installations. All these factors orientates the initial investment (Bergmann, Hanley, & Wright, 2006).

Wind energy is a capital intensive technology, so that majority of cash outflows occur in this phase. The cost of capital can reach 80% of the total cost of the project during its lifetime, with variations between models, and local markets∴The wind turbine is the major cost component, followed by the network. Even after more than two decades of consistent reductions, the capital cost of proposed wind energy has increased by 20% over the past three years. The results show that in the range of 1100-1400 €/kW for new projects in Europe. The costs are smaller in some emerging markets, especially in China and the United States of America. There are also variations in the European Union (Milborrow, 2008).

Figure 5.2 illustrates the complexity of sub-components that make up a wind turbine, and helps explain why these elements are higher costs of initial investment. Note that the value refers to the exceptionally large size in the current market (5 MW, as opposed to 2-3 MW machines being installed in most onshore wind farms). The relative weight of sub-components varies depending on model. Other elements of cost, besides the wind turbine, are needed at the beginning of the project and represent about 18 to 32% of the total capital cost for onshore wind energy projects.

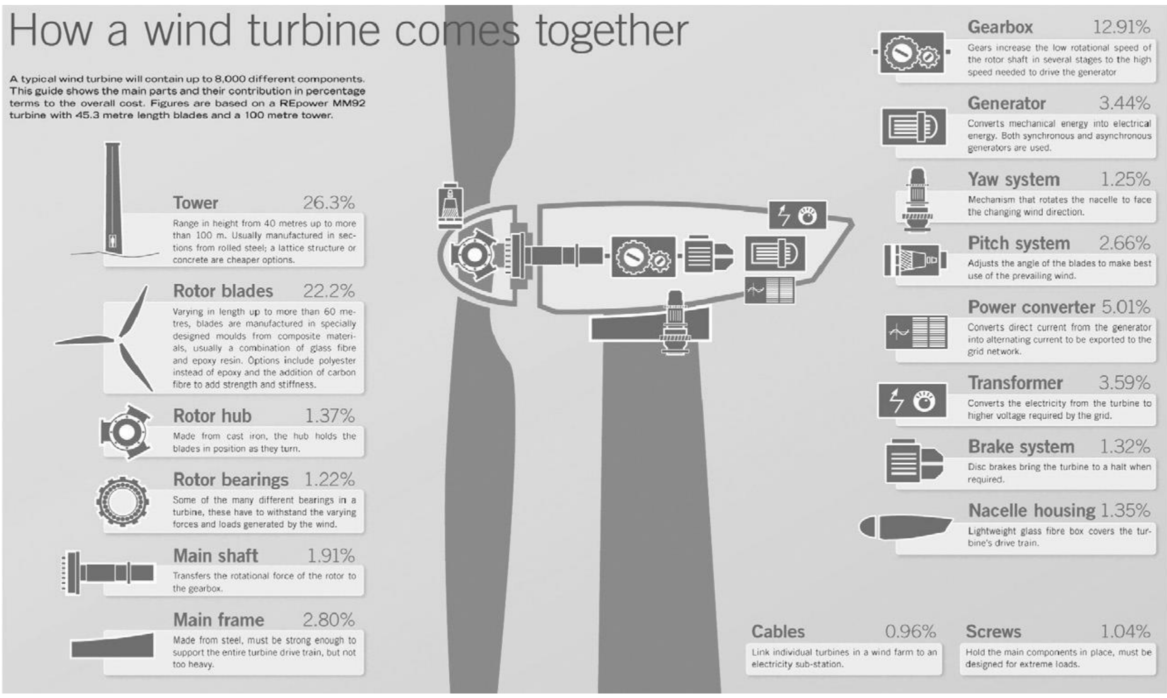

Figure 5.2 Example of the main components of onshore wind turbine with distribution of the overall cost of the 5 MW Repower. Source: Blanco (2009).

Variable costs of production in wind energy projects are directly related to the cost of annual operations and maintenance (O&M) that are relatively high, accounting for 5-8% of initial investment (capital cost). The cost of O&M is particularly high in offshore systems. A distinctive feature of wind energy is the importance of the cost of insurance due to increased risk of equipment damage, downtime and damage to third parties. Wind energy (offshore wind farms in particular) can also involve considerable repair costs∴Although the overall lifetime of the project could be 20-25 years, major repairs may be needed after 10 years of operational wind farm (Milborrow, 2008). Currently, one of the priorities for wind turbine manufacturers is to reduce variable costs, especially those related to operations and maintenance (O&M) through the development of new projects for wind turbines, which require less service visits, resulting in higher productivity of the turbine. It is important to note that the downtime of the turbines is less than 2% per year (George & Schweizer, 2008).

According to BWEA (2006), AEE (2006); Morthorst (2007); Milborrow (2008), DTI (2007a), a prudent level of variable costs would be between 1-2 c€/kWh over the life span of the wind turbine. This would mean 10 to 20% of total costs (about 10% in O&M activities). As with other cost categories, the percentages are only indicative.

Finally, the future development of variable costs should be careful when interpreting the results presented previously. First, wind turbines have economies of scale in terms of reducing the investment per kW with an increase in turbine capacity, economies of scale similar may happen with O&M. Secondly, new and larger wind turbines have reduced the requirements for O&M in relation to older turbines and smaller∴Other costs, including replacement of components, monitoring and insurance may increase due to increases in material costs and risks associated with certain models of large capacity wind turbines (Blanco, 2009).

The local wind resource is the most important factor affecting the profitability of investments in wind and also explains most of the differences in cost per kWh between countries and projects. Wind turbines are useless without adequate wind resource. The correct location of each individual wind turbine is crucial to the economy of any proposed wind energy. In fact, it is widely recognized that during the initial phase of the modern wind industry (1975-1985), the development of the *European Wind Atlas Methodology*[57] was more important to productivity gains that advances in design in wind turbines (Troen & Petersen, 1989).

The size and characteristics of the turbines are adapted according to wind patterns observed, being located after careful computer modeling, based on local topography and meteorological measurements. The average number of hours of full load varies from place to place and from country to country[58]. The range of facilities for onshore wind farms ranges from 1700-3000 hours/year (average of 2342 in Spain, 2300 in Denmark and in 2600 in the UK, to name a few in Europe). In general, good sites are first to be exploited, although they may be located in areas of difficult access (European Commission., 2007).

[57] The European Wind Atlas Methodology developed by Erik Petersen and Troen Lundtang Erik which was later formalized in the WAsP software for wind resource assessment by Risø National Laboratory, Denmark. For more information, see http://www.wasp.dk/.
[58] The full load hours are calculated as average annual production of wind turbine, divided by the nominal power.

The theoretical energy production, based on the power curves of wind turbines and wind regime estimates is reduced by a number of factors, including losses in matrix production (occurring due to wind turbines shadowed each other within the wind farm), losses due to dirt or freeze in spades, mechanical friction losses, losses in transformers and electrical cabling and downtime of wind turbines for scheduled maintenance or technical failure∴The net energy output is usually estimated at 10-15% below the energy calculation based on power curves of wind turbines (Welch & Venkateswaran, 2009).

Wind turbines are designed to generate maximum power at certain wind speed. This power is known as the rated power and wind speed at which it is reached is called the rated speed of the wind. The speed is adjusted according to the local wind regime, with values common to find between 12 to 15 m/s. For the same reason, to values above the rated wind speed is not increasing economic power, it would require the largest of all equipment with a corresponding increase in initial investment, which would draw only a few hours during the year, thus turbine is set at above nominal wind speed and operate at constant power, leading to artificially decrease the efficiency of conversion (Marafia & Ashour, 2003)∴When the wind speed becomes dangerously high (above about 25-30 m/s), the turbine is switched off for safety reasons (the aerodynamic loads increase with the square of wind speed). Today's turbines in the adaptation of the system of production to wind speed at each instant it is set by adjusting the angle of attack of the blades (pitch control) and solution set through mechanical or electrical that has in some cases associated solutions for electronic power control, as well as for controlling the rotation speed. However, in certain situations, is limited to the operating power of the wind turbine (Jenkins, 2001).

A variety of models that analyze the trend of long-term costs of wind and other renewable, have been developed over the last decade, many supported by the European Union[59]. The European Commission. (2007) in the 2007 Strategic Energy Review presents a set of key results, as part of the assessment of impact on renewable energies. This shows that the capital cost of wind power will drop to around 826€/kW in 2020, 788 €/kW in 2030 and 762 €/kW in 2050. A similar pattern is expected for offshore wind energy, as shown in Table 5.2.

Table 5.2 Trends in the cost of capital assumed by PRIMES project for wind energy

	€/kW in2020	€/kW in 2030	€/kW in 2040	€/kW in 2050
Onshore	826	788	770	762
Offshore	1274	1206	1175	1161

Source: European Commission. (2007)

Likewise, the *British Department for Business, Enterprise and Regulatory Reform* (DTI, 2007b) commissioned a study by Ernst & Young to examine current and future costs of renewable

[59] For example, TEEM, SAPIENT, SAPIENTIA, CASCADE-MINTS, co-funded by DG Research.

technologies. Wind energy onshore and offshore provide upward trend until 2010. This will be followed by a decrease, since bottlenecks in the supply chain are addressed. Using specific costs of energy as the basis (cost per kWh produced), the estimated rates of progress in specialized publications are from 0.83 to 0.91, corresponding to learning rates from 0.17 to 0.09 $\therefore$ Then, when the total installed capacity of wind energy doubles, the cost per kWh for new turbines decrease between 9-17%. The recent study by the DTI (2007b) estimates the cost savings of 10% when the total installed capacity doubles. Tables 5.3 and 5.4, have been short of capital costs, energy production and variable costs with their studies and values.

Table 5.3 Summary of some sources about capital costs and production costs of wind power

Study	Capital cost per kW installed	Cost per kWh
Morthorst (2007); Morthorst and Chandler (2004)	900€/kW to 1,175€/kW	n.a
Milborrow (2006)	869€/kW to 1,559 €/kW	n.a
AEE (2006)	971.67€/kW to 1,175.10€/kW	n.a
EER for Vestas (EER, 2007)	1,050€/kW to 1,350€/kW	n.a
BWEA (2006)	1,520€/kW	n.a
IEA (2005) projected costs of producing electricity, 2005 update, IEA publications	1,000–1,600US$ *onshore* (850–1,360€) and 1,600–2,600 US$ *offshore*.	n.a.
IEA (2007) annual report, draft-data provided by Governments	1,365€/kW in Canada; 979€/kW in Denmark; 1,289€/kW in Germany; 1,050€/kW in Greece; 1,200€/kW in Italy; 1,209€/kW in Japan; 1,088€/kW in Mexico; 1100 €/kW in the Netherlands; 1,216€/kW in Norway; 1,170€/kW in Portugal; 1,220€/kW in Spain; 1,242€/kW in Switzerland; 1,261€/kW in the UK; 1,121€/kW in the U.S.	n.a.
UKERC (2006)	n.a.	5.9 c€/kWh with a standard deviation of 2.5 c€/kWh
DTI (2007a)	1,633€/kW (medium scenario); 1,850€/kW (in the high scenario); 1,422€/kW (in the low scenario).	9.3–11.5c€/kWh (high and low)
DTI (2007b)	n.a.	8.1 c€/kWh to 15.9c€/kWh
Bano, Lorenzoni for APER (Blanco, 2009)	1,400 €/kW	9.4 c€/kWh
Wiser, Bolinger for US DOE (Blanco, 2009)	1,480 US$/kW (1,200 €/kW approximately) projects in 2006; 1680 US$/kW (1,428€/kW) for proposed in 2007.	n.a.

Table 5.4 Summary of some sources about variable costs in producing wind energy

Study	O&M costs	Other variable costs
Morthorst (2007); Morthorst and Chandler (2004)	1.2 to 1.5c€/kWh	n.a. (not clear)
Milborrow (2006)	15 to 40c€/kW; 1 to 1.5c€/kWh	n.a. (not clear)
AEE (2006)	1.02c€/kWh	1.03 c€/kWh
EER for Vestas (EER, 2007)	2.5 to 4c€/kWh; 0.25 to 0.40c€/kWh	n.a
BWEA (2006)	23.25c€/MWh	(check)
IEA (2005)	12.50 to 33.8c€/kW	n.a.
DTI (2007b)	61.5c€/kW	n.a.
Bano, Lorenzoni for APER (Blanco, 2009)	1.8c€/kWh	n.a.
Wiser, Bolinger for US DOE (Blanco, 2009)	Partial data; 0.68c€/kWh for the most recent projects; 1.7 c€/kWh for older projects.	n.a.

5.3 MODELS OF PROJECTS ECONOMIC EVALUATION

5.3.1 ECONOMIC BASICS OF PROJECTS EVALUATION

An *"investment"* in the broadest sense is any occasion where financial resources (capital) are put to productive purposes. This money could then be invested in new product development, acquisition of a competitor or to build new plant to generate electricity. In a narrower sense, an investment is limited to cases where financial resources are applied to acquire or build tangible capital assets *("capital cost"*). The purchase of government securities (investments) or project financing to develop new products (intangible investment) is not characterized as an investment in this sense. REPs are typically capital-intensive investments, as mentioned earlier (Damodaran, 2001).

The investments have important consequences for the investor, because a considerable amount of capital is needed and is linked to long and not available for other purposes, equally attractive, if applied (time of operation or life of the project). The consequences of a wrong investment decision can be large, and endangering the investor∴ It is natural that investment decisions are preceded by long and extensive analysis of the potential attractiveness of investment. The analysis of investment attractiveness are called *"economic evaluation of investment"* (Dixit & Pindyck, 1995).

Appropriate setting for the opportunity cost of investment (discount rate or cost of capital), the cost of capital is an appropriate discount rate to be applied in the economic evaluation of projects. Note that in business practice, often we use the average cost of capital (measured in all forms of capital currently used). The most appropriate measure would be the marginal cost of capital (cost of additional capital investment in employee analysis). The marginal cost and average cost are not equal. However, the most common is the *"Weighted Average Cost of Capital"* (*WACC*). It is calculated using the following formula (Damodaran, 2001):

$$r_{WACC} = (1 - W_D) r_E + W_D r_D (1 - t_x) \qquad \text{[\%/yr]} \qquad \text{Eqn (5.1)}$$

where r_{WACC} = *Weighted Average Cost of Capital*; W_D = *Capital Structure*; r_E = *Equity cost*; r_D = *Debt cost before tax* and t_x = *taxes.*

The assets of a project are financed by debt and equity. The *WACC* allows calculation of weighted average cost of funding sources, in which the weight of each is considered in each funding position. This weight is defined as the ratio:

$$W_D = \frac{Equity}{(Equity + Debt)} \qquad \text{[\%]} \qquad \text{Eqn (5.2)}$$

The interest rate for working capital loan is simple (since it is known from the interest payment to creditors). The interest rate to be applied to equity is less obvious. In finance theory suggests alternative methods for estimating the cost of equity, the most prominent are the opportunity cost methods, methods based on Discounted Cash Flow (DCF) and methods based on Capital Asset Pricing Model (CAPM). Both approaches have a disadvantage because they are applicable in open capital markets (sale of shares through stock exchanges) $\therefore$ In these cases, the opportunity cost approach must be taken when the investor is evaluating alternative investment options with equity and/or obvious to the expected return on investment as *"cost of capital"* for the planned project.

An analysis or economic evaluation of investment involves activities undertaken before an investment decision in order to assess the potential of attracting investment by the investor. These evaluations may be limited to purely monetary parameters, which in most cases also include non-monetary parameters (NREL, 1995). This section discusses about economic evaluations methods for REPs, especially wind farms in order to accomplish the objectives of this same section.

5.3.1.1 SIMPLE PAYBACK

The Simple Payback (SPB) is defined as the time (number of periods) required for the project's cash flow[60] refinance the initial investment. In other words, the SPB is required to recover the initial investment through positive cash flows of the project. Before that moment, the project has recovered all the initial investment or at least part of the invested capital is still at risk (if the project fails).

The SPB is used as a measure of project risk: the higher the return time, the greater the risk for investors, because (in part) the invested capital cannot be recovered. In a typical project, the negative cash flow early in the project (initial investment) is followed by positive cash flows (return) in subsequent periods. Mathematically, SPB can be expressed as the smallest *t* that satisfies the condition:

$$(Ci - Co)_{1+} (Ci - Co)_{2+\ldots+} (Ci - Co)_t = \sum (Ci - Co)_t \geq Co_0 \qquad \text{[yrs]} \qquad \text{Eqn (5.3)}$$

where C_i = *Cash inflows*; C_o = *Cash outflows*; C_{o0} = *Initial Investment* and t = *Number of periods.*

Since t is an integer, the sum (Eqn 5.5) is likely to be lower or higher than the initial investment (C_{o0}), but not exactly equal to C_{o0}. The value (decimal) exactly the SPB (where the sum corresponds exactly to the initial investment) can be calculated by linear approximation by using the following formula (Brealey & Myers, 1997):

$$t' = t - \sum (Ci - Co)_t \times \frac{1}{\sum (Ci - Co)_{t+1} - \sum (Ci - Co)_t} \qquad \text{[yrs]} \qquad \text{Eqn (5.4)}$$

with

$$\sum (Ci - Co)_t < Co_0 \ \text{ and } \ \sum (Ci - Co)_t > Co_0 \qquad \text{[yrs]} \qquad \text{Eqn (5.5)}$$

[60] In finance, cash flow (known in English as *"cash flow"*), refers to the amount of cash received and spent by a company during a period, sometimes linked to a specific project. There are two types of streams: - outflow exit, which represents cash outflows, underlying the investment costs - inflow of entry, which is the result of the investment. The value that balances with the outputs and translates into increased sales or represents a reduction of production costs, among others (Brealey & Myers, 1997).

For investment projects in renewable energy, wind energy onshore case, to determine the best project is necessary to consider the cash inflows or revenues uniform (which actually does not happen) during the lifetime of the project. For energy projects, the *SPB* must be calculated using the following equation (Fingersh, Hand, & Laxson, 2006):

$$SPB = \frac{ICC}{AAR} \quad \text{[yrs]} \qquad \text{Eqn (5.6)}$$

where *ICC = Initial Capital Cost* and *AAR = Average Annual Revenue based on hourly production.*

Importantly, this model assumes that the wind farm (project) will generate the same amount of electricity per year to the same sales price during the years of operation under review. As a result, this analysis assumes constant revenue stream. This method does not consider the discount rate or life of the project, so, the analysis of the Simple Payback is not dependent on these values. The SPB is often preferred as a measure of investment merit due to its simplicity. However, there are several other aspects of economic merit $\therefore$ These methods are discussed and compared below; the discussion is in relation to the needs of this particular study. There is a general discussion on the economic values of merit.

Before the occurrence of the *SPB*, the project has not recovered all the initial investment, or at least part of the capital invested is still at risk (if the project fails). The *SPB* has disadvantages that limit its use in business practice in renewable energy:

1. SPB ignores the value of economic resources over time. The positive net cash flows for subsequent periods are treated as if they were carried out at present. Future cash flows are as overweight which leads to SPBs too optimistic.
2. SPB ignores cash flows that occur after the recovery period. It may be that a project has shorter payback, but smaller NPV (Net Present Value) over the life of the entire project. Decide based solely on the SPB, the investor chooses the wrong alternative.

The *SPB* represents the length of time that it takes for an investment project to recover its own initial cost, from the cash receipts it generates $\therefore$ A shorter payback period means a desirable investment. In the case of implementation of a wind energy project, a negative payback period would be an indication that the annual costs incurred are higher than the annual savings produced (Rehman, 2005). For this situation it is necessary try to reduce the production cost by renegotiation with the wind farm`s suppliers. That is why *cost control* and *management accounting* stages as shown in Figure 5.1 is part of the evaluation process of RETs.

5.3.1.2 DISCOUNTED PAYBACK

The Discounted Payback (*DPB*) considers the value of capital over time by discounting net cash flows of each period before sum them and compare them with the initial investment. *BDP*, therefore, can be expressed by the following formula (Brealey & Myers, 1997):

$$\frac{(Ci-Co)_1}{(1+i)^1}+\frac{(Ci-Co)_2}{(1+i)^2}+.....+\frac{(Ci-Co)t}{(1+i)^t}=\Sigma\left(\frac{(Ci-Co)t}{(1+i)^t}\right) \geq Co_0 \qquad \text{[yrs]} \qquad \text{Eqn (5.7)}$$

where C_i = *Cash inflows*; C_o = *Cash outflows*; C_{o0} = *Initial Investment* and i = *Discount rate.*

When investment projects relate to renewable energy, e.g. wind energy power projects, to determine the time of return on investment of the project is necessary to consider the cash inflows or revenues uniform (which actually does not happen) during the period project life. For energy projects, the DPB should be calculated using the following equation (Fingersh et al., 2006):

$$DPB=\frac{ICC}{[AAR-(O\,\&\,M+LLC)]} \qquad \text{[yrs]} \qquad \text{Eqn (5.8)}$$

where *ICC = Initial Capital Cost; AAR = Average Annual Revenue based on hourly production; O&M = Operations and Maintenance cost* and *LLC = Land Lease Cost.*

As *DPB* is discounting the future cash flows (positive), this takes longer periods of recovery that the *SPB*. For any project will exceed the typical *SPB*. Linear interpolation can be used to determine the exact decimal value of *BDP*. According to Eqns 5.4 and 5.5. Unlike *PBS*, which is simplified, the *BDP* believes the discount rate (interest rate) and the fact that not always the expected flows are constant.

The electricity production project from renewable primary energy sources, wind energy project case highlights the importance given to the costs of operations and maintenance as well as lease cost of the land where the wind farm is deployed, if leased. Thus the analysis of investment risk is minimal considering the changing market. This method reveals some weaknesses among other models of investment appraisal. The main limitations of this method are:

1. It has total focus on the variable time, not worrying about possible cash flows after the payback time.
2. Does not discount cash flows properly, because it considers *"surplus"* of investment.
3. Determine the payback period is somewhat arbitrary, because the *DPB* can be expected to take interest or discount rates that are not practiced by the financial market.

For Bhandari (2009) in a project with normal or conventional cash flows the *DPB* is a unique number. The *DPB* based decision rule also provides an objective rule for decision making because accepting project if *DPB* is less than expected life of a project involves no subjectivity. In many instances the lifetime of a project itself is uncertain due to change in technology (case of repowering in wind power industry, consumer preference, competing products, regulatory environment etc.

5.3.1.3 NET PRESENT VALUE

The Net Present Value (*NPV*) is a method of economic evaluation of projects very well-known also. *NPV* takes into account the capital value over time. The value of capital in time refers to the fact that this value is now worth more than the present in time future. This is because an amount placed in time may be invested and getting a return above the rate of inflation. Therefore, future earnings should be discounted. *NPV* has become more widespread and accepted as a measure of financial performance of the project (Brealey & Myers, 1997).

NPV is the direct application of the concept of present value[61] and the difference of present value of cash inflows (inflows) between the present values of cash outflows (outflows). *NPV* is the sum of all discounted cash flows associated with the project. The general equation can be written as (Kaltschmitt et al., 2007):

$$NPV = (Ci_0 - Co_0) + \frac{(Ci_1 - Co_1)}{(1+i)} + .\frac{(Ci_2 - Co_2)}{(1+i)^2} + ... + \frac{(Ci_t - Co_t)}{(1+i)^T} = \Sigma\left(\frac{(Ci_t - Co_t)}{(1+i)^T}\right) \quad [\$M] \quad \text{Eqn (5.9)}$$

[61] It denotes the number of periods elapsing between now and when the payment occurs *i* denotes interest rate or discount period, then the general formula to discount future cash flow is given as: $K_0 = \frac{K_t}{(1+i)^1} = K_t \times (1+i)^{-t}$, and K_0 is called *"present value"* of future payment K_t. (Brealey & Myers, 1997)

where C_i = *Cash inflows*; C_o = *Cash outflows*; C_{o0} = *Initial Investment*, *i* = *Discount rate* and *T* = *Number of periods.*

When investment projects refer to wind projects, to determine the time for return on investment of the project is necessary to consider the entries of cash receipts as uniforms (which actually does not happen) during the lifetime of the project.

For energy projects, the *NPV* is defined as the present value of benefits less the present value of costs. The present value of costs is the cost of initial capital, *ICC*. It is assumed that the distribution of wind speed remains constant from year to year, resulting in uniform amount of electricity produced from year to year (Kaltschmitt et al., 2007). It is assumed that the annual revenue would be uniform. This uniform cash flow must be discounted, since it occurs in the future. The *NPV* of a uniform cash flow is given by Eqn 5.10.

$$NPV = AAR\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right] - ICC \qquad [\$M] \qquad \text{Eqn (5.10)}$$

where *AAR* = *Average Annual Revenue based on hourly production; i* = *Discount rate; N* = *Lifetime of wind farm* and *ICC* = *Initial Capital Cost.*

For independent projects, the investment decision occurs when *NPV* is greater than zero. If the investor decides between two mutually exclusive projects, then the project with higher *NPV* should be chosen. In optimization analysis, the choice is mutually exclusive. It is important to remember that, unlike the Simple Payback, the financial assumptions that count in determining the discount rate and lifetime for *NPV* of the investment can change engineering aspects of the wind farm under consideration.

Once the rotor diameter is the single parameter of the project to be variable, *AAR* and *ICC* can be generalized as functions of rotor diameter, *i* and *N* are chosen, the value of the term $\left[\frac{(1+i)^N - 1}{i(1+1)^N}\right]$ will remain constant and then Eqn 5.10 can be generalized as:

$$NPV = C \times AAR(D) - ICC(D) \qquad [\$M] \qquad \text{Eqn (5.11)}$$

Where *C* is a constant. The maximum NPV is found by differentiating Eqn 5.11 with respect to the rotor diameter, *D*, and equating to zero, as shown below.

$$\frac{dNPV}{dD} = C\frac{dAAR(D)}{dD} - \frac{dICC(D)}{dD} = 0 \qquad [\$M] \qquad \text{Eqn (5.12)}$$

Rearranging the Eqn 5.12, we have:

$$\frac{dNPV}{dD} = C\frac{dAAR(D)}{dD} - \frac{dICC(D)}{dD} = 0 \qquad [\$M] \qquad \text{Eqn (5.13)}$$

Eqn 5.13 shows that the constant, *C*, has no effect on the rotor diameter that maximizes the *NPV*. The financial assumptions that go into determining the discount rate and lifetime of the investment will change the optimal design of engineering of the wind farm.

NPV approach involves assigning a rate of return that is reasonable for, and specific to, the project and then computing the present value of the expected stream of payments. Since the investment is initially expended, it is counted as negative revenue. An appropriate rate of return must be identified (Khatib, 1996). The rate of return is a problem, mostly because of risk associated with the payoffs to the investment, but also because of the incentives of project managers to inflate the payoffs and minimize the costs to make the project look more attractive to upper management (Khatib, 2003).

NPV has disadvantages that may limit the use in the evaluation and management of projects in renewable energy, particularly in wind energy projects:

1. The need to know the actual capital cost of the project. As the interest rate that measures the cost of capital for an investment should include the risk of the project, the task of defining the real value of capital cost is not always easy to accomplish.
2. The discount rate or cost of capital remains unchanged throughout the period under review the project, which is not as fixed as well as the cost of capital depends on financial market behavior and risk of new developments in the analysis.
3. The type of response in money instead of being a percentage, for the assessment of monetary values incurs no assessment of the real purchasing power, if it were in percentage terms; it would make it easier to compare projects in different currencies.

5.3.1.4 INTERNAL RATE OF RETURN

The method of Internal Rate of Return (*IRR*) is to calculate the rate that cancels the net present value of cash flow in investment analysis. Investment which will be attractive internal rate of return is greater than or equal to the rate expected by the investor attractiveness. In comparison of investment, the best is one that has the highest internal rate of return (Kreith & West, 1997).

According to Newnan and Lavelle (1998) the rate is not easily calculated, since it must be determined by *trial and error* or the *least squares method*. We try to rate a likely value and thereafter to make successive approximations. The level of precision in the result of IRR is 0.01%, and should be obtained for a maximum of 10 000 interactions. As the calculations of present value, IRR is used to bring the current date all the cash flows of the project, according to Eqn 5.14.

$$NPV = \sum \left(\frac{(Ci_t - Co_t)}{(1+i)^t} \right) = 0 \Rightarrow i = ? = IRR \qquad [\%] \qquad \text{Eqn (5.14)}$$

where C_{it} = *Cash inflows in period t;* C_{ot} = *Cash outflows in period t; i = Discount rate* and t = *Number of periods.*

In most cases, this equation is a polynomial of degree t that cannot be solved in closed form. Instead, different types of successive approximation should be applied to solve i. The software (MS Excel and RETScreen) offer this functionality as a modern tool inserted in their functions.

IRR is expressed as a percentage (*"return"*) and is easily interpreted as *"return of a project"*. The *IRR* represents the maximum rate of interest that i can still take the project to create the NPV equals zero. If *NPV* is zero means that the project finances the capital invested, plus interest, an *IRR* of 10% means that the project could re-finance the capital invested, plus interest at a maximum of 10% of this capital. At any rate above 10%, the same project creates surplus value (*NPV*> 0) for the investor. At any interest rate below 10%, the project would not be able to refinance the capital invested and pay interest. The investor would have to add extra capital to pay the amount invested, plus interest, and thus reduces your assets. Only 10% would be indifferent to the investor, and neither gain nor loses from the project (Dixit & Pindyck, 1995).

IRR is the discount rate that sets the *NPV* equal to zero (Newnan & Lavelle, 1998). *IRR* of a wind energy project, with uniform revenue is found by solving the equation for the *IRR*. The project *IRR* is greater chosen as best. If *IRR* is maximized, the financial assumptions required to determine the duration of the project, *N*, have no effect on the ideal project. Maximize *IRR* result in the same design when *SPB* is minimized. This is shown below (Kaltschmitt et al., 2007).

$$NPV = AAR\left[\frac{(1+IRR)^N - 1}{IRR(1+IRR)^N}\right] - ICC = 0 \qquad [\%] \qquad \text{Eqn (5.15)}$$

where *AAR = Average Annual Revenue based on hourly production; N = Lifetime of wind farm* and *ICC = Initial Capital Cost.*

The Eqn 5.15 can be rearranged to:

$$\left[\frac{(1+IRR)^N - 1}{IRR(1+IRR)^N}\right] = \frac{ICC}{AAR} = SPB \qquad [yrs] \qquad \text{Eqn (5.16)}$$

By increasing *IRR*, the left side of the Eqn 5.16 decreases for any *N* value. The relationship *ICC/AAR*, which is equivalent to *SPB*, it must also decrease with the increase in *IRR*. This proves that maximize the IRR have the same effect of minimizing *SPB*, no matter what is assumed for the lifetime of the project. Despite its intuitive nature, *IRR* has some drawbacks, therefore, must be applied with care:

1. Depending on the structure of cash flows of the project, a project can have more than one *IRR*. The equation to be solved generates multiple solutions (for example, depending on the value from the iterative approach). So, no clear decision can be made.
2. The IRR implicitly assumes that all cash flows can be reinvested at the *IRR*. *NPV* does not have this disadvantage, since it assumes that cash flows are reinvested in the *i* defined as the discount rate (which is the average cost of capital and represents a more realistic assumption for reinvestment).
3. *IRR* does not take into account the different sizes of investment. An alternative could provide an internal rate of return, but with a smaller initial investment. The absolute gain in wealth for the investor may still be more different with *IRR* that offers a slightly lower *IRR*. *NPV* does not have this limitation.

It is important to highlight that Certified Emission Reductions (CERs)[62] can impact directly on *IRR* results, due to extra revenues made by the wind power project. It is supposed to performance the *IRR* analysis with and without CERs impact.

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[62] According to Bode and Michaelowa (2003) the credited emission reductions are commodities that can be sold and thus provide additional revenues and increase the economic attractiveness of a REPs.

5.3.1.5 REQUIRED REVENUES

Required Revenues (*RR*) is the appropriate concept and applies only to regulated sectors (consumers and producers of electricity are regulated by specific taxes or burdens of government action). The REPs can fit into this profile, because the market power electrical distribution system in a certain region (for large wind farms), which access to the public grids is regulated by tariffs (Tahvanainen, 2010). The method *RR* is the analysis of total revenues (cash inflows), the project received from clients to compensate for all costs associated with the project during its lifetime (NREL, 1995).

$$RR = TLCC = \sum \left(\frac{Co_t}{(1+i)^t} \right) \quad [\$M] \qquad \text{Eqn (5.17)}$$

where *TLCC = Total Life-Cycle Cost;* C_{ot} *= Cash outflows in period t; i = Discount rate* and *t = Number of outflows periods.*

This comparison is not made with absolute (nominal), but with discounted values. The method determines the level annual returns required to cover the cost of the entire project (with discount) (Finnerty, 2007):

$$LevelizedRR = TLCC \times UCRF = \sum \frac{Co_t}{(1+i)^t} \times \frac{i(1+i)^n}{(1+i)^n - 1} \quad [\$M] \qquad \text{Eqn (5.18)}$$

where *UCRF = Uniform Capital Recovery Factor* and *n = Number of periods.*

The *UCRF* converts the current value in the flow of equal annual payments over a specified period of time *t*, *i* the rate specified discount (interest). The Eqn 5.19 shows *UCRF* calculation, where *i = discount rate* and *t = number of periods in years*.

$$UCRF = \left[\frac{i(1+i)^t}{(1+i)^t - 1} \right] \quad [–] \quad \text{Eqn (5.19)}$$

The main purpose of economic regulation is to achieve competitive results in an environment where competition is (for various reasons) not feasible, case of wind power industry. Traditional tariff setting is based on RR that should allow a company to cover its expenses and have a reasonable rate of return on its invested capital (Lesser & Su, 2008).

This is an inverse measure: the lower level *RR* is the project more attractive because it can cover costs of the project (including interest), with lower revenues. When revenues are fixed (i.e., defined by the regulator), the investor or manager of the project (i.e., wind farm manager) will chose an alternative that can maximize the difference between *RR* level per unit of energy and administered prices per unit produced and marketed the electrical distribution network needed to ensure the smallest level of revenues required (Phung, 1980). *RR* has disadvantages that limit their application in the evaluation and management of projects in renewable energy, particularly in wind energy projects:

1. The capacity factor is considered constant throughout the life of the project. In wind energy projects this may fluctuate resulting in annual electricity production variable, so revenue and costs also vary.
2. The financial indicators considered over the life of the project (inflation, discount rate, taxes) also remain constant throughout the analysis period of life of the project.
3. Costs are projected to lifetime of the project, which makes the financial cycle equal to the operational cycle of investment, a fact that the classical rules of accounting does not always coincide.

5.3.1.6 BENEFIT-TO-COST RATIO

The Benefit-to-Cost Ratio (*BCR*) of a project is another application of the principle of the capital in time. BCR analyzes the discounted cash flows. Unlike the *NPV*, cash flows are positive (*"benefits"* of the project) and negative cash flows (cost of the project) are discounted and accumulated separately. The sum of the discounted cash flow positive is placed over the sum of all negative cash flows discounted (NREL, 1995):

if $$PV_{ci} = \sum \frac{Ci_t}{(1+i)^t} \quad [\$M] \quad \text{Eqn (5.20)}$$

and $$PV_{co} = \sum \frac{Co_t}{(1+i)^t} \quad [\$M] \qquad \text{Eqn (5.21)}$$

then, $$B/C = \sum \frac{\sum \frac{Ci_t}{(1+i)^t}}{\sum \frac{Co_t}{(1+i)^t}} \quad [–] \qquad \text{Eqn (5.22)}$$

where PV_{ci} = *Present Value of Cash Inflows* and PV_{co} = *Present Value of Cash Outflows.*

In order to better illustrate the application of this method, using a discount rate of 8% per year returns the discounted cash flow or updated, according to Table 5.5.

Table 5.5 Example of typical cash flow for BCR analysis

In "000 USD", interest rate = 8%/year	*Period (years)*				*Total*
	0	1	2	3	
Cash outflows (-)	-100,0	-30,0	-30,0	-30,0	
Cash inflows (+)	0,0	80,0	80,0	80,0	
Discounted cash outflows	-100	-27,8	-25,7	-23,8	-177,3
Discounted cash inflows	0,0	74,1	68,6	63,5	206,2

Source: NREL (1995)

BCR analysis is 206.2/177.3 = 1.16. Each currency (at current values) generates returns of 1.16 currency units (at current values). The relation B/C above 1 represents attractive investment options in absolute terms$\therefore$*BCR* analysis is not a useful measure to compare mutually exclusive alternatives; since the ratio does not measure the relative attractiveness can be misleading the decision maker. Not necessarily lead to the same result when assessing the attractiveness of a project because the *NPV* is not a widely used measure.

BCR analysis is the ratio of current value of the sum of benefits divided by present value of the sum of costs. It is used as a selection criterion for all eligible projects that have independent cost-benefit ratio, calculated the relevant discount rate (opportunity cost of capital) equal to or greater than unity. Cannot be used to choose between mutually exclusive alternatives (Boardman, Greenberg, Vining, & Weimer, 1996).

BCR compares benefits to costs and is a dimensionless number that indicates how many money of benefit are returned per monetary unit invested beyond the required rate of return expressed by the discount rate. It is computed by dividing total discounted benefits by total discounted costs. A ratio greater than one means that benefits exceed costs. A ratio of 10 to 1, for example, means that, on average, $10 in benefits are produced for every monetary unity of costs incurred, after adjusting for the time-value of money. (Generally, investment costs for the denominator and other costs are deducted from benefits in the numerator) (Prasad & Bansal, 2011).

BCR has disadvantages that limit its application in the evaluation and management of projects in renewable energy, particularly in wind energy projects:

1. The main disadvantage of ratings based on *BCR* is that ignoring non-monetary impacts. Attempts were made to mitigate these limitations through a combination of *BCR* with information regarding these impacts are not likely to denomination, as the approach proposed by the New Approach to Appraisal, used in the UK[63].
2. Another difficulty refers to the *BCR* precise definition of benefits and costs, due to variability in the criteria for more realistic analysis is required a distinction between perfect and total operating costs and investment.
3. The pre-operational wind energy project, (studies, construction and equipment installation, testing and technical adjustments) and the fact considers the costs of O&M constant over the lifetime of the project makes the phase of exploration / production project is different from the life of the project. This interferes with the production time and consequently the entrances and exits of cash flow, which makes the analysis imprecise *BCR* in terms of monetary values.

There are many other microeconomic methods for measuring investment in REPs derived from the ones studied on this chapter, such as Life-Cycle Cost (*LCC*), Net Benefits (*NB*) or Net Savings (*NS*), Savings-to-Investment Ratio (*SIR*), Overall Rate-of-Return (*OOR*). The variety of methods to evaluate the economic performance of (renewable) energy systems serves as a "*tool*" to be chosen by the analyst. A good start point for the evaluation process is to define the problem and the objective of the evaluation (Kreith & West, 1997).

For Ramakumar, Butler, Rodriguez, and Venkata (1993) economic considerations are among the primary factors that influence the evolution of energy systems. Unless the *"cost of energy"* obtained using a particular technology is competitive with the alternatives, that technology will not be viable. However, the *"cost"* considerations should be comprehensive and should include prospecting, collection, conversion, transportation, distribution, storage and reconversion, end use, and the management of power system analyzed.

[63] For further information, see on www.environment-agency.gov.uk.

5.3.2 PECULIARITIES IN THE INVESTMENT ANALYSIS OF WIND ENERGY PROJECTS

The investment analysis can be considered as a set of techniques that allow the comparison between the results of making decisions regarding the different alternatives in a scientific manner. In this comparison, the differences that mark the alternatives should be expressed in quantitative terms. To express in quantitative terms the differences between the alternatives for decision-making uses economic engineering principles.

IRR and *NPV* based on the same principles of equity capital[64] and lead to the same decision. The key difference among the two techniques is that the *NPV* assumes reinvestment at the same cost of capital (discount rate), while the IRR assumes reinvestment will be the actual internal rate of return of the project.

In the case of wind energy projects *NPV* is a function of *AAR* and the *ICC*. As a result, to maximize *NPV* also maximizes the absolute wealth created by investment. Because of this, *NPV* is biased toward larger investments. While on return is greater than the discount rate. The analysis of the *NPV* will push the decision to bigger projects, even if the relative profitability is smaller.

The *SPB*, *DPB* and *IRR* are functions of *ICC/AAR*. Minimizing *ICC/AAR* will maximize the wealth of the equity invested. For the optimization of wind farm, should be determined to maximize the wealth obtained from the absolute wind farm or to maximize the relative wealth produced by the project. As the wind turbine is modular, it is more convenient to choose the size of the rotor, which maximizes the relative ability of the wind turbine to generate wealth $\therefore$In case you decide to minimize the *SPB* because of the method is simpler as shown before, to minimize *SPB* will result in the same optimal design to maximize the *IRR*. An example is when you want to maximize absolute wealth would be if the land available for development of wind farms were limited. In this case, the absolute wealth produced by the wind farm can be maximized by selecting a turbine capable of producing greater.

It is worth being aware of some of the other methods of investment analysis and expresses a wind power project in economic terms. The preferred indicator depends on the exact nature of the project being evaluated, the cash flow profiles and the requirements of the investment analysis to be done (Boyle, 1997). These methods and techniques can be used to decide whether or not to invest in a given wind farm; to determine which system design or size is economically efficient; find the combination of components and systems that are expected to be cost-effective; to estimate how long before a project will break even; and to decide which WECS-related investments are likely to provide the highest rate of return to the investor.

[64] The principle of equity capital is the financial situation at that given rate of return of capital or update makes a series of future values, regardless of their nominal values and terms, when the current values are equal. Thus, to effect any transactions involving securities held in the future you need to know how much currently worth, or what are the current values (Damodaran, 2001)

5.4. MODELS FOR COSTS EVALUATION

5.4.1 SPECIFIC MEASURES OF ECONOMIC PERFORMANCE FOR ENERGY PROJECTS

The costs levelized (or revenue → revenues levelized) is a technique to compare investment alternatives (such as REPs), involving different amounts of capital (i.e., different sizes) and/or different time periods with different life-cycles. Applying *NPV* method is done implicitly on assumptions necessary reinvestment in REPs. These implicit assumptions can be avoided by smoothing of cash flows: even involves the calculation of steady cash flow, net present value (*NPV*) is equal to a given cash flow variable (NWCC, 1997). Suppose that two investment alternatives for REPs have the following net cash flow per period, as shown in Table 5.6.

Table 5.6 Example of net cash flow for economic performance in energy projects (NPV method)

Cash Flows	*Period (years)*						NPV_{years}
	0	1	2	3	4	5	
Alternative 1							
Net Cash Flow	-100	20	40	30	50	10	14,1
Alternative 2							
Net Cash Flow	-50	20	25	30	-	-	11,4

Source: NREL (1995)

The alternative 1 implies a higher initial investment (capital requirements) and provides higher absolute return than alternative 2. Alternative 2 has only a small initial investment, but also shorter lifetime (3 versus 5 years). It is difficult to make a direct comparison between the two projects. In calculating *NPV* of the project (with a discount rate of 10%) results in *NPV* = 14.1 for an alternative 1 and *NPV* = 11.4 to alternative 2. For *NPV* rule suggests that an alternative 1 is chosen. The levelizing of cash flows (net) is to find a constant amount g during the life of the project *NPV* with this flow in equal amounts g to become equal to *NPV* of the original project, as shown in Figure 5.3.

Carrying out a *NPV* analysis essentially requires two things. First, investment and revenues must be estimated. This is a challenge, especially for new products where there is no direct way of estimating demand, or with uncertain outcomes like wind power projects. Second, an appropriate rate of return must be identified∴The rate of return is a problem, mostly because of risk associated with the payoffs to the investment, but also because of the incentives of project managers to inflate the payoffs and minimize the costs to make the project look more attractive to upper management (Salles, Melo, & Legey, 2004).

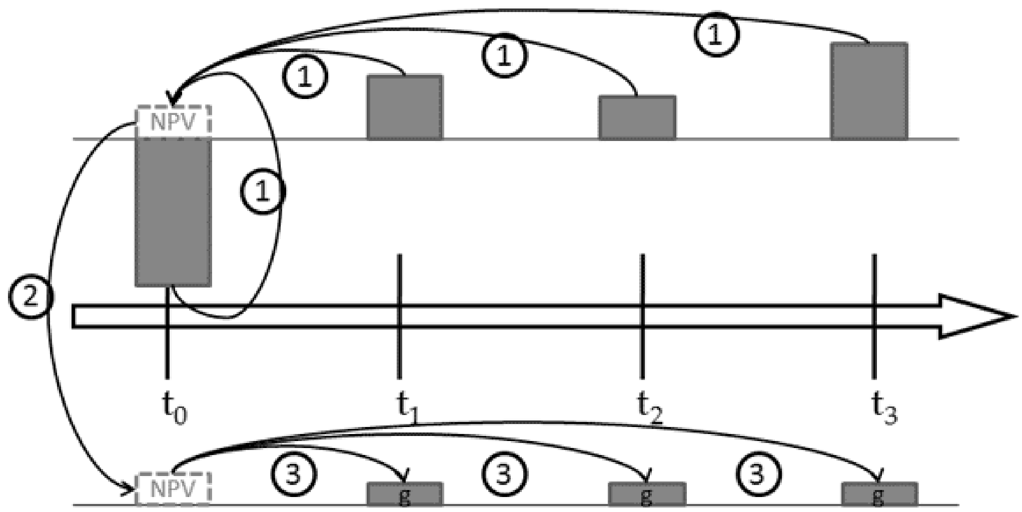

Figure 5.3 Scheme of the cash flows levelizing process for REPs. Source: IEA (1991)

This amount g (also called *"annuity"*) is calculated using the Eqn 5.23 below:

$$g = NPV \times UCRF = NPV \times \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \quad [-] \qquad \text{Eqn (5.23)}$$

The Uniform Capital Recovery Factor (*UCRF*), is the factor by which *NPV* must be multiplied to reach the constant value *g* given discount rate *i* for a series of *n* periods. In the example in Table 5.6, the alternative creates an annuity of 3.73 (in monetary units). The five cash inflows of 3.73 are equal to a *NPV* of 14.1, exactly equal to *NPV* of cash flows of the project plan (including initial investment). Alternative 2 generates annuity of 4.58 (in monetary units). By comparing the potential of their projects to generate stable cash flows, the alternative 2 should be higher than the alternative 1.

Annuities are not specific to REPs. The concept *LCOE* is used to compare the different alternatives of energy production. Revenues are fixed and equal between these alternatives (e.g., because the price is set by the regulator and does not depend on the technology used to generate energy, then the alternatives differ only in their costs (cash flows of revenues are equal to all alternatives) (NREL, 1995).

The above concept is applied only to cash outflows (costs). The sum of all costs involved in the project during its full life cycle — Total Life Cycle Cost (*TLCC*) are discounted to present value and converted into a stream of equal cash outflows for each year of the project *("annuity* *negative"*). If the value is divided by the annual amount of energy produced, the result is called the *Levelized Cost of Energy* (*LCOE*). *LCOE* is assigned each unit of energy produced (or saved) by the project during the analysis period is equal to the *TLCC* when discounted to the base year (period 0). *LCOE* can be used to rank different alternatives for production (or consumption) of energy, as shown in Figure 5.4.

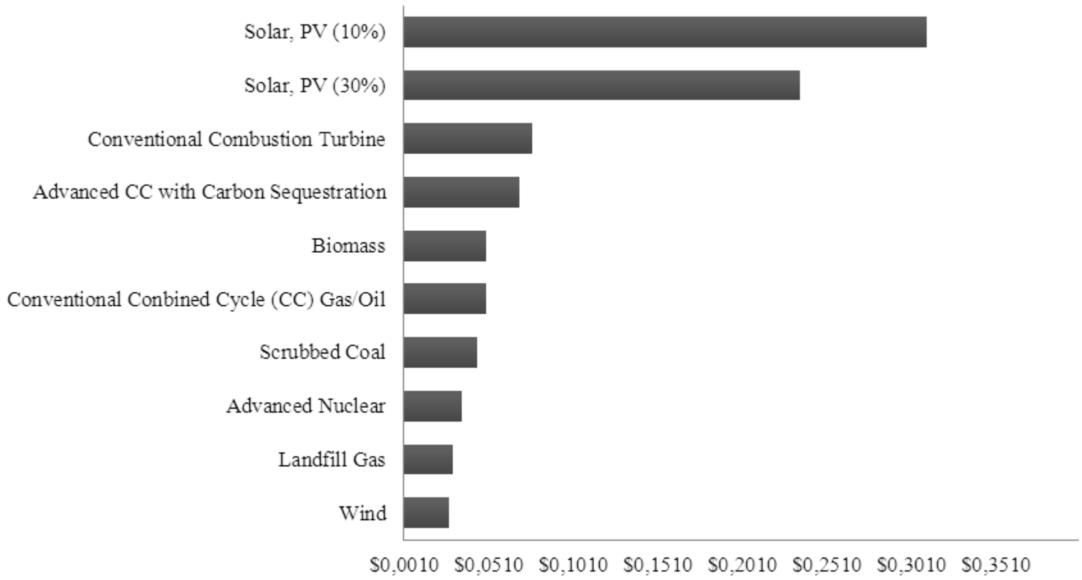

Figure 5.4 Values in $/kWh LCOE in 2005 for various conventional and renewable technologies. Source: NREL (1995)

5.4.1.1 LEVELIZED COST OF ENERGY

The Levelized Cost of Energy (*LCOE*) is the real cost of production of kilowatt-hours (kWh) of electricity. This measure includes the total construction phase costs, central production costs of the power station during its economic lifetime, financing costs, return on capital and depreciation. Costs are levelized in current monetary values, or adjusted to eliminate the impact of inflation (Friedman, 2010).

LCOE is what it would cost the owner of the facility to generate one kWh of energy. Most of the wind power projects have a lifetime for 20-25 years, a long period, so the inflation impact can sufficiently change and economic evaluation of the same project, which is why to take into consideration the inflation during the lifetime of the project (Sevilgen, Erdem, Akkaya, & Dağdaş, 2005). For electricity production, *LCOE* is a method to compare renewable energy technologies adopted to generate electricity. The model *LCOE* most known and used in energy projects by the *National Renewable Energy Laboratory* (Cohen, 1989). The calculation method is defined below.

$$LCOE = \frac{FCR \times ICC + LRC}{AEP_{net}} + O\&M + PTC \qquad [\$/kWh] \qquad \text{Eqn (5.24)}$$

where *FCR = Fixed Charge Rate; ICC = Initial Capital Cost; LRC = Levelized Replacement Cost; O&M = Operations and Maintenance; PTC = Production Tax Credit* and AEP_{net} = *Net Annual Energy Production.*

The calculation of *LRC* can be accomplished with the Eqn 5.25, where *MR = Machine Rating* (NREL, 1995).

$$LRC = \frac{\$}{kW} MR \qquad [\$/kW] \qquad \text{Eqn (5.25)}$$

For correct analysis of the levelized cost of energy, the net annual energy production of the wind farm is given by Eqn 5.26. The *availability* is defined as the ratio of hours the wind system is capable of producing energy relative to the number of hours during the study period and losses represent loss of matrix, dirt on the blades and ice formation, the central production downtime for maintenance and miscellaneous system losses in production and distribution of energy to the electric grid (RETScreen® International Clean Energy Decision Support Centre, 2008).

$$AEP_{net} = AEP_{gross} \times \text{Availability} \times (1 - losses) \qquad [kWh] \qquad \text{Eqn (5.26)}$$

where AEP_{gross} = *Gross Annual Energy Production.*

LCOE was adopted by the United States Department of Energy in the Low Speed Wind Turbine Program (LWST) and makes reasonable approximation of the Cost of Energy (*COE*), which is estimated by the potential investor to consider the reliability of the equipment to determine *AEP*, *O&M* and *LRC*. *AEP* is affected by the availability of equipment due to the shutdown of wind turbines due to scheduled and unscheduled maintenance. The costs of *O&M* consist of programmed costs (preventive) and costs unscheduled (repair) maintenance, including costs for replacement parts, supplies, manpower, leases (royalties) of land, among other expenses arising from the operation of a wind farm.

Fixed Charge Rate

The capital cost component of *COE* is determined by the spread of installed capital cost over the lifetime of the project done in a linear basis over the years through *FCR*. *FCR* is a percentage of the cost of installed capital costs including debt service (financing costs) allocated to each year of the project (for more analytical detailed, see Tegen et al. (2012)). The component of the cost of capital is analogous to a payment of fixed rate mortgage of a house, or fixed amount per pay period during the term of the debt. The analysis period may be the life of a physical plant for the production or lifetime for accounting purposes. The lifetime of a wind farm ranges from 20 to 30 years, while lifetime used for financial accounting purposes may be smaller (Harper, Karcher, & Bolinger, 2007; NREL, 1995). *FCR* is the annual value for each monetary unit of initial capital cost needed to fully cover the initial capital cost, return on equity and debt, and other overheads. The fee is charged from a hypothetical project, spread over cash flow. The current base model, *FCR* must include funding for construction, financing rates, return on equity and debt, amortization of equipment and facilities, tax revenue and profits all on an annual basis (Cohen, 1989).

Initial Capital Cost

The Initial Capital Cost (*ICC*) is the sum of the cost of wind power system and the cost structure of the wind farm. Not included is cost of financing the construction or financing rates, as they are calculated and added separately through *FCR*. Nor does it include the costs of the reserve fund for debt service (charges for financing costs). This cost measure includes all the planning, equipment acquisition, construction and installation costs of the wind system, leaving the wind farm ready to operate. This cost includes wind turbine towers and delivered and installed on site along with all maintenance, electrical system and other infrastructure support. For a wind farm, the cost of installed capital should include the system of collection of electricity which extends from each wind turbine to the substation and point of interconnection with the grid. Depending on the policy and practice of grid administrator and distributor, the electrical system may or may not be included in the cost of capital (NREL, 1995). *ICC* includes costs for buildings to support the operation and maintenance, the initial stock of spare parts and maintenance of diagnostic equipment. Other costs should be included as costs of pre-construction planning, including assessment and analysis of wind resources, surveying, and consultancy for obtaining financing. The installed capital cost of a wind farm includes the following elements (NWCC, 1997):

1. Assessment and analysis of wind resources;
2. Construction of service roads;
3. Construction of foundations for wind turbines, infrastructure to mount transformers and substations;
4. Purchase of wind turbines and towers with local delivery and installation;
5. Construction and installation of wind sensors, able to communicate wind turbine units for controls;
6. Construction of the power reception system, including wiring of each wind turbine for the mounting of the transformer and deck mount transformers for the substation;

7. Construction of facilities needed for operations and maintenance during the regular operation of the wind farm;
8. Construction and installation of the communication system of wind farms to support the command and control data flow from each wind turbine to a central facility operations;
9. Integration and verification of all systems for proper operation of the wind farm;
10. Commissioning for wind farm period of decommissioning.

Levelized Replacement Cost

The *Levelized Replacement Cost* (*LRC*) is a cost component used as a saving account for the wind power project. Depending on the details of the project, the major review of the wind turbine occurs every 5, 10 or 15 years. The review focuses on the large gears, bearings, seals and other moving parts. Usually the nacelle and its machinery are removed from the tower and transported to the plant maintenance garage of the wind farm. Often, removal of the nacelle and equipment is replaced immediately by all already rebuilt (NREL, 1995). The replacement of the blades of wind turbines is an example of this category of frequent replacement of subsystems. Since these costs occur at intervals of several years and infrequent during each year, correct accounting for these costs requires annual exercise of funds (working capital). The aim is to make funds available when needed to repair or total replacement of occurrence. The exercise involves calculating the net present value or even to allocate costs for review and replacement on an annualized basis consistent with other cost elements (NWCC, 1997).

Operations and Maintenance Cost

The costs of *Operations and Maintenance* (*O&M*) include costs normally associated with recurrent routine operation of the plant installed. *O&M* costs do not include overtime worked or infrequently, such as major repairs of wind turbines and other systems. These costs are included in the cost component *LRC*. Most of *O&M* costs is associated with maintenance and generally grouped into three categories (Christopher, 2003):

1. Cost of unscheduled visits, but statistically predictable, routine maintenance visits to troubleshoot the operation of wind turbines;
2. Scheduled preventive maintenance costs for wind turbines and energy collection system;
3. Costs of major repairs and replacements scheduled subsystems of wind turbines.

The first two costs occur during the course of a year in operation and are included in the cost component of *O&M*. The third occurs at intervals of 5, 10 or 15 years and involves financial year over the next few years, therefore, is included in the cost component *LRC*. The purpose of preventive maintenance is to replace components and reform systems that have finite lifetime, generally smaller than the projected life of the turbine. Tasks include periodic inspections of equipment, lubricating oil and filter changes, calibration and adjustment of sensors and controllers, replacement of consumables such as brake pads. The cleaning of the blades in general, fits into this category. The specific tasks and frequency are usually explicitly defined in the maintenance manuals provided by the manufacturer of the turbine. The costs associated with planned maintenance can be estimated with reasonable accuracy, but may vary according to labor costs location, location and accessibility. The scheduled maintenance costs also depend on the type and cost of consumables used (IEA, 2005). The unscheduled maintenance should be anticipated in any proposed wind energy production. Commercial wind turbines contain a variety of complex systems that must function correctly for the turbine work and get best possible performance. Failure or malfunction of the smaller component (subsystem), it often shuts down the turbine and require the attention of maintenance professionals. Unplanned costs can be separated into direct and indirect costs. Direct costs associated with labor and equipment needed for repair or replacement and consumables used in the process. The result of the indirect costs associated with the revenue lost due to stop the turbine. Depending on the details of ownership and location of the wind farm, there may also be costs associated with negotiating land use agreements, contracts, power purchase agreements and access to transmission and distribution of energy produced (Blanco, 2009). Besides the cost of operations and maintenance, spare parts and other maintenance items in the cost element of O&M may also include:

1. Taxes on property where the wind farm operates;
2. Payment of land use;
3. Miscellaneous insurance;
4. Access to transmission and distribution rates;
5. Management fees and general and administrative expenses.

The values of cost of operations vary with the situation. The tax structure is where the wind farm contract, land use, insurance rates and other fees vary from location to location and installation of wind farms to another. In comparison to maintenance costs, operating costs are typically very small relative to the cost of production of a central power production (Christopher, 2003).

Production Tax Credit

The *Production Tax Credit* (*PTC*) is a type of public incentive, usually granted by the Governments for the renewable energy sector. This incentive is offered in the form of tax credits for producing energy for a certain period of operation of the central production of energy. *PTC* is adjusted for inflation rate prevailing in the country concerned, within 10 to 15 years, falling on each MWh of renewable energy produced and sold to the distribution grid. For the production of wind power in Portugal, *Decree-Law No. 33-A/2005*[65] stipulates that farms that have already obtained permission to establish the date of entry into force of the law or they may obtain the license for establishment within one year after the entry into force, maintaining the current tariff of 88.20€/MWh from 2005, progressing at the rate of inflation, for a period of 15 years from the date of entry into force of that legislation. At the end of this period, the rate will converge to market price plus the premium for the sale of green certificates.

[65] Available in http://www.edpdistribuicao.pt/pt/produtor/renovaveis/EDP%20Documents/DL33A-2005.pdf.

The cost of energy produced by a wind farm represents an indicator for economic efficiency of the wind power plant. The LCOE/NREL methodology is assumed as one of the most complete ways to calculate and compare the monetary production cost by renewable energy technologies. The levelized cost of electricity (*LCOE*) is one of the most important indicators for evaluating fiscal performance of power supply systems such as WECS. *LCOE* is a technique applied by the techno-commercial analysts to calculate the unit cost throughout the economic life of the project. The levelized cost for WECS can be describe as the ratio of the total annualized cost of the WECS to the annual electricity produced by the system.

According to Roth and Ambs (2004, p. 2127) *LCOE* can be interpreted as *''a constant level of revenue necessary each year to recover all expenses over the life of a power plant''.* So it is useful for wind power plant management and economic evaluation process. We must remember that wind power plant is a non-conventional industrial unit, in case of production output, it only can be expected not programmable, it means, the level of revenues is function of the production and sales levels. The capacity factor of the power plant will vary during the project´s lifetime.

The calculation of *LCOE* provides a common way to compare the cost of energy across renewable technologies because it takes into account the installed system costs and other associated costs such as financing, land, insurance, transmission, operation and maintenance, and depreciation, among other expenses. Carbon emission costs and wind farm efficiency can also be taken into account.

The Levelized Cost of Energy method has drawbacks that limit its application in the assessment and management of projects in renewable energy, particularly in wind energy projects:

1. The technical and economic parameters directly impact the method *LCOE* and should be carefully considered in the analysis of the final cost of energy produced. The dramatic reductions in *LCOE* occur when the wind farm wind resource is above average, or when we obtain improvements in capacity factor. This suggests that the increase in capacity factor from values below the levels of average capacity factor can lead mainly to large reductions in *LCOE* (Cory & Schwabe, 2009).
2. *LRC* that matches the costs for equipment replacement in the long term, it has been reported to be increasingly significant component to the annual cost of wind power and if it is overvalued, can inflate the cost of energy currently produced. The technological improvement in wind power can make the cost of capital is smaller in the coming years.
3. *LCOE* is a methodology for determining and analyzing the cost of energy production restricted to certain period of time. The fact that the analysis is for one year of production (a single unit of time) ignores gains economies of scale throughout the project life.

We can see one difficulty in evaluation of the cost of wind power — the average cost depends on the scale, and can vary greatly, and the marginal cost is very low. Presumably we want to compare average costs, and for this we need a sense of scale. The usual cost measure in the power industry is *LCOE*. This is defined as the constant cost at which electricity would have to be sold for the production facility to break even over its lifetime, assuming that it operates at certain capacity factor.

5.4.1.2 TOTAL LIFE-CYCLE COST

The evaluation method Total Life-Cycle Cost (*TLCC*) method is derived from *NPV*, as it takes into account only items of costs (cash outflows). *TLCC* evaluates the differences in cost (and time of occurrence of costs) between project alternatives over the life cycle. Cash outflows associated with the project (alternatives) are evaluated for each period and are then discounted to present value using a discount rate as defined in *NPV* approach (Kreith & West, 1997). *TLCC* calculate the present value of all cash outflows (cost items), but no cash inflows (revenues). This only makes sense if:

1. There is no revenue produced by the project (Note that the cost saved are recorded as revenue) or,
2. Revenues are independent of the investment decision (e.g., because revenues are fixed, no matter what the investment decision is chosen).

The analysis may focus only on cash outflows. Soon *TLCC* takes no account of the project incomes, which makes this indicator not adequate to evaluate absolute attractiveness of an investment alternative. It can be used to evaluate the relative attractiveness of alternative investments when considering the cost per unit of output as a factor of choice. By definition, the calculation of *TLCC* is defined by the following Eqn 5.27 (Cory & Schwabe, 2009):

$$TLCC = \frac{Co_1}{(1+i)} + .\frac{Co_2}{(1+i)^2} + ... + \frac{Co_t}{(1+i)^t} = \sum\left(\frac{Co_t}{(1+i)^t}\right) \quad [\$M] \qquad \text{Eqn (5.27)}$$

where C_{ot} = *Cash outflows in period t; i = Discount rate* and *t = Number of periods.*

According to Lu et al. (2010) life cycle cost estimate of power system planning, provides a new idea and effective way to enhance the cost management business for the enterprises. However, it is worth noting that the accuracy of *LCC* model is dependent on the data for calculation and the uncertainties. *TLCC* is a derivation of *LCC* and have to be distinguishing as well as possible. For Asiedu and Gu (1998) it is necessary separate the cost of the production components and the production cost of a plant. These are different things, in the case of the wind power plants the costs of machines and other facilities/equipment are summer up into Initial Capital Costs (*ICC*), described in sub-section 5.4.1.1. The rest of the costs (operation and maintenance, financial, taxes, interests, etc.) are incorporated into *FCR*, *LLC* and *O&M*, as follow as LCOE/NREL methodology.

LCC is an economic method to get the whole cost of production. It is a special approach that examines all the parts of the cost. It is used to produce a spend profile of the goods or service over its all lifetime. The results of *LCC* analysis are used to help managers in the decision-making process. *LCC* analysis sees projects further into the future. It is very valuable as a comparative tool when long term investment in some goods is considered (Lee, An, Cha, & Hur, 2010).

For Woodward (1997) the costs can be classified or considered into different categories during the lifetime of a project. These costs can be divided into the three categories of: *engineering and development*; *production and implementation*; and *operation* (see Figure 5.5).

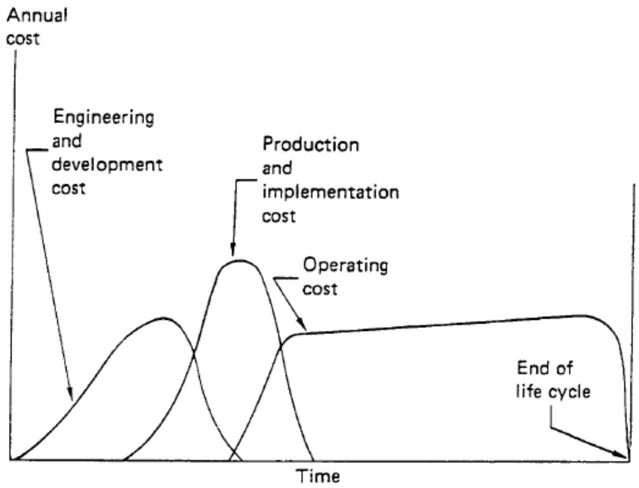

Figure 5.5 Cost categorization during the phases of LCC. Source: Woodward (1997)

We have to pay attention to the external factors for a better economic evaluation of wind farm which mainly include electricity price, taxes, repayment load and time of wind power plant. All these factors can influence directly on the cost of the wind power project (Tai & Wen-rui, 2009).

TLCC has disadvantages that limit its application in assessing and managing projects in wind energy projects:

1. The need to know the actual capital cost of the project. As the interest rate that measures the cost of capital for an investment should include the risk of the project, the task of defining the real value of capital cost is not always easy to accomplish.
2. The failure to consider the project's revenues, there is interference by the revenue costs, because there are costs that are directly influenced by income, as is the case of taxes on income in energy projects that may or may not be supported by incentive programs governments on renewable energy.
3. Costs are projected for the life of the project, which makes the financial cycle equal to the operating cycle of the investment, which by classical rules of accounting does not always match.

5.4.1.3 NET PRESENT COST

The Net Present Cost (*NPC*) of a REP is the sum of the current value of all costs during the project's interest period (generally considered its lifetime), including residual values[66] as costs. The net present cost of a project is the sum of all cost components, including (Blackler & Iqbal, 2006):

1. The investment of capital or initial capital cost;
2. O&M costs, excluding fuel (in case of wind);
3. Costs of major replacements;
4. Energy costs (fuel costs, including other associated costs);
5. Any other costs such as fees and legal fees, among others.

If a series of projects or investment options are being considered, the lowest net present cost will be the best option. By definition, the formula for calculating *NPC* is defined as Eqn 5.28 (George & Schweizer, 2008; NREL, 1995):

$$NPC = \frac{Co_1}{(1+i)} + .\frac{Co_2}{(1+i)^2} + ... + \frac{Co_t}{(1+i)^t} + \frac{D_v}{(1+i)^N} = \Sigma\left(\frac{Co_t}{(1+i)^t} + \frac{D_v}{(1+i)^N}\right) \quad [\$M] \qquad \text{Eqn (5.28)}$$

where C_{ot} = *Cash outflows in period t; i = Discount rate; t = Number of periods of outflows; N = Lifetime of wind farm* and D_v = *disinvestment value.*

NPC is one of the principal economic indicators for the cost-benefit analysis. All quantities and costs are expressed as present worth cost. There are many ways to calculate the economic cost of production, distribution of renewable energy and/or efficiency projects. The capital and replacement costs, the operation and maintenance costs must be combined in some manner so that a comparison may be made with the costs of not doing the project (Hakimi & Moghaddas-Tafreshi, 2009).

We must highlight the conception of "*costs*" considered for this method. It is the *private* conception, but there are other conceptions that we could include in this method, such as *environmental* and *social* costs. Costs of industrial activity are always included in the price paid by the consumers and the unpaid costs also called *"external environmental and costs"* (Frangopoulos & Caralis, 1997).

[66] It is understood by residual values, the difference between the book value of the commercial value of a fixed asset after the project lifetime. (Newnan & Lavelle, 1998)

For Dekker, Nthontho, Chowdhury, and Chowdhury (2012) *NPC* can be calculated within HOMER[67] using Eqn 5.29:

$$NPC(\$)=\frac{TAC}{CRF} \qquad [\$M] \qquad \text{Eqn (5.29)}$$

where *TAC* = total annualized cost (which is the sum of all annualized costs of each system component). The *Capital Recovery Factor* (*CRF*) is the same *Uniform Capital Recovery Factor* (*UCRF*), so is given by Eqn 5.19, already described.

It is assumed that all prices escalate at the same rate, and uses *"annual real interest rate"* rather than the *"nominal interest rate"*, which makes the inflation effect be factored out of the analysis. That is a way to reduce to performance and economic analysis within the most real values as possible.

It is also important to explain the difference between *price* and *cost*. The price includes all costs and *expected return* by investor or producer. The *cost* only includes the outflows (expenses) related to the product/service production/supply (Tai & Wen-rui, 2009).

NPC has disadvantages that limit their application in the evaluation and management of wind energy projects:

1. The discount rate or cost of capital remains unchanged throughout the period under review the project because the cost of capital depends on the behavior of the risk of the activity that tends to be decreasing with the years of operation and technological maturity.
2. The financial indicators considered over the life of the project (inflation, discount rate, insurance, taxes, among others) also remain constant throughout the period analyzed what makes the NPC not to be influenced by the uncertainties of the economic scenario where the projects are inserted.
3. The fact of considering the value of disinvestment, especially for wind energy projects, because it is capital intensive project, makes the value of the divestment is high compared to other renewable technologies. In the case of wind energy projects return higher net present cost.

[67] HOMER is a software developed by NREL that simplifies the task of designing distributed generation (DG) systems - both on and off-grid. HOMER's optimization and sensitivity analysis algorithms allow to evaluate the economic and technical feasibility of a large number of renewable energy technologies options and to account for variations in technology costs and energy resource availability. For more details, please check on https://analysis.nrel.gov/homer.

5.4.1.4 LEVELIZED ELECTRICITY PRODUCTION COST

The *Levelized Electricity Production Cost* (*LEPC*) per kW is the proportion of the total cost over the lifetime of the project from anticipated results expressed in equivalent terms by the current value. This cost is equivalent to the average cost being paid by consumers to cover production costs included capital costs, operations and maintenance, fuel, rate of return equivalent to the discount rate. The Eqn 5.30 is used for calculating *LEPC* for one unit of electricity production is defined by IEA (1991):

$$LEPC = \frac{\sum\left[\left(I_t + M_t + F_f\right)\left(1+r\right)^{-t}\right]}{\sum\left[AAR\left(1+r\right)^{-t}\right]} \quad \text{[\$/kWh]} \qquad \text{Eqn (5.30)}$$

where I_t = *Investment expenditures in the year t;* M_t = *Operations and maintenance expenditures in the year t;* F_t = *Fuel expenditures in the year t; AAR = Average Annual Revenue based on hourly production and r = Discount rate; t = Number of outflows periods.*

By comparing *LEPC* for wind energy projects in different sites, it is important to define the limits of *"production system"* and costs that are included in it. For example, transmission lines and distribution systems should be included in the cost? Usually only connection costs to the production source for the transmission system is included as cost of production. One must be careful to delimit the border of cost analysis, what should or should not be included in the cost of energy (IEA, 2005).

According to Elkinton, Manwell, and McGowan (2008); Elkinton, Manwell, and McGowan (2005); Elkinton, Manwell, and McGowan (2006) to analyze the cost of one unit of electricity produced by a renewable power system is a great challenge. First of all we have to collect accurate and current data. In the case of wind power projects, for onshore applications, there are many researches done and real data are available for this kind of analyzes. For a broader understanding of the WECS Elkinton et al. (2008; 2005; 2006) studied the impact of Offshore Wind Farm Layout Optimization (OWFLO) on the cost per kW using *Levelized Production Cost* (*LPC*).

LPC is a similar method of *LEPC*, but the last one has a structure routine for OWFLO which is analyzed with the following criteria: *(1) as lower as the LPC as better as OWFLO* and *(2) as higher as the LPC as worst as OWFLO*. So it is an inverse economic measure. We must consider the fact that is not useful with excluding or different projects. This analyzes must be undertaken with the same project in different options or configurations. This assumption is also applied to *LEPC* method, remember that different wind power projects, different results we get it from it!

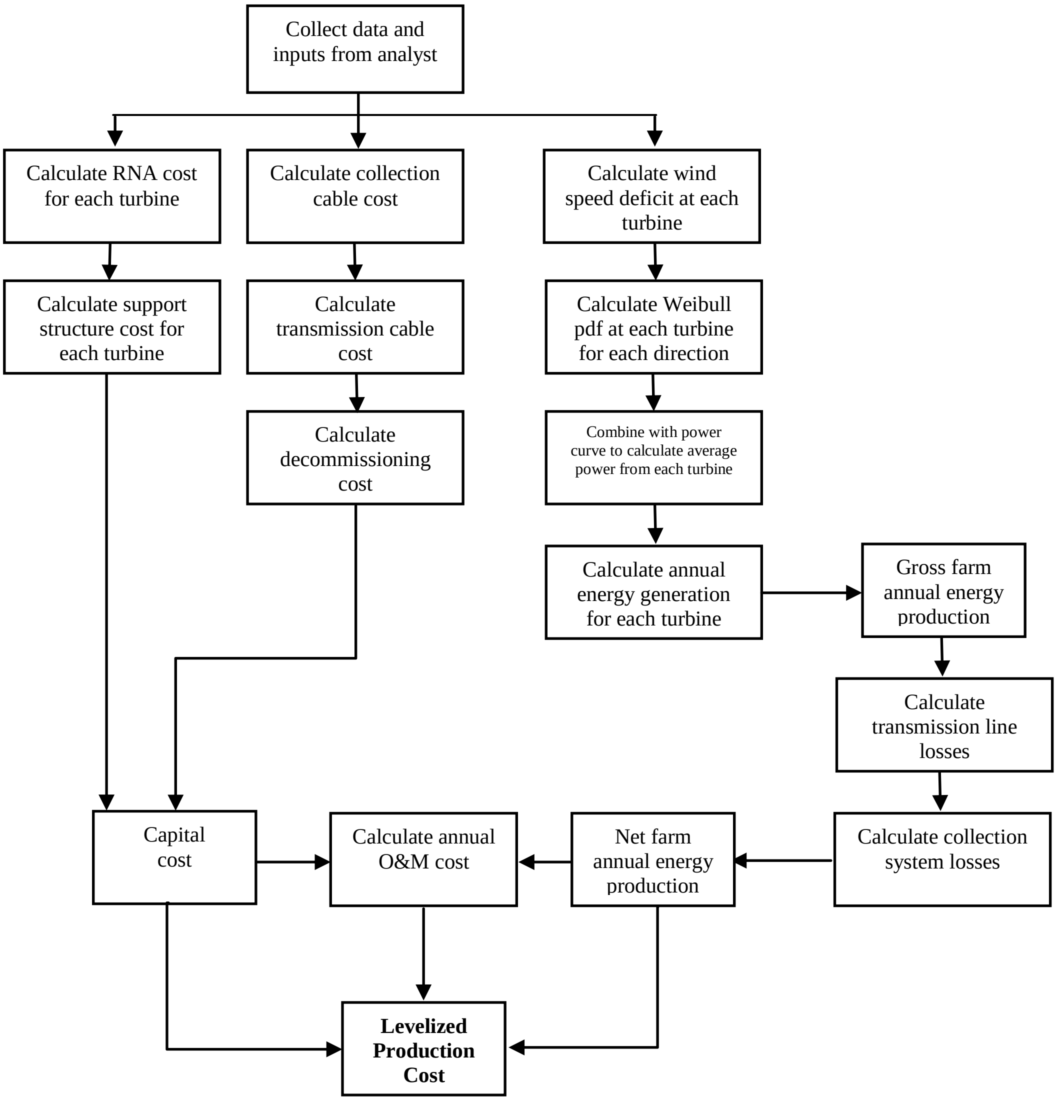

Figure 5.6 Flowchart for LPC Calculation. Source: Elkinton et al. (2008; 2005; 2006)

LEPC has disadvantages that limit application in the evaluation and management of projects in wind energy projects:

1. The discount rate or cost of capital remains unchanged throughout the period under review the project because the cost of capital depends on the behavior of the risk of the activity that tends to be decreasing with the years of operation and technological maturity.
2. Capital costs are regarded as a lump sum at the beginning of the analysis; however there are other capital costs as major equipment installations and replacements that occur in other periods of the plant's lifetime production.
3. All recurrent costs begin to accumulate from the first period and are grouped together and considered to occur at the end of the current period. By using the discount rate to update and add costs in different periods, one runs the risk of this rate is different from the rate at which raise costs and other current expenditure over the life of the project.

5.4.1.5 UNIT PRESENT AVERAGE COST

The *Unit Present Average Cost* (*UPAC*) is significant for each year. However it is less meaningful if the evaluation period extends from the investment decision until the end of the lifetime of the plant production. The average annual cost per unit calculated for the two solutions, both technically and financially different, may be the same and be different than the interest of such solutions. To obtain the average unit cost updated, update separately charges (investment, operations and maintenance, fuel, and others) and total output during the lifetime of the plant production. Assigning charges generally updated by PV_{Co} and annual accumulated and updated by PV_{sAEP}, *UPAC* ($/kW), is given by (NREL, 1995):

$$UPAC = \frac{\sum PV_{Co}}{PVs_{AEP}} \qquad [\$/kW] \qquad \text{Eqn (5.31)}$$

where PV_{Co} = *Present value of cash outflows* and PVs_{AEP} = *Present value of cumulated annual energy production.*

The update is to calculate the amount as payments and receipts made on various dates if made at time $t = 0$. To set the model to consider is necessary to establish precisely what is expected escalation for the exits and entries for cash. A fairly general model can admit that both the inputs (energy sales) and cash outflows (investment, operating costs) are irregularly spread over a period of n years of life. Although payments and receipts are distributed more or less irregularity over time, can be assumed:

1. Expenditure is done on the first day of the year during which it is paid;
2. Revenues go into the last day of the year in which they actually receive it.

The interest and depreciation depend on the conditions of financing, accepted the same for all projects being compared. The following calculation is the average cost to date, considers itself neither interest nor amortization. Invested capital and its depreciation could never be considered simultaneously, it would be a duplication (Damodaran, 2001). In this model of assessment of costs, cash outflows are classified as investment costs and operating expenses. The investment costs include all cash outflows arising from the physical structure of the central production (machinery and equipment, civil works, roads and access, control systems, among other things of that nature). As operating costs we should include *O&M* costs, fuel and other charges related to the regular operation of the power plant. The calculation of *UPAC*, starting of the Eqns 5.31 and 5.32, it is assumed the following parameters:

1. Investment (*ICC*) focuses on the initial moment of the project ($t = 0$).
2. The annual use of power (capacity factor for wind projects) installed is constant throughout the lifetime of the project.
3. *O&M* costs are constant over the useful lifetime and equal to $C_{O\&M.}$
4. There are no charges for fuel, will be the case of small hydroelectric plants, wind farms and photovoltaic cells.
5. The various charges are void or may be included in the *O&M* costs.

Accordingly, *UPAC* is defined by Eqn 5.32:

$$UPAC = \frac{ICC\left(1+\alpha C_{O\&M}\right)}{\left(\alpha AEP\right)} = \frac{ICC\left(\beta + C_{O\&M}\right)}{AEP_s} \qquad [\$/kW] \qquad \text{Eqn (5.32)}$$

where *ICC* = *Initial Capital Cost*; $C_{O\&M}$ = Operations and Maintenance costs and AEP_s = *Cumulated annual energy production.*

For those factors $\alpha = \left[\frac{(1+i)^t - 1}{i(1+i)^t}\right]$ and $\beta = UCRF = \left[\frac{i(1+i)^t}{(1+i)^t - 1}\right]$, where: i = *interest rate* and t = *number of outflows or lifetime of the project*.

UPAC has disadvantages that limit its use in evaluating and managing projects in wind energy:

1. Capital costs (*ICC*) are considered as a fixed sum at the beginning of the project; however there are other capital costs as major equipment installations and replacements that occur in other periods of the plant's lifetime production.
2. The capacity factor is not fixed throughout the period of operation of the project (lifetime), which makes the wind production variable over the years. By oscillating energy production, there is also fluctuation in wind energy revenues and costs.
3. *O&M* costs are not fixed over the lifetime of the project. The maintenance contracts for wind farms are defined according to the warranty period given by equipment manufacturers. The duration of maintenance contract outside the manufacturer’s warranty is 5 to 12 years, yet the life of the wind farms are for at least 20 years.

5.4.2 PECULIARITIES IN THE COST ANALYSIS OF WIND ENERGY PROJECTS

The adoption of standardized methodology for calculating the cost of wind energy projects is necessary in the efficient management of a wind farm. Some approaches can be used for economic assessment in various contexts, to reflect the criteria and priorities of different economic agents involved in the venture. The choice of wind power system has the greatest impact on the cost of wind power produced. The link between wind turbine production capacity and production cost stems partly from technical economies of scale. In addition to technical economies of scale, there are production economies of scale that reduce the cost of wind power. However, this does not guarantee that a specific wind project will generate power at a competitive cost level. The capacity to optimize production costs depends on a number of other factors (Valentine, 2011).

According to Dicorato, Forte, Pisani, and Trovato (2011) the cost analysis of a wind power plant must be done by *cost centers*, classified into *wind turbines cost center*, *electrical system cost center* and *grid interface cost center*. These cost centers change its costs and sub-divisions depending on the kind of application of wind power plant. If it is related to an Offshore Wind Farm (OFWF), the costs of foundations and electrical system and grid interface are higher. In the case of a Nearshore Wind Farm (NWF) the same costs are less than the OFWF, especially, the costs with electrical system and grid interface. Then, for an Onshore Wind Farm (OWF), most of the costs are less expensive, but the wind resources are also less intense, so this fact requires a much better efficiency in wind turbine technology. In the power industry in general, the more efficient more costly, that is why in OWF applications, most of the costs are for *wind turbines cost center* (Milligan, 2004).

For the correct definition and calculation of the cost of one unit of energy produced by a central production is essential to characterize the boundaries of the project under study. It is important to compare the power plants meet the cost of energy produced in isolation, but may not reflect the total economic impact of new power when connected to the network within an existing electrical system. It is important from the standpoint of the producer to estimate the cost of producing one unit of energy for the management and evaluation of the project as a business unit must ensure that economic return for the investor/manager (Johasson, 1993).

The average cash cost methodology for the series of costs to present values at a given base year by applying the discount rate. The discount rate considered appropriate for the energy sector may differ from country to country, and in the same country, from technology to technology. Applying the discount rate takes into account the time value of money, or an amount earned or spent in the past or future, has the same value as the same amount (in real terms) gained or spent on this. The discount rate may be related to rates of returns that can be earned on typical investments, which may be a fee required by regulators incorporating the provision for financial risks and /or derived from national macroeconomic analysis∴Despite the investment option not to depend entirely on how it is financed, as it should be profitable by itself, funding may influence the attractiveness of the project. This is especially true for REPs. How often it is very capital intensive and require large amount of initial debt and equity. The financial conditions for such a loan, becoming an important factor in the project evaluation (Harper et al., 2007).

5.5 OPTIMIZATION MODELS APPLIED TO REPS

5.5.1 CONCEPTS OF SIMULATION AND OPTIMIZATION

In a wide variety of economic, political, scientific, and social situations often arise in that if you want to maximize or minimize a certain amount that is a measure of the efficiency of the activity. This amount can be, for example, the total production in a certain period of time, or the cost of the operation, these problems are optimization problems that are known as *mathematical programming* problems. The mathematical optimization models find an optimum expansion plan by using a calculation procedure that solves a mathematical formulation of the problem (Latorre, Cruz, Areiza, & Villegas, 2003)∴Specific classes of these problems are those involving only *linear equations* and *inequalities*. And, the most popular method to solve *linear programming* problems is the *simplex* method (Nocedal & Wright, 1999).

The objective of simulation optimization process is *minimizing the resources* spent while maximizing the information obtained in a simulation experiment (Carson & Maria, 1997). In mathematics, the term optimization, or *mathematical programming*, refers to the study of problems in that search minimizing or maximizing a *function* (mathematical model) through systematic choice of whole or real variable values within a set feasible (optimization strategy). In engineering, administration, logistics, transport, economy, biology or other sciences, when it manages to build *mathematical models* quite representative of their dynamic systems under study, it is possible to apply the mathematical techniques of optimization to *maximize* or *minimize* a *function* previously defined as *performance index (PI)*, or *index of performance (IP)*, in order to find an optimal solution of the problem, that is, that results in the *best* possible performance of the system, according to this previously defined *performance criteria (PC)* (Christodoulos & Panos, 2009).

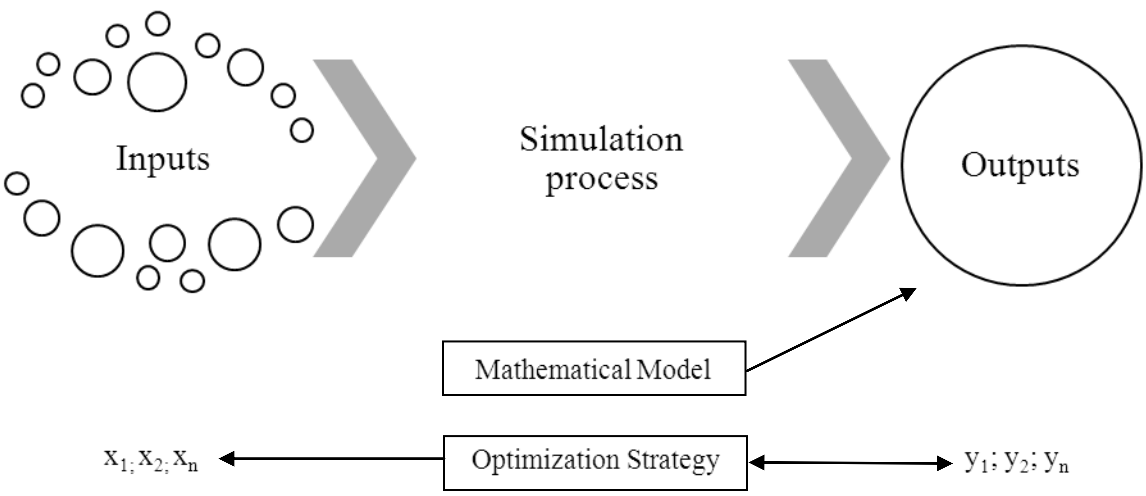

Figure 5.7 Simulation optimization model framework. Source: based on Carson and Maria (1997)

According to Figure 5.7 we can discuss about *inputs*, *simulation process (mathematical model and optimization strategy)* and *outputs.* In the *systemic theoretical*[68]approach, the broadest conception, a *"system"* may be described as a complex of interacting components together with the relationships among them that permit the identification of a boundary-maintaining entity or process. The *inputs-process-outputs* relation must work as an organism∴The optimization strategy can be understood as a continuum interaction for improving the whole system, which can be a power plant.

So the concept of *optimization* can be taken as a way or technique to improve the efficiency of a system in general (for an optimal condition). For this precise and complex duty the optimization process have to be measure anyway. The method adopted for measuring the optimization process depends on the nature of *inputs-process-outputs* relation. In the Figure 5.8 is displayed the six major categories of simulation optimization methods. In the literature on energy systems, the word *optimization* is often used in cases where the proper word is *improvement*. The two words do not have the same meaning and care should be exercised in their use.

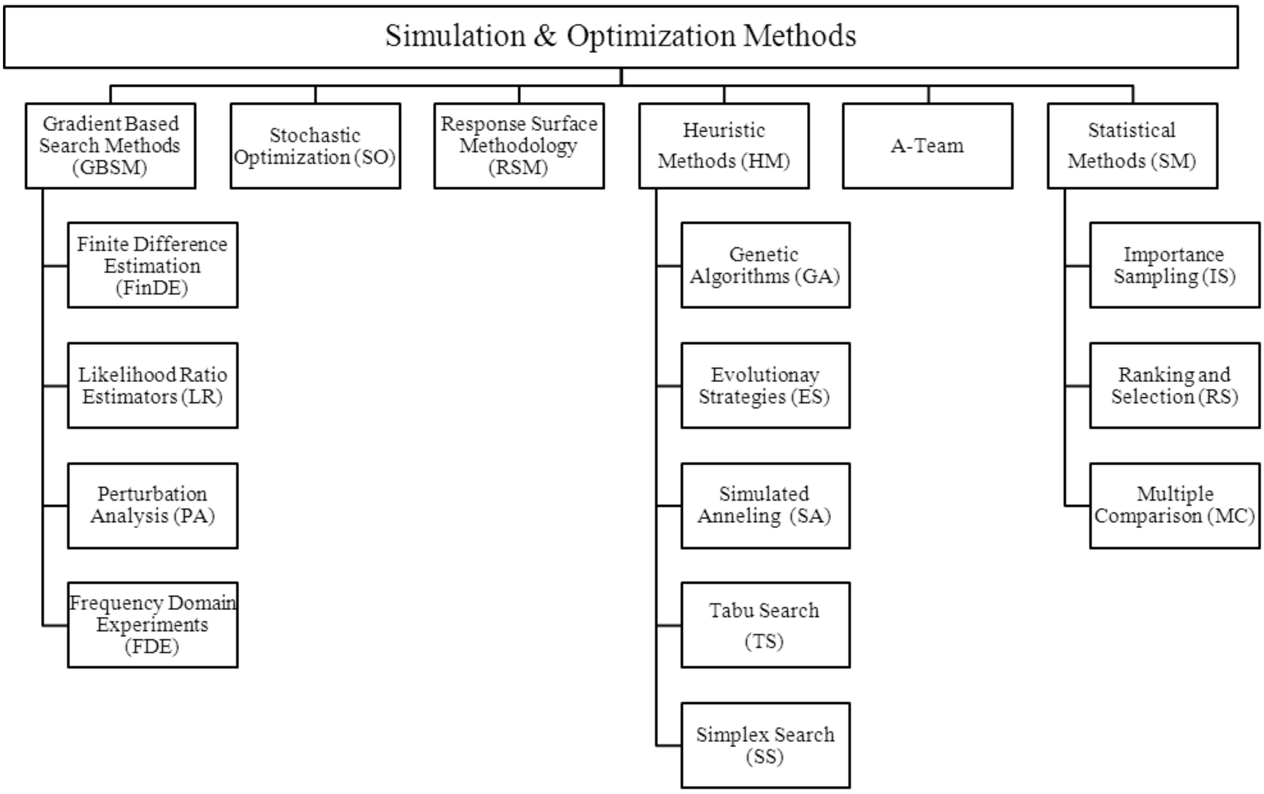

Figure 5.8 Simulation & optimization methods. Source: Nocedal and Wright (1999) and Christodoulos and Panos (2009)

[68] The General Systems Theory (GST) was developed by biologist Von Bertalanffy, to search for an explanatory scientific model of the behavior of a living organism. A system is defined as a whole organized consisting of interdependent elements, which is surrounded by an external environment; If the system interacts with the outside environment is called *open system*; System relations with the exterior render themselves through exchanges of information and energy which is called *input* or *output*; the channels that convey the input-output information or energy called *communication channels* (Von Bertalanffy, 1972).

5.5.2 AN OVERVIEW OF SIMULATION AND OPTIMIZATION METHODS

The simulation is one of the most powerful tools available to decision makers responsible for the design and operation of complex systems and processes. Throughout the study on this topic, prior to work, met some definitions found in articles of authors with research in the area. Then are given two of these settings found, so the *"simulation"*:

1. According to Banks (1999) is *"the imitation of the functioning of a real-world system or process over time. Involves the creation and observation of an artificial history so the system can draw conclusions about the nature of the real system represents."*
2. For Shannon (1992) is "*the process of designing a model of a real system, conduct experiments using this same model with the purpose of understanding the behavior of the system and/or evaluate various strategies for its functioning. Thus, it is crucial that the template is designed so that its behavior mimics the behavior of the real system events that occur over time."*

These two definitions it is concluded that both authors agree that simulate is the act of imitating the behavior of a model of a real system. This conclusion leads to the need to define the terms *"model"* and *"system"*. Also for these two terms there are in the literature various definitions∴For Carson and Maria (1997), a *model* is a representation of a system or process, and a *simulation model* is a representation that changes within time and a *system* is a group of interconnected elements that cooperate in order to achieve a defined objective.

The *optimization* is process the improvement of a system functioning in its best outputs as possible. The simulation and optimization models can be classified as *continuous or discrete*, *static or dynamic* and *stochastic or deterministic* (Andradóttir, 2007):

1. *Continuous* — the simulation time progresses continuously at intervals of equal times;
2. *Discrete* — the simulation time is based on the occurrence of events, namely advances in event;
3. Static — the state of the system is described only to given time and usually the time variable is not important;
4. *Dynamic* — the state of the system is described based on a time variable, this evolves over time.
5. *Deterministic* — the values entered in the simulation are constant;
6. *Stochastic* — the values entered in the simulation are constant; for stochastic models, the entered values are random.

The simulation and optimization problems are often driven by maximization or minimization expected values of the objective function designed to represent the system behavior∴This, however, does not have to be always the objective of the simulation and optimization problems. On other situations, one might be interested in minimizing the dispersion of the values rather than its expected values (Azadivar, 1999).

The simulation and optimization problems consist of a determination of the extreme (minimum or maximum) of an objective function under certain constraints or restrictions∴It is usually mathematically shown as follows:

$$Minimize\ f(x) \qquad [-] \qquad \text{Eqn (5.33)}$$

considering

$$x = (x_1, x_2, \ldots, x_n) \qquad \text{Eqn (5.34)}$$

$$a_i(x) = 0 \qquad i = 1,2,\ldots,m \qquad \text{Eqn (5.35)}$$

$$b_k(x) \le 0 \qquad k = 1,2,\ldots,n \qquad \text{Eqn (5.36)}$$

where x = set of all the independent variables; a_i = equality constraint functions *("strong constraints")*, which constitute the simulation model of the system and are derived by an analysis of the system (energetic, exergetic, economic, etc.); b_k = inequality constraint functions *("weak constraints")* corresponding to design and operation limits, state regulations, safety requirements, etc.

When we refer to power systems analysis, independent of the type of power system, it is usually helpful to classify the independent variables into three categories (described in Table 5.7):

$$x \equiv (o, d, s) \qquad \text{Eqn (5.37)}$$

Table 5.7 Classification for independent variables for power system optimization analysis

Variable	Category	Meaning
o	Operation	Load factors components, mass flow rates, pressures and temperatures of streams, etc.
d	Design	Nominal capacities of components, mass flow rates, pressures and temperatures of streams, etc.
s	Synthesis	There is only one variable of this type for each component, indicating whether the component exists in the optimal configuration or not; it may be a binary (0 or 1), an integer, or a continuous variable such as the rated power of a component, with a zero value indicating the non-existence of a component in the final configuration.

Source: Frangopoulos (2003)

As we could understand about the definitions of the terms *"simulation"* and *"optimization"* adopted in this research, it is also necessary to discuss about the most common methods used in simulation and optimization process for power systems evaluations. In Figure 5.8 are shown the six most used methods of simulation and optimization.

The Gradient Based Search Methods (GBSM) estimate the response of the *gradient function* (∇f) to assess the shape of the objective function and employ deterministic mathematical programming techniques. The most used gradient techniques are *(1) Finite Difference Estimation (FinDE)*; *(2) Likelihood Ratio Estimators (LR); (3) Perturbation Analysis (PA) and (4) Frequency Domain Experiments (FDE)* (Fu, 1994).

The Stochastic Optimization (SO) methods are optimization methods that generate and use random variables. For stochastic problems, the random variables appear in the formulation of the optimization problem itself, which involve random objective functions or random constraints, for example. Stochastic optimization methods also include methods with random iterates. Some stochastic optimization methods use random iterates to solve stochastic problems, combining both meanings of stochastic optimization. Stochastic optimization methods generalize deterministic methods for deterministic problems (Spall, 2003).

For Kleijnen (2008) the Response Surface Methodology (RSM) explores the relationships between several *explanatory variables*[69] and one or more *response variables*[70]. The method was introduced by G.E.P. Box and K.B. Wilson in 1951∴The main idea of RSM is to use a sequence of *designed experiments*[71] to obtain an optimal response. Box and Wilson suggest using a *second-degree polynomial*[72] model to do this. They acknowledge that this model is only an approximation, but use it because such a model is easy to estimate and apply, even when little is known about the process.

An Asynchronous Team (A-Team) is a scale efficient network of distributed computer agents working together to solve a difficult problem. An A-team is a process that involves combining various problem solving strategies so that they can interact synergistically. A-Teams, which are biologically inspired, are characterized by autonomous agents and cyclic data flow (Carson & Maria, 1997).

The Statistical Methods for simulations and optimization procedures related to power systems reflect the deterministic optimization models *via* statistical frequency analysis, probability distributions, multiple regression and inference analysis (Frangopoulos, 2003). The statistical methods and techniques aim to find existing relations between the historical data production, explanatory variables and information collected in real time∴These models have the advantage that they do not need physical modeling. However, for the process of parameters estimation is necessary to possess a wide range of historical data and measurements in real time. The most used statistical techniques are *(1) Importance Sampling (IS)*; *(2) Ranking and Selection (RS) and (3) Multiple Comparison (MC).*

[69] This categogy is also classified as *"independent variables"*represents those ones that intentionally are introduced (by the researcher) to verify the relationship between their variations and the behavior of other variables, it corresponds to what in function of which to achieve what was predicted and/or get results (Montgomery, 2008).
[70] *Response variables* or *dependent variables* are those whose behavior if you want to check in function of the oscillations of the *independent variables*, it corresponds to what you want to predict and/or get as a result. It happens depending on the completion of the experiment in a research (Montgomery, 2008).
[71] For Montgomery (2008)*"a designed experiment is a test in which some purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for changes in the output response. Experimental design methods play an important role in process development and process improvement."*
[72] A *second-degree polynomial* model should be formulated by an equation in which one or more of the terms is squared but raised to no higher power, having the general form $ax^2 + bx + c = 0$, where *a, b,* and *c* are constants.

5.5.3 TYPES OF OPTIMIZATION MODELS FOR ENERGY SYSTEMS

In the last 20 years we could see a great improvement of renewable energy technologies, especially wind and solar energy technologies worldwide that can also be seen as an answer to several energy related environmental problems∴The renewable energy systems (power plants and individual applications) are complex systems (Oliveira & Fernandes, 2011b) and one of the most important issues is the efficiency of the systems or *coefficient of performance (COP)*. So this hard duty to make the energy systems work in the best COP as possible, which is a complex problem to solve.

Energy systems have been evoluting jointly with energy demand of humankind, so these systems have to generate more and more energy∴This necessity brings up the concept of system optimization in energy systems. In a conventional design procedure (in the earlier times), the objective is to reach an opertationable system (system had to work), i.e. a system that performs as was designed within the imposed constraints or technical limitations. However, in general, there will be more than one operationable design; and, in fact, there may be any number of improved designs that the conventional procedure may not identify. The role of optimization is to reveal the best (under certain criteria and constraints) design and the best operational point of the system automatically, with no need for the designer to study and evaluate one by one among several others possible designs.

The objective of the optimization can change depending on the objective of the designer or analyst. The optimization process of an energy system can be considered at three levels (Frangopoulos, 2003):

1. *Design optimization.* The word *design* here is used to synonym of technical features of the systems components and the working properties of each component at the nominal load of the system. The *design point* of the system is nominal load or operational conditions of the energy system. However in order to distinguish the various levels of optimization and due to the lack of a better term, the word *design* will be used with the particular meaning given here.
2. *Synthesis optimization.* The term *synthesis* refers the components that work in a power system and their interconnections or relations. After the synthesis of an energy system has been successfully composed, the flow diagram of the system can be drawn.
3. *Operation optimization.* For a given energy system (i.e. one in which the synthesis and design are known) under specified conditions, the *optimal operating point* can be known, as it is defined by the operating properties and interconnections of components in the system (speed of revolution, power output, mass flow rates, pressures, temperatures, composition of fluids, etc.).

Of course if complete optimization is the objective, each level cannot be considered separately from the others. So, afterwards, the complete optimization problem can be stated by the following question: *What is the synthesis of the system, the design features of the components and the operating strategy that lead to an overall optimum situation of the whole power system?*

The following aspects show the necessity of applying optimization procedures in the design and operation of energy systems: *(1) Increasing the quality and capacity of the power plants while reducing costs in order to be competitive, case of wind power*; *(2) Fulfilling ever increasing specification as well as considering reliability and safety conditions, observing strict pollution regulations, and saving energy and material resources* and *(3) Saving time and spending less money in the initial power plant´s lifetime*.

As we can notice, optimization algorithms fit as a *suitable tool* for solving complex problems in the field of renewable energy systems. Figure 5.9 shows an exponential evolution in the number of optimization algorithms using for solving complex problems in renewable energy systems. Some authors have reviewed different types of models such as *renewable energy models*, *emission reduction models*, *energy planning models*, *energy supply-demand models*, *forecasting models*, and *control models* using optimization methods (Jebaraj & Iniyan, 2006), but many researchers are continuously proposing and applying new or *hybrid methods* applied into different renewable energy technologies simultaneously (Castronuovo & Lopes, 2004; Deshmukh & Deshmukh, 2008).

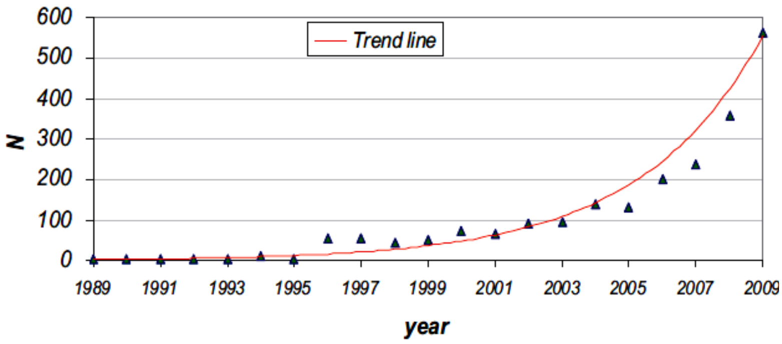

Figure 5.9 Evolution of optimization algorithms solutions in RETs. Source: Baños et al. (2011)

The great expansion and diffusion of optimization algorithms for solving complex problems in RETs is a clear response for the *"boom"* of renewable energy industry globally. When we match the global annual installed capacity for wind power (see Figure 3.12) with the utilization of optimization algorithms as shown in Figure 5.9, there is clear positive evidence between them. We must remember that renewable energy technologies and sources have as a central common aspect, the *uncontrollability*, and the outputs are expectable, case of electricity produced by a wind farm or a solar central power or still some other RETs.

In order to classify in groups of optimization, taking into consideration the objective of the algorithm, we can organize them into two big groups (see Tables 5.8 and 5.9)∴The first one is *EConomic Optimization Algorithm* (*ECOA*) and the second is *ENgineering Optimization Algorithm* (*ENOA*). Both groups are inter-linked because any effect in each of them will reflect in the other, consequently.

Table 5.8 Economic models of optimization algorithms for wind and hybrid power system

Group	Subgroup	Algorithm
1. ECOA	1.1 Economic Models	
	1.1.1 Huang (2007); Huang, Fu, and Guo (2009)	$\cos t_{tot} = \cos t_{gy} N\left(\frac{2}{3}+\frac{1}{3}e^{-0.00174N^2}\right)$ and $profit = \left[s-\left(\frac{\cos t_{tot}}{E_{tot}}\right)\right]E_{tot}$
	1.1.2 Lundberg (2006)	$E_{\cos t} = \frac{Invest}{P_{out,AVG^T}} \times \frac{r(1+r)^N}{(1+r)^N-1} \times \frac{100}{100-PR} = K\frac{Invest}{P_{out,AVG^T}}$
	1.1.3 Hetzer, Yu, and Bhattarai (2008)	$C_{w,i}(w_i) = d_i w_i$
	1.1.4 Salcedo-Sanz, Saavedra-Moreno, Paniagua-Tineo, Prieto, and Portilla-Figueras (2011)	$\cos t = N\left(\frac{2}{3}+\frac{1}{3}e^{-0.00174N^2}\right)$
	1.1.5 Zhang, Chowdhury, Messac, and Castillo (2010, 2012)	$C_t = \frac{1}{n}C_{in} + C_{O\&M}$
	1.1.6 Fuglsang and Madsen (1999); Fuglsang and Thomsen (1998)	$C = \sum_{i=1}^{N_{COM}} C_i$, $C_i = R_i(b_i + (1-b_i)m_i)$
	1.1.7 Sisbot, Turgut, Tunc, and Camdali (2010)	$TotalCost = \ell C_{cp} + C_{op}$
	1.1.8 Elkinton et al. (2008)	$LPC = \frac{CC}{a.E_a} + \frac{C_{O\&M,a}}{E_a}$
	1.1.9 Emami and Noghreh (2010)	$g = w_1 \cos t_m + w_2 \frac{1}{P_{total}}$, $w_1 + w_2 = 1$
	1.1.10 Habib, Said, El-Hadidy, and Al-Zaharna (1999)	$C_{i,t} = C_{i,PV} + C_{i,W} + C_{i,Q}$, $C_{i,PV} = AC \times A_{PV} \times X_i$, $C_{i,W} = WC(1-X_i)$ and $C_{i,Q} = BC \times Q$
	1.1.11 Ozturk and Norman (2004)	$profit_{\max} = \left[k-\left(\frac{\cos t_{tot}}{P_{tot}}\right)\right]P_{tot}$
	1.1.12 Yang, Lu, and Zhou (2007)	$LCE = \frac{\frac{(CO_{PV})/Y_{PV}}{Y_{PV}} + \frac{(CO_W)}{Y_W} + \frac{(CO_{Bat})}{Y_{Bat}}}{E_{an}(\gamma,\beta,h)}$
	1.1.13 Yang, Wei, and Chengzhi (2009)	$ACS = C_{acap}(P_V + W_{ind} + B_{at} + T_{ower}) + C_{arep}(Bat) + \ldots$ $\ldots + C_{amain}(P_V + W_{ind} + B_{at} + T_{ower})$
	1.1.14 Zhao, Chen, and Hjerrild (2006)	$OBJ = LPC + \beta \times R_s$
	1.1.15 Koutroulis, Kolokotsa, Potirakis, and Kalaitzakis (2006)	$system_{\cos t} = c_s \times \alpha_s + c_w \times \alpha_w$
	1.1.16 Benitez, Benitez, and van Kooten (2008)	$TC_{\min} = \sum_{i=1}^{N}\left(F_i C_i + \sum_{t=1}^{T}(pf_i E_{t,i} + c_i Q_{t,i})\right)$
	1.1.17 Jong-Bae, Ki-Song, Joong-Rin, and Lee (2005)	$C = \sum_{j \in J} F_j(P_j)$, $F_j(P_j) = a_j + b_j P_j + c_j P_j^2$

Source: own construction. Note: The nomenclature of these formulas is in Appendix A.

Table 5.9 Engineering models of optimization algorithms for wind and hybrid power system

Group	Subgroup	Algorithm
2. ENOA	2.1 Engineering Models	
	2.1.1 Rašuo and Bengin (2010)	$f(x_1)=\frac{P_{total}}{P_{\max}}$, $f(x_2)=\frac{costs}{P_{total}}$
	2.1.2 Marmidis, Lazarou, and Pyrgioti (2008)	$Obj=\frac{cost}{P_{tot}}u_i=u_0\left[1-\sqrt{\sum_{i=1}^{N}\left(1-\frac{u}{u_0}\right)^2}\right]$
	2.1.3 Gonzalez, Rodriguez, Mora, Santos, and Payan (2010)	$E_{WF}=T\sum_{j=1}^{N_t}\int_{v_{ci}}^{v_{co}}P_{gen}j(v)p_j(v)d_v$
	2.1.4 Mustakerov and Borissova (2010)	$P=h_y\eta NP_{wt}$, $N=N_{row}N_{col}$, $N_{row}=\frac{L_x}{SD_x}+1$, $SD_x=k_{row}D$ and $N_{col}=\frac{L_y}{k_{col}D}+1$
	2.1.5 Diaf, Diaf, Belhamel, Haddadi, and Louche (2007)	$P_{tot}(t)=P_{PV}(t)+P_{WD}(t)$
	2.1.6 Ashok (2007)	$P_{tot}(t)=\sum_{h=1}^{N_h}P_h+\sum_{w=1}^{N_w}P_w+\sum_{s=1}^{N_s}P_s$
	2.1.7 RETScreen® International Clean Energy Decision Support Centre (2008)	$e_{base}=(e_{CO2}GWP_{CO2}+e_{CH4}GWP_{CH4}+e_{N_2O}GWP_{N_2O})\frac{1}{\eta}\frac{1}{1-\lambda}$
	2.1.8 Huang (2007)	$P_{tot}=\sum_{i=1}^{N}P_i$
	2.1.9 Moran and Sherrington (2007)	$E_{windfarm}=IC\times CF\times h_{year}$
	2.1.10 Diveux, Sebastian, Bernard, Puiggali, and Grandidier (2001)	$E_{AP}=\frac{8760}{1000}\frac{\rho_{air}}{2}\times S_R\times\int_{V_i}^{V_f}V^3f(V)C_P(V)\eta_{GB}(V)\eta_G(V)dV$
	2.1.11 Flores, Tapia, and Tapia (2005)	$P_{opt}=k\omega_r^3$
	2.1.12 Vallée, Lobry, and Deblecker (2011)	$MAWPC=(1-FOR_t)\cdot IWPC$
	2.1.13 McWilliam, Van Kooten, and Crawford (2012)	$N=\frac{4n\pi\pi^2}{\sqrt{3X_p^2}}$
	2.1.14 Maki, Sbragio, and Vlahopoulos (2012)	$V=V_{ref}\left(\frac{Hub_{Ht}}{H_{ref}}\right)^{0.34}$
	2.1.15 Szafron (2010)	$E_y=\lfloor(E_i-(w_{ake})_i-(coll_{ection})_i)\cdot(a_{vail})_i\rfloor-(trans_{mission})$
	2.1.16 Habib et al. (1999)	$P_{i,j}=P_{sj}X_i+P_{wj}(1-X_i)$
	2.1.17 Kiranoudis, Voros, and Maroulis (2001)	$C_p=C_{pr}\exp\left[\frac{(\ln u-\ln u_r)^2}{2(\ln s)^2}\right]$

Source: own construction. Note: The nomenclature of these formulas is in Appendix B.

The optimization models applied to wind power system in the last decade started to increase in the same rhythm as wind power industry has increased. According to Yin and Wang (2012) the most common three types of WECS problem can be categorized into: *(1) Integrate power conversion*; *(2) Structural system design* and *(3) Wind turbine placement.*

The *integrate power conversion* refers to technical issues such as wind intermittency and grid reliability. The conventional management of transmission and distribution operation is challenged by electricity market restructuring, security of supply concerns and the integration of newer production technologies such as wind power.

The WECS transform kinetic energy of the air motion into mechanical and electrical. It is a chain conversion process which starts by wind turbines. So, the *structural system design* of a WECS must include the blades, engines, and the tower structure∴All these elements represent a critical factor for maximizing energy production. To maximize the power production per unit of cost, the number of *installed turbines and the spacing* between them should be optimized. As we can see in Figure 5.10, there is an obvious correlation between the layout optimization and energy production cost.

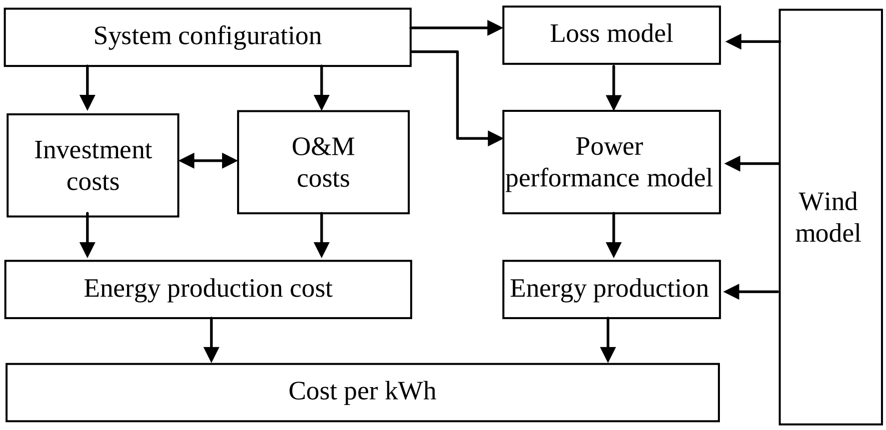

Figure 5.10 The layout optimization and its relationship. Source: adapted from Lundberg (2006)

The cost per kWh from a power plant, a wind farm, must be understood as a result from a systemic components interlinked. A wind farm depends on directly the physical and environmental conditions. The physical refer to the system configuration (layout, technology employed, local terrain configuration, etc.) and environmental conditions refer to the local weather such as wind intensity and speed, air humidity, *flora* and *fauna* aspects (specially flying animals as bats, birds, etc.). The system configuration has impacts on investment and *O&M* costs, which reflects on energy production cost by a wind farm∴Also, we can see the system configuration has influence on loss model and power performance model, we mean, the energy produced by the same wind farm. The relation of energy production cost and (net or available) energy production is finally the *cost per kWh*.

5.6. SUMMARY AND CONCLUSIONS

As far as investment decisions when dealing with uncertainty of future events that may not be totally avoided. The decision is based on estimates and assumptions about future developments and future states (prices, volumes, market sizes, regulations, etc.). The reality may eventually be less favorable than the original estimate of project. It is not a productive strategy for evaluating investments working hypotheses, very negative∴The objective of the investment should not be too pessimistic, but to evaluate adequately the uncertainties involved in analyzing and quantifying this uncertainty in some analytical way∴One rule applies to all methods of economic evaluation of projects and costs for the private view, if two projects generate the same results in the future, but are associated with different degrees of uncertainty, the more uncertain project will be considered less attractive. There is an inverse relationship between uncertainty and attractiveness of the project. Like any other project, the REPs should ensure financial returns to investors and managers. The evaluation is not limited to assessment of financial attractiveness, but should include several other factors.

As we explained in this chapter, the attractiveness of an investment project should be quantified in an analytical way. Methodologically, to arrive at this result it is necessary to sort and organize items in the project cost. In the case of wind energy projects, the costs are classified and structured investment costs, operating costs, maintenance costs and financial costs∴All these classes and cost structure have their own characteristics depending on the location, size, types of financing and regulations. These costs behave differently from project to project, from country to country (region), from author to author, in summary, we present estimates for these costs, as shown in Tables 5.3 and 5.4.

Although the crucial important aspect for classifying and structuring the cost of wind energy projects used to the proper application of existing models for economic evaluation of projects, considering the objectives of the evaluation itself∴For this research, the purpose and scope of the theme, we studied the main methods of economic evaluation of projects and their applicability in wind energy projects. The indicators studied were *SPB*, *DPB*, *NPV*, *IRR*, *RR* and *BCR*.

SPB and *DPB* measure the return time of investment, although *BDP* discounting project costs (usually operating costs). *NPV* analysis measures the level of wealth that the investor receives the bet on any one project with its own capital and/or others. In *IRR* analysis, which refers specifically rate the investment can pay for the capital (the higher the rate, the better the project)∴For models of economic evaluation of projects studied were identified limitations or weaknesses of each.

However, for sectors where there is strong government regulation of economic activity, if the renewable energy sector, we need to analyze, also what level of minimum income that the project in question needs. This response is given by *RR* analysis. For a *RR* analysis, the smaller the need for revenue, better the project is. The analysis of *BCR* is the ratio of the current value of the sum of the project benefits divided by present value of the sum of project costs. *BCR* analysis is used as a criterion for selection of independent projects that have benefit-cost ratio greater than or equal to unity. It cannot be used to choose between mutually exclusive alternatives. For wind energy projects, methodologies were also analyzed with emphasis on analysis of the cost production per MWh∴Among the indicators studied were *LCOE*, *TLCC*, *NPC*, *LEPC* and *UPAC*. These indicators of attractiveness and cost of projects are for specific REPs. Together with other indicators of financial attractiveness of the project is a set of tools that can be used selectively to evaluate and project management. They were also pointed out factors that limit each type of cost analysis. It is comparative analysis of methodologies studied in Table 5.10, considering the main aspects that impact on economic assessment of wind energy projects and their costs.

Table 5.10 Overview of economic measures applying to specific investment features and decision

	Methods of economic evaluation of projects and costs								
	NPV	*IRR*	*TLCC*	*SPB*	*DPB*	*BCR*	*LCOE*	*RR*	*UPAC*
Significant investments (negative net cash flow) after first return	Possible	Not useful	Possible	Possible	Possible	Possible	Possible	Possible	Not useful
Investment subject to regulation	Possible	Possible	Possible	Possible	Possible	Possible	Possible	Preferred	Possible
Project-specific debt-financing needed	Possible	Possible	Possible	Not useful	Not useful	Possible	Possible	Possible	Not useful
Social costs (externalities)	Preferred	Possible	Possible	Possible	Possible	Preferred	Possible	Possible	Possible
Taxes	Possible	Possible	Possible	Not useful	Not useful	Possible	Possible	Possible	Possible
Select from mutually exclusive alternatives	Preferred	Not useful	Possible	Not useful	Not useful	Not useful	Not useful	Possible	Possible
Ranking (Limited budget)	Possible	Possible	Possible	Not useful	Not useful	Preferred	Preferred	Possible	Possible
Risks	Possible	Possible	Possible	Preferred	Preferred	Possible	Possible	Possible	Possible

Source: adapted from IEA (1991).

The methodologies for economic evaluation of projects and costs are summarized in Table 5.10. Economic measures are suggested which better suited for each specific analysis∴Different economic measures apply to different situations and it is believed to be preferable to use several methodologies to evaluate an investment project in the energy area. Sometimes the objective of economic evaluation is to find the most appropriate combination of each method available in engineering economics.

After analysis of these economic models applied to wind energy projects, we highlight that:

1. The attractiveness of the proposed wind energy can vary considerably between evaluation of the private and public sector. The public sector takes into account additional factors such as externalities, public authorities for tax purposes or long-term effects that are beyond the horizon of private investors.
2. The financing structure is very important influencing factor for the attractiveness of wind energy project. In many cases, economic agents practice their actions by means of financing the project in order to earn sufficient income to meet the demands from investors and other economic agents involved.
3. The project's economic attractiveness of wind energy is influenced by government intervention through regulatory actions. Common tools of public intervention are *tax incentives, direct subsidies, regulated tariffs (revenue) or subsidized loans (low interest loans).*

The REPs can be analyzed using essentially the *"tool kit"*, presented in this chapter. The financial attractiveness is an integral part of any project. The economic agents involved must offer sufficient guarantees to the financial return in order to make it attractive. There are a number of other factors and peculiarities that make the evaluation of REPs little more difficult than in *"normal"* projects. So far, possible investments in REPs have been treated as if the consequences were entirely predictable. In reality, the consequences are still very uncertain. This situation applies to projects of all types and especially for wind energy projects (Gottschalk, 1996).

In order to improve the reliability of projected and REPs already in operation the key players of renewable energy industry, case of wind energy sector, more and more adopt simulation and optimization methods. The simulation and optimization methods since the end of nineties decade, as shown in Figure 5.9 have increased exponentially∴This growth as an answer for complex problems that has appeared related to renewable energy systems design and operation. It is a way to explain and understand system behavior and improves it as a whole, so consequently, spent less money and until lower the cost of energy produced. For a wind farm that the occupies a given land area, if the *wake effect*[73] of wind turbines is ignored, more wind turbines lower the unit average cost, and the better the economic efficiency of the whole wind farm.

[73] Wind energy converster systems produce electricity by extracting the energy in the wind. Consequently, the air mass leaving the turbine must have lower energy content and by implication lower speed than the air arriving in front of the turbine. In other words, the turbine positioned upstream in the wind direction influences the wind speed at turbine locations on its downwind (Jiang, Yan, & Feng, 2009).

Techniques for simulation and optimization of RETs vary greatly depending on the exact problem setting. The case of RE projects the local conditions such as orography, (micro) climate, local population and government must be taken into consideration. Many systems simulation and optimization in areas such as *manufacturing, distribution, financial evaluations*, are too complex to be analyzed discretely. Discrete event simulation and optimization has long been a useful *tool* for evaluating the performance of such systems. However, a simple evaluation of performance is often insufficient and a more exploratory process may be needed in the manner of simulation and optimization situations. Simulation and optimization is the process of finding the best values expected of some decision variables for a system where the performance is evaluated based on the output of a simulation model of this system (Olafsson & Jumi, 2002).

There has been many work on simulation and optimization procedures (techniques) in the specialized literature, and more recently optimization routines has been incorporated into several *commercial simulation package and softwares*[74].The choice of the procedures (software) to use in the simulation and optimization study depends on the analyst or researcher and the problem itself to be solved.

The success expansion of WECs worldwide is obviously a direct response of economic scale phase this *industry* has entered during the last decade. From now and on, the great challenger is maintain this rhythm of growth by improving the power output through the development of better aerodynamic performance offers some potential economic return; however, the focus is on the cost of energy produced of the entire system. The main objective of this Chapter has been discuss about economic measures and optimization models applied to RETs, with focus on wind power technology in order to *establish a framework* for a much better utilization in *economic engineering evaluation of a project in a microeconomic view*.

In Table 5.8 and 5.9 are summarized the economic and engineering models of optimization algorithms for WECS and hybrid power systems. We could conclude that the economic view is given an emphasis on cost and profit produced by the system, however in engineering view the emphasis is addressed to cost/production, electricity production and wind farm capacity. There is a question we try to understand as how these two aspects are linked and which is more important in determine the cost of energy produced. That´s why is necessary to do simulation and optimization procedures through a new reread of the *economic measures and optimization models* applied to wind energy projects.

For this reason in the Chapter 6 is discussed and presented the *methodology proposed* by this Ph.D. research work related to the scientific field of Economics developed in the Department of Economics, Management and Industrial Engineering of the University of Aveiro, applied to Renewable Energy, case of WECS. The simulation and validation of the proposed methodology is performance in Chapter 7 and the results and discussions with conclusions and implications are presented in Chapters 8 and 9.

[74] For more details, please see Connolly, Lund, Mathiesen, and Leahy (2010); Quaschning, Ortmanns, Kistner, and Geyer (2001); RETScreen® International Clean Energy Decision Support Centre (2008, 2009).

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Do not merely listen to the word, and so deceive yourselves. Do what it says.
James 1:22

CHAPTER 6

RESEARCH METHODOLOGY

This chapter explains about the research methodology aspects used in this Ph.D. research work. The epistemological and methodological research issues, rationale of the study, research framework and design are explained in details. Summary and conclusions are presented at the end, with the respective references.

6.1 INTRODUCTION

Humanity has always tried to understand and solve the questions and challenges that have emerged over time, not only to overcome his own reason, but also for the sake of survival∴And the extent to which these challenges were getting increasingly complex tools to address them failed to follow the same rhythm, until the mathematics began to be developed as an aid to science and used to understand observations in nature and solve their problems.

Finally, in the process of creating a model, we have, as a first step the definition of objective(s), we can start with the following question: *what we want to achieve with this model?* Then define what will be the *model decision variables*: cost, size or quantity? And so how these variables are related to each other and with the constraints of the problem (often *"resources")* or method used to do the modeling, which gets its name from its *restrictions*.

In wind energy conversion systems, as it is expressed in its name, productive process occurs in a system operative conception and engineering and economic architectures∴So it is possible to be reduced to a mathematical model by formula within its variables and relationships. In other words, we can simulate it as in a real world situation∴We have to follow some criteria related to its own scientific nature, that is why in Chapter 4 was reviewed the *Wind Energy Conversion Systems* (WECS) in details and Chapter 5 also reviewed issues about economic measures and optimization/simulation models for better understanding the economic variables and relations of this interesting production system.

In this chapter we present the mathematical model that was developed and used in the *economic optimization model for wind farms in function of the cost of energy produced*. First, it is explained the development of each of the variables and constraints that make up the model and the objective function, after this, the ratings used are presented, and so the model is presented.

This chapter discusses and summarizes the way in which the research process was performance. It begins with an epistemological and methodological conceptualization (section 6.2) and introduces a brief overview about operational research and optimization methods∴The rationale of the study is discussed with current data about wind power worldwide, is also shortly discussed some researches about economic analysis approach and our motivation for this research. The research framework and design is detailed (section 6.4), some literature statistics is shown in Table 6.1 where is explained thematic areas present in literature review process (see Figure 6.4) and the relationship within this research. Methodology procedures and phases of this research (section 6.1.2) are discussed and present some difficult found during the elaboration of this study. The theoretical framework and hypotheses development steps are justified in section 6.4.3, which results in the objectives (section 6.4.3.1), approach adopted (section 6.4.3.2), concepts and variables analyzed (section 6.4.3.3) and hypotheses and limitations (section 6.4.3.4) considered for this Ph.D. research work. In the research design (6.4.4) we can see the relation of variables and research boundary (6.4.4.1), mathematical model structuring (6.4.4.2) and the numerical simulation and validation process (6.4.4.1) are detailed and justified. Finally, in the section 6.5 presents the summary and conclusions of the whole chapter as well as section 6.6 the references used.

6.2 EPISTEMOLOGICAL AND METHODOLOGICAL RESEARCH ISSUES

Epistemology concerns what constitutes acceptable knowledge in a field of study. The central problem of epistemology is to decide how we can acquire knowledge which Plato and others following him have defined as "*justified true belief*". This definition of knowledge creates three substantive issues: *the nature of belief, the basis of truth* and *the problem of justification* Phillips (1974)∴This definition of knowledge is widely accepted, but the definition brings us some implications such as *"what is the source of our belief"*, *"how we determine what is true"* and *"how we justify our belief"*? These weighty issues each have their own branch of philosophical enquiry.

The implications about *"what is the source of our belief"*, *"how we determine what is true"* and *"how we justify our belief"* are driven by the research process. Research is a process of intellectual discovery, which has the potential to transform our knowledge and understanding of the world around us. The word research is composed of two syllables, "*re*" and "*search". The "re"* is a prefix meaning *again, a new or over again* and "*search"* is a verb meaning *to examine closely and carefully, to test and try, or to probe*. Together they form a noun "*describing a careful, systematic, patient study and investigation in some field of knowledge, undertaken to establish facts or principles"* (Kothari, 2009).

The research philosophy is a belief about the way in which data about a phenomenon should be gathered, analyzed and used. The term *epistemology* (what is known to be true) as opposed to doxology (what is believed to be true) encompasses the various philosophies of research approach. The purpose of science, then, is the process of transforming things *believed* into things *known*: *doxa* to *episteme*. Two major research philosophies have been identified in the Western tradition of science, namely positivist (sometimes called scientific) and interpretivist (also known as antipositivist)∴The research problem should determine the choice of methods — not the researcher's knowledge or experiences of different research methods. The nature of our research is interdisciplinary as we could notice during the literature review phase explained in section 6.4.

This Ph.D. research work needed to be driven methodologically (section 6.4.3.2) by an interdisciplinary branch of applied mathematics and social applied science that uses mathematical modeling methods and algorithms to arrive at optimal or near optimal solutions to complex practical problems, known as "*operations research"*. Operations research helps the manager/investor to achieve its goals using scientific methods and can be used in particular for wind farm design decisions. It is often concerned with optimizing of some objectives (maximum of profit, performance, etc. or minimum of loss, risk, cost, etc.) at limited resources. The majority of real-world optimization problems are multiobjective by nature — they have more than one and usually conflicting objectives that must be satisfied simultaneously. Instead of aiming at a single solution finding, the multiobjective optimization methods try to generate a set of good trade-off solutions (Pareto-optimal solutions) from which the decision maker could select∴Nevertheless, there exist some practical problems where the single criterion optimization would be able to get an optimal solution with less calculation difficulties. One of the questions that should be answered when using optimization methods for the wind farm design is the effectiveness and advisability of single or multicriteria optimization application (Mustakerov & Borissova, 2010).

6.3 RATIONALE OF THE STUDY

The availability of electrical energy is a precondition for the functioning of modern societies. It is used to provide the energy needed for operating information and communication technology, transportation, lighting, food processing and storage as well as a great variety of industrial processes, all of which are characteristics of a modern society∴Because the energy for many of the technologies, systems and possibilities that are a property of the developed world is provided as electricity, it can be presumed that there is a link between the level of penetration and consumption of electricity on the one hand and various properties of a society on the other. The relation between economic and societal development and electricity consumption is bidirectional. The availability of electricity greatly facilitates industrialization, because electricity is a convenient way to replace human power by other sources of energy, which are converted into electricity for transmission, distribution and consumption (Slootweg, 2003).

There are other electricity production technologies using renewable primary energy sources that do hence not involve the disadvantages of nuclear and thermal production. Examples are wave and tidal power, solar power and wind power∴In wave and tidal power plants, energy are extracted from the waves and from the water flows caused by the tide. In solar power plants, consisting of solar panels, sunlight is converted into electricity, whereas in wind turbines, the energy contained in flowing air is converted into electricity (Rosa, 2009).

One technology to generate electricity in a renewable way is to use wind turbines that convert the energy contained in the wind into electricity. The wind is an infinite primary energy source. Further, other environmental impacts of wind power are limited as well. Although they affect the landscape visually and emit some noise, the consequences of this are small and ecosystems seem hardly to be affected∴Further, once removed, their noise and visual impact disappear immediately and no permanent changes to the environment have occurred. A wind turbine generates the energy used to generate and install it in a few months so that the energy balance over the life cycle is definitely positive (Kennedy, 2005; Oliveira, 2010). According to Global Wind Energy Council (2012) the growth of wind power during the last decade in the world. The global cumulative installed of wind power capacity is growing approximately exponential over the past five years, annual growth has been above 30%.

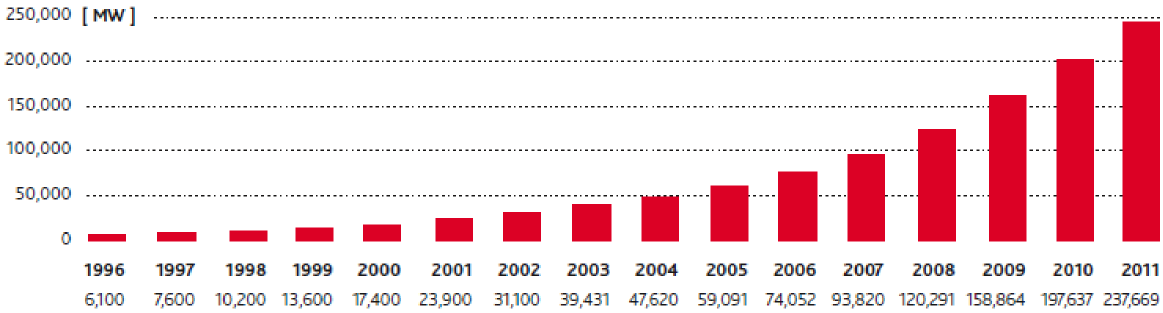

Figure 6.1 Global cumulative installed wind capacity 1996-2011. Source: Global Wind Report 2011 (GWEC, 2012)

Wind was even more dominant as a destination for investment in 2009 than in the previous year. In 2008, it accounted for $59 billion or 45% of all financial investment in sustainable energy, but in 2009, its share rose to 56%∴Total financial investment in wind last year was $67 billion, compared with $119 billion for all sustainable energy technologies (SEFI, 2010).

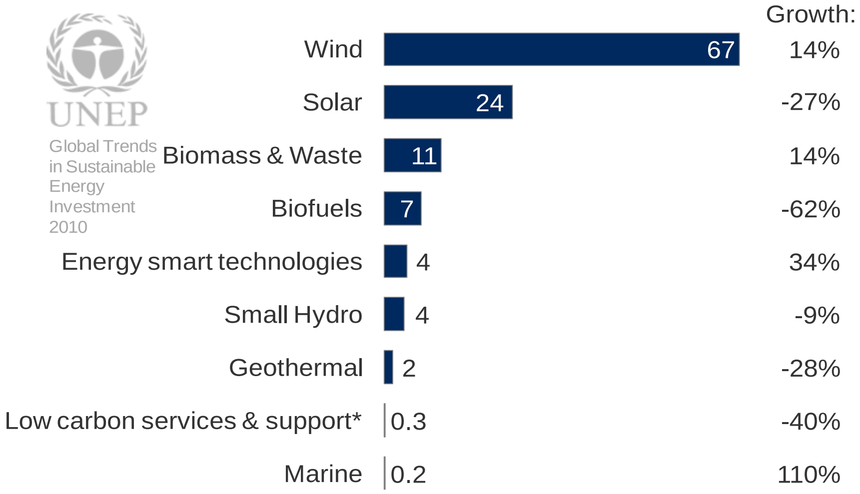

Figure 6.2 Financial new investment ($bn) and growth by technology (2008-2009). Source: SEFI (2010)

The strength of wind reflected several developments. One was the financial go-ahead for a number of large offshore wind farms in the North Sea, notably the 1GW London Array, the 317 MW Sheringham Shoal project and the first, 165 MW phase of Belwind∴Another was that, in uncertain economic and financial circumstances, wind was seen as a relatively mature and therefore lower risk, sub-sector of clean energy than some others (SEFI, 2010).

According to Wagner and Epe (2009) to promote wind energy, the research needs must be identified and the research work carried out. Initially, there are such environmental and social challenges as integration into the landscape, noise impact, bird flight paths, life cycle analysis and sustainability∴And of course, wind turbine and component design have to be improved continually, *i.e.* basic research in aerodynamics, structural dynamics, dynamic forces, new materials, feasibility studies into new systems, generators using permanent magnets, gear boxes, etc. For planning and building wind turbines and wind farms, commonly accepted certification procedures must be formulated and standardized∴For an optimized grid integration of wind energy, especially in great quantities, power quality can be supported by better forecasts of wind resources and by the use of storage sites.

El-Kordy, Badr, Abed, and Ibrahim (2002) the evaluation of the economics of energy systems strongly depends on the four cost factors: *capital cost; maintenance cost; fuel cost; and external cost*, when considered. Fuel and external costs are sensitive to fuel type and efficiency of the used system. Economic parameters such as discount, inflation and escalation rates, deeply affects the evaluation. Future sums of money must be discounted because of the inherent risk of future events not turning out as planned, the present worth method being considered as a suitable tool for comparing the different alternatives. The IEA (1991) developed a guidelines for the economic analysis of renewable energy technology applications that can be summarized as in the Figure 6.3.

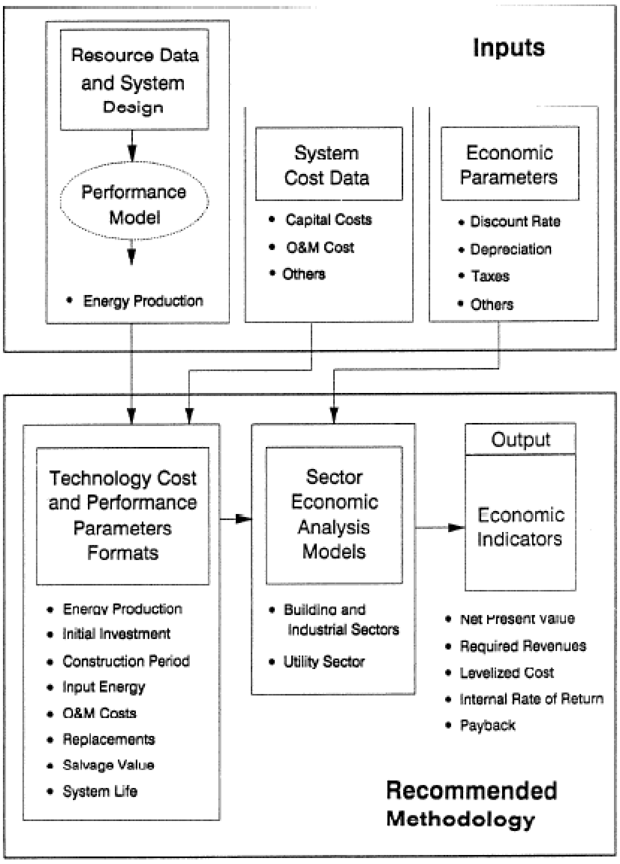

Figure 6.3 Diagram of recommended economic analysis approach. Source: IEA/Guidelines for the economic analysis of renewable energy technology applications IEA (1991, p. 12)

The IEA´s recommended methodology represents a consistent, structured, generalized approach which is appropriated for feasibility analysis for both public and private sector∴The Figure 6.3 shows the relationship between the inputs, costs, performance formats and sector analysis models. The entire economic indicator will be discussed ahead.

For Gökçek and Genç (2009) the calculation of the electrical energy production cost, all payments required for the installation of the power plant must be known∴The cash flow for the project includes the expenditures such as land, construction, fuel and operating and maintenance. In general, in power plants, cost per unit energy is calculated by dividing the amount of energy produced to the total expenditures made along the certain time interval. The levelized cost of electricity *(LCOE)* is one of the most important indicators for evaluating fiscal performance of power supply systems such as wind energy conversion system (WECS). *LCOE* is a technique applied by the techno-commercial analysts to calculate the unit cost throughout the economic life of the project. The levelized cost for WECS can be describe as the ratio of the total annualized cost of the WECS to the annual electricity produced from the system.

A techno-economic analysis of electricity production from wind energy made by Arslan (2010) discuss about Life-Cycle Cost analysis for onshore wind farm connected to a grid which essentially includes two main components, which are the investment and operations and maintenance (*O&M*) costs∴The investment cost includes the costs of the turbine, foundation, grid connection, and civil work. The environmentalist economists maintain that the real cost of a process must be calculated by adding to the investment and operational costs the cost of the damages to both human health and nature.

Zhang, Chowdhury, Messac, and Castillo (2010) introduce a new concept for economic evaluation of wind farms. Its formulation is based on *cost of energy (COE)* optimization. The result showed that *(i)* the profitability is particularly sensitive to changes in the capital cost, the capacity factor, the electricity escalation rate, and the initial installation cost; *(ii)* the profitability is slightly less sensitive to changes in the *O&M* cost; and *(iii)* the impact of the turbine rated power and the inflation rate is limited.

Nouni, Mullick, and Kandpal (2007) developed the levelized unit cost of electricity (*LUCE*). *LUCE* is one of the commonly used indicators for financial performance evaluation of renewable energy based decentralized power supply systems∴Total annualized cost is calculated by taking into consideration the capital costs of the different sub-systems of the SWEG project and its annual operation and maintenance cost.

The NREL (1995) compiled a *Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies* that provides guidance on economic evaluation approaches, economic measures, while offering a consistent basis on which analysts can perform analyses using standard assumptions for each case∴It not only provides information on the primary economic measures used in economic analyses and the fundamentals of finance but also provides guidance focused on the special considerations required in the economic evaluation of renewable energy projects.

Oliveira (2010) makes an overview about the indicators of attractiveness and risks like *simple payback (SPB), discounted payback (DPB), net present value (NPV), internal rate of return (IRR), benefit-to-cost ratio (BCR) and required revenues (RR)*. Also are discussed about some indicator of cost analysis in energy projects just like *LCOE*, *total life-cycle cost (TLCC), net present cost (NPC), levelized electricity production cost (LEPC)* and *unit present average cost* (*UPAC*). A simulation studied with these indicators concludes that they must be used as *tool kit* for wind energy project economic evaluation∴The indicator studied is not recommended to be applied alone, better combine the indicators in function of the evaluation objective.

There are many software available in the market that can be possible to make a sophisticated economic evaluation of an energy project for both renewable and efficiency application. We can cite the *RETScreen® International Clean Energy Project Analysis* used as an investment tool decision, *the HOMER energy software* applied to determinate the size of a power system with all its features for the system works as it must be∴It is possible to make a list of software used professionally by engineers, designers, economists and related professions.

The cost of the renewable technology can be evaluated by its cumulative production, research, development aspects. Many authors such Kobos, Erickson, and Drennen (2006), Ibenholt (2002), Lund (2006), Neij (1999, 2008), Pan and Köhler (2007) and Sorensen, Org Econ, Dev, and Dev (1997). For onshore and offshore wind energy technological aspect and its improvements have a great impact on cost reduction of wind energy project analysis∴It is an important aspect to be considered.

Efficiency planning and resource management is the key to the success of an energy project. Wind is one of the most potent alternative energy resources; however the economics of wind energy is not yet universally favorable to place wind at a competitive platform with conventional energy (fossil fuels) (Zhang et al., 2010). The *optimization model for economic evaluation of wind farms*, developed in this research, would allow investors and managers to better plan their projects, as well as provide valuable insights into the areas that require further development to improve the overall economics of wind energy.

As we can notice there is an exhaustive list of authors, institutions about economic evaluation methodologies and approaches applied to energy projects∴Each methodology and approach has its own objective, although they usually highlight economic merits only — in an energy project it is also interesting engineering and physics variables. In economics view it is necessary that the project could remunerate its costs and create profits for investor as well as any other economic agent involved. In the other hand, in engineering aspects, the project must be size according to its equipment, utilities and machinery used in the power station. How is it possible to optimize a wind farm, in a project conception or in a real system, in both economical and engineering point of view?

Both onshore and offshore wind energy has a growth during the last decade in the world and the importance of renewable energies technologies is more and more emphasized by public authorities because climate change and global warming is a concern for modern world, so methodologies which could become investment in this kind of technology more safe with simulation and optimization analysis will be welcome∴Wind energy is one of the renewable technologies that is becoming more and more competitive at the global level, but has not received enough attention on optimization process for economic evaluation of wind farms by the researchers in both economic and engineering aspects. Indeed, most of the optimization models reflects aspects of Engineering and Physics sciences, but in the economic view has not been analyzed in the depth that it deserves.

So, try to develop an economic optimization procedure of wind farms in function of the cost of energy produced using algorithm is a step ahead for economic evaluation methodologies, and I hope to apply it my professional life as Project Finance and Management Consultant in a few years for better decisions and make the alternative investment in renewable energy projects rightly and securely way to explore the resources from nature, help the economy growth and the environment protection. It is a way to join my professional experience and background with the new knowledge acquired during my Ph.D. in Economics in a specialized and scientific area, *Energy Economics*.

6.4 RESEARCH FRAMEWORK AND DESIGN

6.4.1 LITERATURE REVIEW

During the research, the literature review (1st phase of the research work) was undertaken from primary, secondary and tertiary sources comprising books, websites, and reports from companies operating in the wind energy sector and public organizations and papers published in scientific journals. The objective was to gain an understanding of the problem and possible approaches, building up a theoretical framework of this research work. In the Table 6.1 details a summary of literature review main sources.

Table 6.1 Literature review statistics

	Type of source	Number	Percentage (%)
✡	Books or books sections	100	11.0
✡	Conference proceedings	83	9.1
✡	Government documents	34	3.7
✡	Journal articles	558	61.3
✡	Magazine articles	10	1.2
✡	Others(*)	21	2.3
✡	Thesis	21	2.3
✡	Web pages	83	9.1
	Total	910	100.0

Source: Own elaboration
(*) Pamphlet, patents and reports.

It is important to highlight that most of journal articles reviewed is related to energy economics scientific field, such as, *Energy, Renewable and Sustainable Energy Reviews, Energy Conversion and Management, Energy Policy, Wind Energy Conversion, Energy Economics, Renewable Energy, Renewable & Sustainable Energy Reviews, Renewable Energy, Wind Energy, Electric Power Systems Research, Journal of Wind Engineering and Industrial Aerodynamics, Journal of Energy and Development, Applied Energy, Energy Problems and Environmental Engineering, Resource and Energy Economics, Global Journal of Researches in Engineering, Energy and the Environment, Energy Sources, Power Systems, Wind Engineering, Ecological Economics, Climate Policy* and others.

The work also included an extensive wind turbine data analysis, which focused mainly on the maximum power curve available on *Product Database of RETScreen Software*. The technical characteristics of the existing wind farms were obtained from official reports of specialized public and private organizations related to wind energy technology (sources as government documents, magazines articles and web pages)∴It is relevant to emphasize the self-constructed approach taken during the research project, because research on renewable power system optimization is encouraged by R&D priorities.

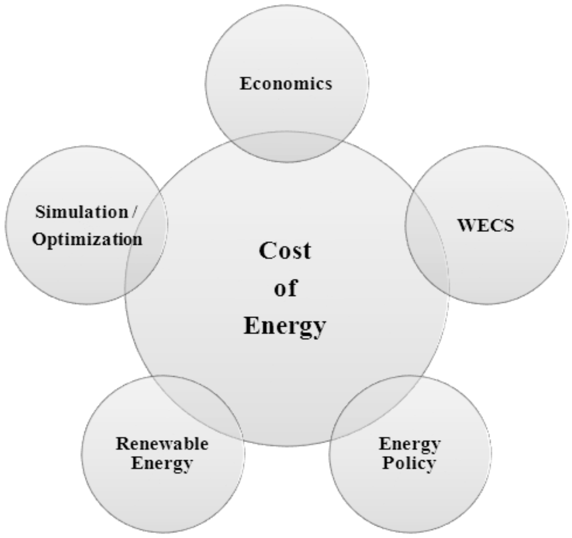

Figure 6.4 Thematic areas in literature review process. Source: Own elaboration

There are five main thematic areas in which this research is related to (see Figure 6.4), which detailed discussions were done in previous chapters. An analysis of literature on *economic measures* applied for renewable power systems, aiming to introduce and confront the different techniques of economic evaluation, in a microeconomic view. Also, a review on WECS was important to undertake, specially the identification of the rule and routine of wind energy systems operate∴In WECS thematic was examined the wind energy converters types, physics basics, describes how energy is extracted from the wind, explain about power coefficients and its limitations on wind power systems and what problems must be considered.

The *energy policy* and *renewable energy* thematic areas were analyzed altogether into the global status of wind energy market. The energy policy and renewable energy thematic areas address the wind energy situation worldwide in order to establish a context for understanding the contemporary wind energy industry∴It was explored the global character of wind energy sector, describing its R&D trends, technological evolution and diffusion process, investment focus, global market share and the global drivers for the expansion of this renewable technology.

The *simulation/optimization* thematic area was involved in this research due to its nature and the research object requires an interdisciplinary approach. In this thematic was introduced the concept of simulation and optimization, the objective of this process, model framework, main methods and techniques currently used∴During the literature review in this thematic we could classify the most used economic and engineering models of optimization algorithms for wind and hybrid power system (Tables 5.8 and 5.9). The costs of energy produced from RETs/WECS could be understood as a combination of components interlinked. A wind farm depends on directly the physical and environmental conditions. As shown in Figure 5.10 the system configuration has impacts on investment and *O&M* costs, which reflects on energy production cost by a wind farm∴Also, we can see the system configuration has influence on loss model and power performance model.

6.4.2 METHODOLOGICAL PROCEDURES

The research problem should determine the choice of methods — not the researcher's knowledge or experiences of different research methods. As we established in Chapter 1, the research was driven by the central research question:

What is the minimum difference between maximum power production and minimal total costs based on LCOE/NREL methodology proposed for a wind farm? If any, which possible strategies could be followed?

This question led us to a research trajectory which should be classified in phases. Each phase of the research is shown in Figure 6.5. The research methodology is structured in three phases: *1) Literature Review*; *2) Database Analysis* and *3) Simulation and Optimization.*

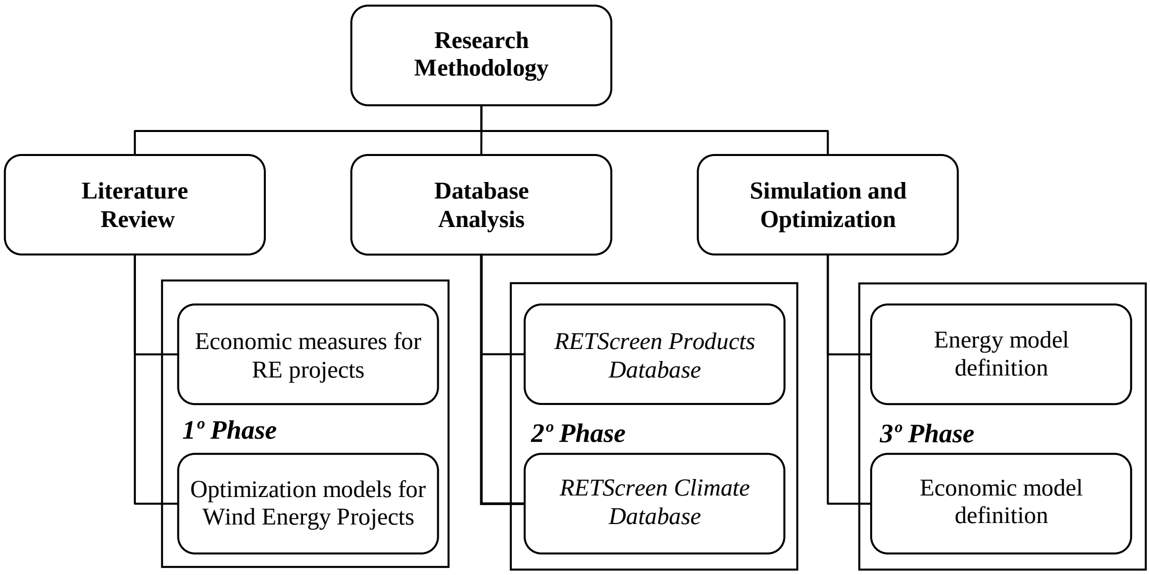

Figure 6.5 Research methodology overview. Source: Own elaboration

In the first phase of this research, literature review was undertaken on economic measures for Renewable Energy projects and optimization models (studies) for wind energy projects and the research question and objectives formulation. It was necessary to engage in different approaches, but complementary, microeconomic project evaluation methods and optimization methods applied to engineering solutions in renewable power systems, as detailed in Chapter 5. For this reason, and considering the objectives of each study, different approaches were followed in order to understand what could be complemented for an optimization model, both in economic and technical issues, as detailed in Chapters 4 and 5.

For the second phase of this research, database analysis, the choice of *RETScreen Product and Climate Database* was made by the worldwide recognition and scientific application in renewable energy projects economics analysis∴The key items checked in *RETScreen Product Database* were *capacity per unit, hub height, rotor diameter per turbine, swept area per turbine* and *power curve*. For *RETScreen Climate Database* were *"annual wind speed"*, *"air temperature"* and *"atmosphere pressure"*, because both technical and climate aspects influence directly on wind energy production (see Figure 6.7). In *RETScreen Software* it is possible to choose and change these inputs, so for simulations analysis it is useful (Himri, Stambouli, & Draoui, 2009; RETScreen® International Clean Energy Decision Support Centre, 2008). According to Connolly, Lund, Mathiesen, and Leahy (2010) *RETScreen Software* can be applied for scenario and investment optimization/simulation analysis, but not for operation optimization of power plants.

According to RETScreen® International Clean Energy Decision Support Centre (2008)*"the product data incorporated directly into the RETScreen Software provides access to over 6,000 pertinent product performance and specification data needed to describe the performance of the proposed clean energy system in the first step of the RETScreen analysis",* as the research is focused in WECS due to the objective, the technology chosen to be analyzed is wind turbine.

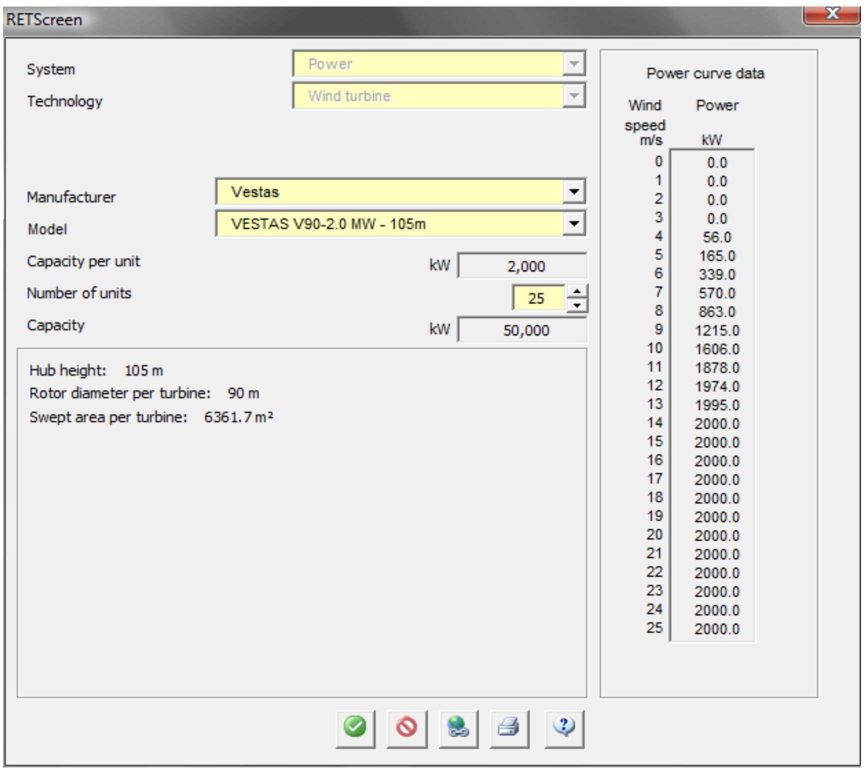

Figure 6.6 RETScreen Products Database information for wind energy projects models. Source: RETScreen® International Clean Energy Decision Support Centre (2009)

The *power curve*[75] of a wind turbine is one of the most important aspects to be check in this technology when the objective is optimizing the power system. We must notice that each turbine

[75] The *power curve* is a graph that indicates what the electric power output available in the wind turbine at different wind speeds.

has each own features and will condicionate the technical operation of the power plant at all∴Apply the best equipment is crucial for a lower cost of electricity produced from a wind farm!

The last phase of this research, *simulation and optimization*, it was firstly necessary develop an *energy model*[76] with technical features as the best performance as possible. It is possible only because the *RETScreen Product and Climate Database* analysis and chosen the optimized conditions. For developing the economic model it was necessary an exhausted analysis of feasibility and evaluation indicator for renewable energy projects. The optimization model was based on the combination of two fundamental methods: *i) maximize the total power output* and *ii) minimize the cost per unit power produced*. The mathematical formulation is based on the block diagram of the wind farm simulation and optimization algorithm developed during this research (see Figure 6.16). The models were then implemented in a computational language and solved using MS Excel-MATLAB®[77], as detailed in section 6.4.4 and Chapter 7.

The *energy model definition* has to take into consideration the variables shown in Figure 6.8, reflecting technical and local climate features of wind farm location. The optimization model developed is going to maximize the equipment used (wind turbines) with the actual climate site conditions *(wind speed, air temperature and atmosphere pressure)*. Figure 6.7 shows the meteorological site information available at RETScreen Software databases fed by NASA's satellite.

Site reference conditions — Select climate data location

Climate data location: Cape Saint James

Show data ☑

	Unit	Climate data location	Project location
Latitude	°N	51,9	51,9
Longitude	°E	-131,0	-131,0
Elevation	m	92	92
Heating design temperature	°C	-0,8	
Cooling design temperature	°C	17,7	
Earth temperature amplitude	°C	3,6	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		4,6	86,0%	0,70	100,1	11,1	7,9	415	0
February		5,2	84,3%	1,44	100,0	10,6	7,7	358	0
March		5,7	82,9%	2,62	100,0	9,2	7,7	381	0
April		6,8	81,4%	4,04	100,4	8,9	8,3	336	0
May		8,8	84,8%	5,29	100,5	8,1	9,8	285	0
June		10,8	87,1%	5,71	100,7	7,5	11,7	216	24
July		13,0	89,5%	5,40	100,8	7,2	13,6	155	93
August		14,1	88,7%	4,66	100,7	7,0	14,7	121	127
September		13,2	85,8%	3,44	100,5	7,5	13,9	144	96
October		10,1	86,3%	1,84	100,2	9,5	11,8	245	3
November		6,9	84,3%	0,91	99,9	10,3	9,8	333	0
December		5,2	85,5%	0,57	100,1	10,8	8,5	397	0
Annual		8,7	85,6%	3,06	100,3	9,0	10,5	3.387	343
Measured at	m					10,0	0,0		

Figure 6.7 Site reference conditions used for wind energy projects models. Source: RETScreen® International Clean Energy Decision Support Centre (2009)

[76] In this case, the *energy model* means features or specific parameters describing the location of the energy project, the type of system used, the type of technology for the power plant, the loads demanded, and the renewable energy resource (for RETs).
[77] For more information, please see at http://www.mathworks.com/products/matlab.

The *economic model definition* also has to take into consideration the variables shown in Figure 6.8, reflecting economic and financial features of a typical wind farm project∴The cost optimization algorithm developed is going to minimize the cost of energy produced from the power plant (wind farm).

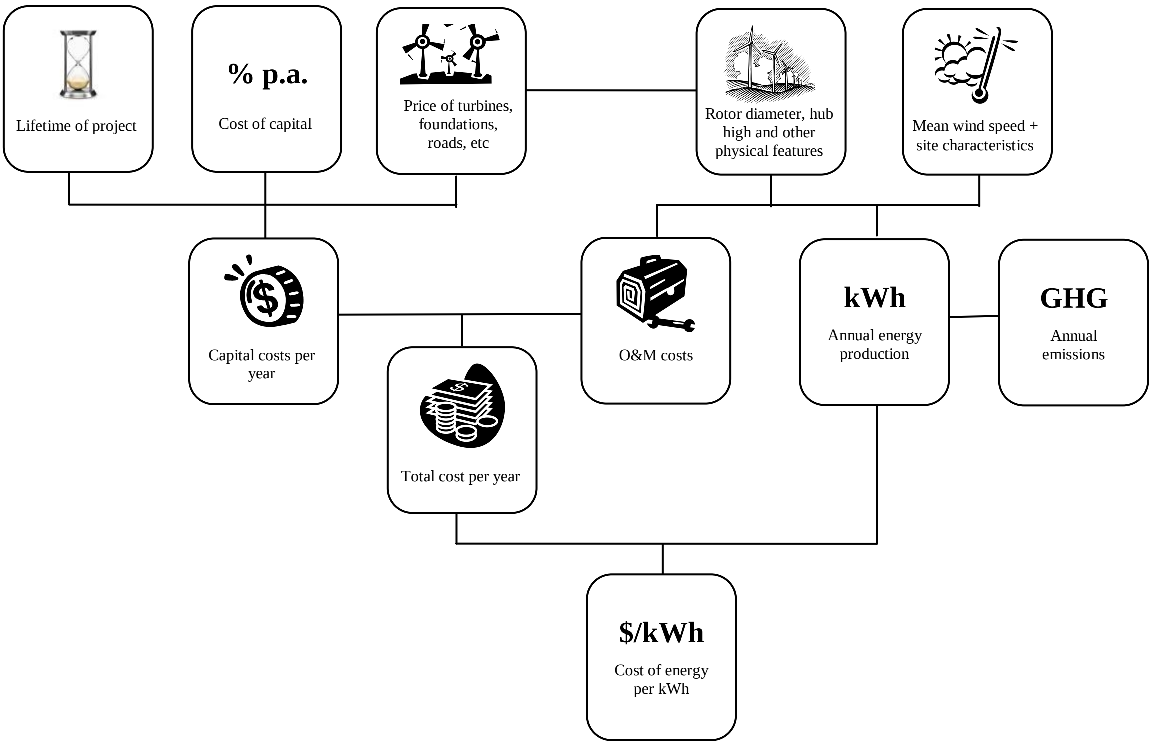

Figure 6.8 Variables influencing on COE in a wind power plant. Source: based on Morthorst and Shimon Awerbuch (2009)

As we can see, the lifetime of the project, cost of capital, price of wind turbines (with foundations and others auxiliaries infrastructure) reflect directly on capital cost per year in a wind power project. According to Milborrow (2008) the cost of capital can reach 80% of the total cost of the project during its lifetime, with variations between models, and local markets∴*O&M* costs depend on technical features of the wind power plant (e.g. rotor diameter, hub high and other physical features of the BOP[78]). The configuration of the wind farm and climatic conditions (see Figures 6.7 and 6.8) determine the expected wind farm production and also the annual emissions of greenhouse gases[79] (GHG). The *cost of energy (COE)* per kWh is a result from total cost per year in relation to annual energy production of a wind power plant. That is why in the *economic model definition* we must consider the variables and their relationship and influence ones each other.

[78] The BOP is the acronym of "*Balance Of the Plant"* and refers to the infrastructure of a wind farm project, in other words all elements of the wind farm, excluding the turbines. It includes civil works, SCADA and internal electrical system. It may also include elements of the grid connection. For more details, please see WindFacts (2010).

[79] The gases whose absorption of solar radiation is responsible for the greenhouse effect, including carbon dioxide, methane, ozone, and the fluorocarbons.

6.4.3 THEORETICAL FRAMEWORK AND HYPOTHESES DEVELOPMENT

Many issues related to renewable energy project analysis are truly interdisciplinary in their nature. Therefore, research within the field should reflect that fact and should; if possible, it is used more than one scientific discipline or method. Thus, model results and insights become supported by not just one but several scientific disciplines. The optimization model for economic evaluation of wind farms can be as an efficient planning and resource management, which is the key to the success of an energy project∴Wind energy is one of the most potent alternative energy resources; however the economics of wind energy is not yet universally favorable to place wind at a competitive platform with coal and natural gas (fossil fuels)∴Economic evaluation models of wind projects developed would allow investors to better plan their projects, as well as provide valuable insight into the areas that require further development to improve the overall economics of wind energy projects.

According to Benatiallah, Kadia, and Dakyob (2010) the economic model should be made while attempting to optimize the size of integrated power production systems favoring an affordable unit price of power produced∴The economic analysis of the wind system has been made and the cost aspects have also been taken into account for optimization of the size of the systems. For Baños et al. (2011) some of these optimization methods are based on traditional approaches, such as *Mixed-Integer and Interval Linear-Programming*[80], *Lagrangian Relaxation*[81], *Quadratic Programming*[82], and *Nelder–Mead Simplex Search*[83], while a growing number of research papers tackle these problems using *heuristic optimization methods*[84], especially *Genetic Algorithms*[85] and *Particle Swarm Optimization*[86]. Besides purposes and approaches of models used, the models can also be distinguished according to their structure, more specific the assumptions on which the structure is based. For each type of model, a decision has to be made on which assumptions will be embedded in the model structure (the internal assumptions) and which are left to be determined by the user (i.e., external assumptions). In this research, the model proposed followed by the research objectives and approach which influence directly on internal and external assumptions considering in the analytical model resulted from this Ph.D. research work.

[80] Mixed Integer Programming (MIP) is actually an extension of Linear Programming which allows for greater detail in formulating technical properties and relations in modeling energy systems. Decisions such as *Yes/No* or *(0/1)* are admitted as well as nonconvex relations for discrete decision problems. MIP can be used when addressing questions such as whether or not to include a particular energy conversion plant in a system. By using MIP, variables that cannot reasonably assume any arbitrary (e.g., small) value — such as unit sizes of power plants — can be properly reflected in an otherwise linear model (World Bank, UNDP, & ESMAP., 1991).

[81] *Lagrangian Relaxation* consists in removing some of the restrictions of the original formulation, but attempts to embed these inequalities in the objective function. The idea is to penalize the objective function when the restrictions removed are violated. The *"weight"* of these penalties is controlled by coefficients called *Lagrangian multipliers* (Fisher, 2004).

[82] It is the problem of optimizing (minimizing or maximizing) a quadratic function of several variables subject to linear constraints on these variables (Nocedal & Wright, 1999).

[83] It is also called *"Simplex Search"* which uses the concept of a simplex, which is a special polytope of $N + 1$ vertices in N dimensions. Examples of simplices include a line segment on a line, a triangle on a plane, a tetrahedron in three-dimensional space and so forth. The method approximates a local optimum of a problem when the objective function varies smoothly (Carson & Maria, 1997).

[84] Heuristic optimization is the process that adopts methods beginning with an initial solution and utilizes types of operations to modify this solution. This gives these methods the flexibility to move to another solution and continue the improvement process (Ozturk & Norman, 2004).

[85] Genetic Algorithms (GAs) are computer imitation of a simplified and idealized evolution. DNA is represented as a string where each position in the string may take on one of finite sets of values. The fitness of the organism is determined by a fitness function; the function decodes the string and returns a real scalar value (Carson & Maria, 1997).

[86] Particle Swarm Optimization (PSO) mimics the behavior of individuals in a swarm to maximize the survival of the species. In PSO, each individual makes his decision using his own experience together with other individuals' experiences. It is the representation of a metaphor of social interaction, searches a space by adjusting the trajectories of moving points in a multidimensional space (Jong-Bae, Ki-Song, Joong-Rin, & Lee, 2005).

6.4.3.1 RESEARCH OBJECTIVES

As discussed before in this chapter the main objective of this thesis is to verify how concepts derived from the Theory of Simulation and Optimization can be helpful to *develop an algorithm for Economic Optimization of Wind Farms in Function of the Cost of Energy Produced.* Particularly, it intends to maximize wind farm´s production, mainly in terms of power delivered and the lowest production cost, and what its relationships. More specifically it aims to:

1. Apply a combination of methodologies and approaches of optimization procedures according to a microeconomic point of view for economic evaluation applied on wind farms, in an investment and management context, determining the best option that results in the best decision-make for an optimization model.

2. Review and systematize methods and techniques of economic evaluation applied to renewable energy projects, specific to wind energy projects∴Both project and cost methodologies of economic evaluation are reviewed for a model optimization construction for a proposed optimization model with its objective function most appropriated.

3. Propose a methodology based on assumptions of *Theory of Simulation and Optimization* that could develop the best solution for investment and management decisions with a different approach, non-deterministic nature, for validating the new concepts of economic project evaluation, supported by the analysis process, design and objective function developed with its constraints.

The overall model must recognize the multiple and conflicting objectives involved in energy decisions, dealing with the large economic and engineering costs involved and also eliciting the priorities variables∴The process must combine simultaneously efficiency with investment planning, assessing whether incremental investment should be met through existing economic advantage or through the addition of new production capacity, in order to maximize its production.

Based on accomplishing of these three objectives, it is expected as contribution of this thesis:

1. Development of a new methodology able to inform the investor or manager of a wind energy project what its size, initial investment, *O&M* costs (including frequency of maintenance routines), replacement cost, annual energy production, maximum losses expected, how many turbines, high hub, minimum wind speed, as well as its maximum variation;

2. Make an integration of methods applied to economics and engineering sciences in function to the multivariable problem and create a planning and managing tool for energy projects, special to onshore wind energy that could be used in the future for new methodologies and approaches of economic evaluation for renewable energy projects.

3. Create a tool applied to competitiveness ranking for wind farms in a place, region and district considering the cost of energy produced. It is important to classify economically the land or areas and gives an idea of competitiveness' measurement.

6.4.3.2 RESEARCH APPROACH

The overall approach taken to reach the research objective was to investigate the formulation and logics of the various evaluation models/indicators, each model has its own variables and relations to explain the results and objectives for each model studied∴At first, it checks only the economic models and then engineering evaluation models are analyzed with its objectives too. According to the central question or this research, it is an industrial problem and the steps to follow might be considered as follows (Hillier, Lieberman, & Hillier, 1995):

1. *Define the problem of interest and gather relevant data* — why is there dissatisfaction with the present operations and what alternative courses of action appear to hold most promise of being effective solutions to the problem, relative to a set of pertinent objectives. The size of a wind farm project and the size of the wind turbine itself will vary depending on the amount of electricity the developer intends to produce∴Costs of components per unit size tend to decrease as size increases, and through economies of scale, the construction costs per unit manufactured decreases as more wind turbines are manufactured (at least to the point where equipment and personnel are adequate). However, because the mass of the wind turbines' materials increases at a cubic rate to its rotor diameter, and the power rating increases with the square of its rotor diameter, there will be a critical size that increases the cost per kW of maximum power (Johnson, 2001). As wind energy is an intermittent source of power, this fact gives rise to extra costs in production, distribution and transmission, as well as the cost associated with the intermittency of wind.

2. *Determine a suitable "measure of effectiveness" (often called the "objective function") to be optimized* — the wind energy industry is capital intensive, so wind farms' investment must be returned at an expected rate at investor point of view. Usually, the wind farm promoter (manager) needs to overcome some technical and economic issues about sub operation which has to be maximized or certain costs minimized. Thus, most optimizations are economic optimizations.

3. *Elaborate a model to represent the system whose optimization is desired* — a model may be defined as a device, physical or symbolic. Models are almost always necessary in industrial work since experimentation with full-sized industrial equipment disrupts production and is very costly in money and time. And sometimes industrial equipment is only contemplated in design or as replacements. Usually, the most desirable model is the mathematical model, which employs mathematical statements to represent the system and enables responses to be calculated rather than be measured. The measure of effectiveness is expressed as a function of a set of variables at least one of which is subject to control. (The variables involved are often functionally interrelated so that they behave similarly to the active variables in the realistic system simulated)∴As the variables are manipulated; their effectiveness in optimizing the objective is changed. Often there are restrictions imposed on the values of the independent variables, or functional restraints involving these variables, and such restraints are expressed by supplementary equations and/or inequations.

4. *Solve the problem* — determine the values of the independent (controllable) variables which optimize the objective (*i.e.*, maximize the effectiveness of the system) subject to any restraints imposed on the system (equipment limitations, rigid management policy, operating limitations, minimum quality characteristics, market restrictions, legal limitations, etc.).

5. *Test the model and calculated solution obtained from it* — if adjustment is indicated, readjust the model, determine a new solution, and check again. A carefully chosen initial model may eliminate difficulties here.

6. *Establish controls* — the lack of effective control over certain variables might seriously invalidate the appropriateness of the original model∴The need for a change in the original controllable variables to offset changes in uncontrollable variables must be recognized and a new optimum solution found.

7. *Implement the suggested solution* through appropriate organizational channels, and establish a set of operating procedures so that those concerned with control of the operation can attain the optimum as easily as possible.

It proved necessary to investigate the various aspects of a microeconomics view, as a power station unit, because when it is studied separately, it is necessary to understand the wind system conversion, its electro-mechanical, layout and economical restrictions. As it has been said about wind farms, the intermittency must be considered into economic evaluation methodologies, fundamental difference can be found when the intermittency is not considered∴It was hence impossible to draw conclusions with respect to the isolated impact of the intermittency effect, because it was made simulation and the conclusions had to be qualified for the minimum cost of energy and other economic indicators being used.

The widely used *RETScreen software*, version 4, a tool for analyzing the technical and financial viability of potential renewable energy projects is now being used by more than 35,000 people in over 196 countries around the globe (RETScreen® International Clean Energy Decision Support Centre, 2008) was also used for the research∴At the start of the research project, it was quickly found that there was not a unique methodology or optimization procedure model included in the standard libraries (products and projects database) of this software. Further study showed that at that time, this also needed to other simulation packages, and that wind technologies available are based only on manufactures´ information∴It was therefore inevitable to adopt another methodology for optimization process and try simulation by nonlinear algorithms.

Finally we studied extensively the *Theory of Simulation and Optimization* and take advantage of practical aspects of the simulation approach, as well as the manipulation of variables and its results. Then, we developed an optimized technology and calculated the best economics results for a hypothetical wind energy project∴A preliminary validation of the developed model was carried out using different combinations of wind technologies available in the *RETScreen Products Database*. It is important to say again, the software does not make simulations, only deterministic and probabilistic calculations.

6.4.3.3 CONCEPTS AND VARIABLES

As we already discussed about philosophical, epistemological, methodological issues and paradigms of research in function of the research object — economical optimization of a wind farm *via* cost of electricity produced — the next step is determine the *concepts* and *variables* to be analyzed through a research. Figure 6.9 shows the inter-relations of these aspects in the research process.

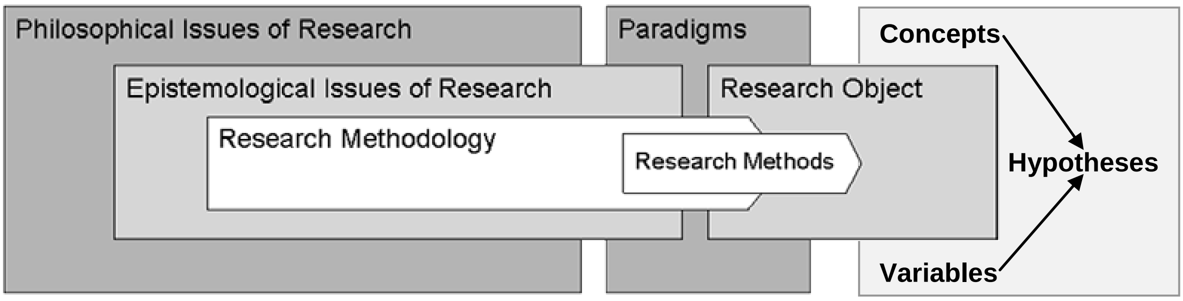

Figure 6.9 Epistemological tree for research concepts and variables integration. Source: adapted from Smyth and Morris (2007)

As we can notice in Figure 6.9, concepts, variables and hypotheses constitute the links between theory and practical (empirical) analysis. Concepts are terms that refer to the characteristics of events, situations and individuals that are studied∴In order to apply the theory or preposition; we make the operationalization of the main definitions adopted for this research (see Table 6.2) through quantification of them. According to Magoha (2001) for economic analysis of wind energy, a variety of methods can be adopted: their accuracy is strictly related to the type of the WECS technology and its application for each power plant (*e.g.* whether it is for remote autonomous use or for grid connection).

The conceptualization is based on the *LCOE/NREL methodology*[87] presented and explained in Chapter 5, through the Eqn (5.24), with the following formula:

$$LCOE = \frac{FCR \times ICC + LRC}{AEP_{net}} + O\&M + PTC \qquad [\$/kWh]$$

We understand that this equation can be analyzed into two aspects: the one is *"economics"* and the other is *"engineering"*. The economic nature of the formula is related to *FCR, ICC, LRC, O&M* and *PTC* elements. AEP_{net} represents the power output (production), so the "*engineering"* part.

[87] *NREL/LCOE* is the acronym of National Renewable Energy Laboratory/Levelized Cost Of Energy. For more details about this methodology, please see Cohen (1989); Cory and Schwabe (2009); George and Schweizer (2008); Milligan and Graham (1997); NREL (1995); Tidball, Bluestein, Rodriguez, and Knoke (2010).

We must highlight that *PTC* element add to this economic part the public influence on cost of energy produced from RETs$\therefore$In other words, *LCOE/NREL* methodology is a comprehensive economic metric for cost of energy production and also can be applied to WECS. We possible compare different technologies or the same technology in different places.

Table 6.2 Conceptual and operational definitions used for the Ph.D. research work

	Conceptual definition	Operational definition
Economic Optimization	In economics, the term *economic optimization* means that resources are being used in the best possible way to meet the needs of people's desires. In other words, the existence of *optimization* is synonymous with absence or minimal losses. In micro-economic terms, *economic optimization* in terms of production means that, given the available technology and the prices of production factors, determined agent was able to generate as many goods with minimal production costs (Griffiths & Wall, 2000).	It was run the algorithm developed during this Ph.D. research for economic optimization of wind farms (see Eqn 6.2). $LCOE_{wso} = \frac{LCCCM_{WF} + LRCM}{LCPM_{WF}} + O\&M_{WFCM} + RCM_{WF} - REPIM$
Simulation Model	It is a descriptive model based on a logical representation of a system, and it is aimed at reproducing a simplified operation of this system. A simulation model is referred to as static if it represents the operation of the system in a single time period; it is referred to as dynamic if the output of the current period is affected by evolution or expansion compared with previous periods (Van Beeck, 1999).	Run the *objective function* ($LCOE_{wso}$) which represents the real system through a computational language and solved using commercial and/or academic softwares (e.g. MS Excel-MATLAB®).
Levelized Cost of Energy (*LCOE*)	*LCOE* is the real production cost of kilowatt-hours (kWh) of electricity. Includes the total construction, central production costs of the power station during its economic lifetime, financing costs, return on capital and depreciation. Costs are leveled in current monetary values, or adjusted to eliminate the impact of inflation (Oliveira, Fernandes, & Gouveia, 2011).	*LCOE* methodology was based on *LCOE/NREL*. Each element was changed by the formulas present in section 6.4.4.2. $LCOE = \frac{FCR \times ICC + LRC}{AEP_{net}} + O\&M + PTC$
Annual Energy Production (AEP)	The calculation of theoretical production of electricity by the wind farm is result of the product among installed electricity capacity *(P_c)*, capacity factor *(C_F)* and total hours of production (24 hours x 365 days[88]) of the wind farm. The capacity factor is in function of production losses, maintenance stops and periods when the wind speed is not suitable for electricity production by the aerogenerators. The capacity factor is also named utilization factor of the production system (Tidball et al., 2010).	We also make the equivalence to the *Annual Energy Production Net* (AEP_{net}) for annual production electricity by the wind farm. The wind farm production for this Ph.D. research work is measure by the $LCPM_{WF}$ variable. $LCPM_{WF} = f(WF_{CM}; WT_{LM}; PC_{PM}; P\&D_{LM})$
Cost of Energy (COE)	The ratio of the *total costs (C)* to the *annual energy production (AEP)*. The *total cost per year* is the sum of *capital costs* and *O&M costs per year* (see Figure 6.8) (Fuglsang & Madsen, 1999; Fuglsang & Thomsen, 1998). It is usually measured in $/kWh.	We adopted the concept of unit cost for the *COE*. It has been considered the relation of *total costs* and *total output*, in our case, the *annual energy production* (Griffiths & Wall, 2000). $COE \Rightarrow Unit\ Cost = \frac{C}{AEP}$

Source: Own elaboration

[88] Some authors consider 365.25 days/year for annual production estimation by the wind power plant, so is added more six hours of production per year, in other words, 8 766 hours per year. In our research we consider what is the most hours of production used for wind power production estimation (8 760 hours per year).

6.4.3.4 RESEARCH HYPOTHESES AND LIMITATIONS

According to Figure 6.9, from the epistemological aspects of the research, research approach (paradigm) and conceptual and operational definitions already done the research hypotheses can be developed in order to check whether the new theory formulated *(Economic Optimization Algorithm Proposed)* is valid[89] or not. For Jensen and Bard (2003) the research hypotheses are fundamental and necessary and a scientific *"piece"* in a research work∴One another important aspect is the relationships between the variables analyzed in a research work, these variables can be classified into univariate (related to a single variable), bivariate (the relationship between two variables, one dependent and other independent) and multivariate (relate more than two variables) (Kothari, 2009). In this research there were used multivariate variables and the systemic approach in an operational research context.

During the literature review (1st phase of the research work) we could map five thematic areas (see Figure 6.4) for a better and comprehensive understanding about the cost of energy produced from a wind farm, in economic terms, considering manufacturing nature of the WECS∴It has been necessary to study the inter-relations among the variables which influence on *COE*, as shown in Figure 6.8. For resuming these thematic areas in Figure 6.10 is shown how was studied the cost of energy during the Ph.D. research work.

$$COE = Economics + WECS + EnergyPolicy + RenewableEnergy + Simulation/Optimization \quad \text{Eqn (6.1)}$$

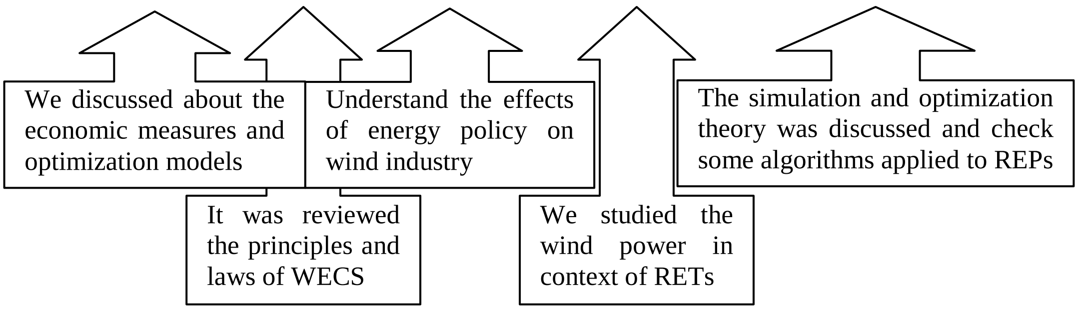

Figure 6.10 Contributions of each thematic area during the literature review process. Source: Own elaboration

COE can be analyzed in many ways, but we focus on the producer point of view, in other words, what is the *real minimum cost* for the power producer in a wind farm? It is necessary to understand how the WECS works, what king of relation the wind power producer has within the electricity market and what renewable energy policies can influence on the power production cost. WE could see during the extensive literature review, the lifetime of the REPs is around 15 to 25 years, case of wind energy projects∴Gökçek and Genç (2009) have made an economic analysis for long term (more than ten years), it is better consider the whole lifetime for the same analysis.

89 The term *"valid"* derives from *"validation"* that conveys a sense that a scientific effort must be justified in some logical, objective, and algorithmic way (Kleindorfer, O'Neill, & Ganeshan, 1998).

The research work was driven by *COE* minimization during the wind farm´s lifetime that is why we consider *LCOE* more appropriate to our research objectives. The cost is the most important pledge for economic operation of wind farm. There are two theories for minimum of wind power cost: *economy of scale*[90] and *square-cube theorem*[91]. Many authors suggest we should develop great unit, and it emphasizes wind speed is proportionate to altitude; while other scholars consider the captured energy is proportionate to diameter of wind turbine, meantime, mass of wind turbine (i.e. cost) is proportionate to square of diameter (Tai & Wen-rui, 2009). It is assertive to use the two theories, however, cost of energy produced will not be totally proportionate to the production in a yearly basis, it must include other factors, and the cost function *($LCOE_{wso}$)* for the Ph.D. research work was developed considering the following hypotheses as shown in Table 6.3.

Table 6.3 Research hypotheses considering for the Ph.D. research work

Hypotheses	Statement	Basis
RH_1	The WECS is dependent on the local wind resources. The better the local wind resources more electricity production.	The theoretical power output in the current wind technology is equal to the cube of the wind speed. However, the power production profile of a wind turbine is typically more proportional to the square of the average wind speed (Manwell, McGowan, & Rogers, 2002).
RH_2	The higher the production of the wind farm, the less will be the unit cost of electricity, is an inverse relationship.	Considering the ratio between costs of the wind farm and power output (production), and if we keep constant the costs and increase the production, the cost per unit falls, taking into consideration some proportions (Fuglsang & Madsen, 1999; Fuglsang & Thomsen, 1998).
RH_3	It is possible to determine the *break-even-point* of a wind farm from the wind speed and the minimum *LCOE*.	Wind power plants generate electricity when wind blows and the plant output depends on the wind speed (Georgilakis, 2008).
RH_4	The layout of wind turbines has impact directly on *LCOE*. It can increase or decrease *LCOE*, depends on the design used.	The wind farm layout possible can lead to lower than expected wind power production, increased or decreased *O&M* costs, investment costs and in general the cost of energy produced (Kusiak & Song, 2010).
RH_5	The smaller *LCOE*, more optimized is the wind farm, in economic terms.	The increasing in capacity factor from values below the levels of average capacity factor can lead mainly to large reductions in *LCOE* (Cory & Schwabe, 2009).

[90] The *economy of scale* is a reduction in cost per unit resulting from increased production, realized through operational efficiencies. Economies of scale can be accomplished because as production increases, the cost of producing each additional unit reduces (Griffiths & Wall, 2000).

[91] Discovered in the 16th century by Galileo, this *theorem* explains that no biological organism can suffer a change of size (consequently, in scale) without changing its shape or conformation: the volume of this organism will grow in a cubic reason, but the surface which contains itself increases into a square ratio only. In WECS, the output power is just the cube of wind speed (see Chapter 4, section 4.4.1).

Table 6.3 Research hypotheses considering for the Ph.D. research work (continuation)

Hypotheses	Statement	Basis
RH_6	The maintenance program can be used as a strategy of optimization of the wind farm, in technical and economic terms.	Maintenance management for wind power production systems aims at reducing the overall maintenance cost and improving the availability of the systems. Since the operation and maintenance costs represent a substantial portion of the total life cycle costs of wind power production systems (Ding & Tian, 2012; Tian, Jin, Wu, & Ding, 2011).
RH_7	The type of energy policy (EP) can influence directly on *LCOE*. It depends on the focus of the EP instrument adopted.	The renewables support instruments can be applied quite differently. Many of the available instruments can essentially be classified in grants about *investment costs* and *operation (production).* As well as *investment incentives*, *incentives for operational costs* are subsidies to reduce the cost of energy produced (Wohlgemuth & Madlener, 2000).

Source: Own elaboration

According to the objectives and hypotheses research developed for this Ph.D. research work, we have to face some limitations. These limitations of this work should be mentioned∴The studies included in this research focus on *cost of energy* (electricity) produced from a wind farm. So we can list the most important limitations of this research work:

1. *There is no standard LCOE to be reference for this kind of research.* There is not a single price and cost of energy for wind farms. Both depend on the location, size and number of turbines, in addition to being influenced by political incentives or subsidies granted by governments. These facts will affect the generalization done in the simulations which criterion is the *minimum LCOE* reached from the results in the studies done.

2. *It is not possible to harmonize all input assumptions.* A large number of assumptions have to be made before model simulations/optimization is carried out. Even though the input assumptions have been harmonized to an extensive degree in all sub-models, it has not been possible to reach full harmonization. The reason is that the sub-models are designed differently. Some of these differences make it impractical to fully harmonize model input without impacts the functionality of the sub-models inter-linked, and some of these differences significantly affect model results in general.

3. *Recognize the "locational" differences for the model proposed as universal methodology for economic optimization of wind farms.* As for *"locational"* differences may involve e.g. how are considered and practiced some rules, e.g. energy markets, policy instruments and taxation. This is strongly influenced by the *"energy history"* of a certain place. Models based on countries where a certain technology to the existing date has played an important role tend to look generously on the prospects for technology also in the future.

6.4.4 RESEARCH DESIGN

The research design is the conceptual structure and way within which the research work would be conducted. The function of research design is to provide for the collection of relevant scientific and valid information with intention to give an answer to the problem of the research work (Kothari, 2009). The research design was developed during the Ph.D. research work and adapted to its inter-disciplinary nature, among the simulation and optimization theory, economic measures applied to RETs, WECS and energy policy.

We can summarize that a problem of optimization is formed by choosing *variables*, *objective function* and *group of answers viable*. The problem is choosing *the best viable alternative*. In General, the theory of simulation and optimization allows the representation of the problem in a search for the *maximum* or *minimum* of objective function in respect to the variables of choice and subject to restrictions $\therefore$ For this research work we have been considered the *clusters of variables* to be analyzed in the new *LCOE* methodology proposed:

1. *Wind speed* (v_w) — the energy production cost is strongly dependent on the average wind speed. As an example, the energy production cost at an average wind speed of 6.5m/s was twice as high as the cost for an average wind speed of 10m/s. It was also found that the energy production cost decreases when the power output of the wind farm increases (Lundberg, 2006). There is clear evidence about the effect of the wind speed at the cost of energy produced in WECS.

2. *Wind turbines layout* (L_{wt}) — the wind turbines layout has direct impact on wind farm production and costs. As we have already discussed in Chapter 4, sections 4.5.1, 4.5.2 and 4.5.3 by many researcher the most factors that usually affect wind turbines location are: *(1) optimization of energy production and COE output; (2) turbines loads; (3) noise emissions* and *(4) visual impact* (Gonzalez, Rodriguez, Mora, Santos, & Payan, 2009; Payan, Gonzalez, Rodriguez, Mora, & Santos, 2011; Zhang, Chowdhury, Messac, & Castillo, 2012b). The Ph.D. research work has focused only on *optimization of energy cost*.

3. *Operations and Maintenance management* ($O\&M_{manag}$) — *O&M* management aims at improving the availability of the systems and reducing the overall maintenance cost (Ding & Tian, 2012). This variable can be also classified into *scheduled maintenance* and *unscheduled maintenance*, as already explained in Chapter 5, section 5.4.1.1.

4. *Energy policy instruments* (E_{pi}) — a strong focus on capacity installations might result in the construction of projects with little productive efficiency. Production incentives, in contrast, help to specially stimulate the development of efficient projects, resulting in a higher output of renewable energy per supporting capital involved (Enzensberger, Wietschel, & Rentz, 2002).

In order to test and understand the impact of these *clusters of variables* on $LCOE_{wso}$ we have made several simulations. We have done 900 interactions within the *cluster of variables*, considering 3 different sites for a hypothetical wind farm, as detailed in Table 7.16.

One of the reasons for these sites (Brazil, Canada and Portugal) was based on *installed capacity of wind energy* at the end of 2011 of 1 509 MW, MW 5 265 and 4 083 MW, respectively, according to the GWEC (2012). The *annual mean of wind speed* was the determinant factor to choose the best site in these countries with geographies, climates, and structure, politics, technological development and different public perception about RETs∴Table 6.4 shows these locations used for the simulations and optimization procedures.

Table 6.4 Locations chosen for simulations procedures within criteria and reasons

Location	Criteria	Reason
1. Aracati, Ceara, Brazil	Local wind resources; Energy policy	The annual calculated mean of wind speed is 7.4m/s
2. Cape Saint James, British Columbia, Canada	Local wind resources; Energy policy	The annual calculated mean of wind speed is 12.5m/s
3. Corvo Island, Açores, Portugal	Local wind resources; Energy policy	The annual mean of wind speed is 9.1m/s

Source: RETScreen® International Clean Energy Decision Support Centre (2009)

For each site selected in the *RETScreen Climate Database* (2nd phase of the research work) we have gotten the following information about, as shown in Figures 6.11, 6.12 and 6.13.

Site reference conditions

Select climate data location

Climate data location: Aracati

Show data ☑

	Unit	Climate data location	Project location
Latitude	°N	-4,6	-4,6
Longitude	°E	-37,8	-37,8
Elevation	m	17	17
Heating design temperature	°C	23,1	
Cooling design temperature	°C	30,6	
Earth temperature amplitude	°C	6,6	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		26,8	73,6%	5,69	100,4	4,2	28,9	0	519
February		26,8	74,7%	5,67	100,4	3,5	28,9	0	470
March		26,6	77,9%	5,17	100,4	2,9	28,5	0	515
April		26,7	78,5%	5,04	100,4	3,4	28,3	0	500
May		26,9	75,4%	5,23	100,5	4,3	28,2	0	522
June		26,9	71,1%	5,18	100,6	5,7	28,1	0	506
July		26,8	66,6%	5,53	100,7	6,2	28,3	0	520
August		27,3	61,0%	6,21	100,7	6,9	29,2	0	537
September		27,5	60,6%	6,69	100,6	7,3	29,8	0	525
October		27,5	61,8%	6,69	100,5	7,0	30,3	0	544
November		27,4	64,4%	6,50	100,4	6,6	30,2	0	523
December		27,1	68,8%	6,13	100,4	5,5	29,7	0	530
Annual		27,0	69,5%	5,81	100,5	5,3	29,0	0	6.211
Measured at	m					10,0	0,0		

Figure 6.11 Site climate conditions used for simulation/optimization of the wind power plant in Aracati (Brazil). Source: RETScreen® International Clean Energy Decision Support Centre (2009)

Site reference conditions

Select climate data location

Climate data location: Cape Saint James

Show data ☑

	Unit	Climate data location	Project location
Latitude	°N	51,9	51,9
Longitude	°E	-131,0	-131,0
Elevation	m	92	92
Heating design temperature	°C	-0,8	
Cooling design temperature	°C	17,7	
Earth temperature amplitude	°C	3,6	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	4,6	86,0%	0,70	100,1	11,1	7,9	415	0
February	5,2	84,3%	1,44	100,0	10,6	7,7	358	0
March	5,7	82,9%	2,62	100,0	9,2	7,7	381	0
April	6,8	81,4%	4,04	100,4	8,9	8,3	336	0
May	8,8	84,8%	5,29	100,5	8,1	9,8	285	0
June	10,8	87,1%	5,71	100,7	7,5	11,7	216	24
July	13,0	89,5%	5,40	100,8	7,2	13,6	155	93
August	14,1	88,7%	4,66	100,7	7,0	14,7	121	127
September	13,2	85,8%	3,44	100,5	7,5	13,9	144	96
October	10,1	86,3%	1,84	100,2	9,5	11,8	245	3
November	6,9	84,3%	0,91	99,9	10,3	9,8	333	0
December	5,2	85,5%	0,57	100,1	10,8	8,5	397	0
Annual	8,7	85,6%	3,06	100,3	9,0	10,5	3.387	343
Measured at (m)					10,0	0,0		

Figure 6.12 Site climate conditions used for simulation/optimization of the wind power plant in Cape Saint James (Canada). Source: RETScreen® International Clean Energy Decision Support Centre (2009)

Site reference conditions

Select climate data location

Climate data location: Corvo Island

Show data ☑

	Unit	Climate data location	Project location
Latitude	°N	39,7	39,7
Longitude	°E	-31,1	-31,1
Elevation	m	26	26
Heating design temperature	°C	11,9	
Cooling design temperature	°C	23,2	
Earth temperature amplitude	°C	3,9	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	15,6	73,0%	1,62	102,0	8,4	16,3	76	172
February	15,0	73,2%	2,31	102,1	8,3	15,8	84	140
March	15,0	74,5%	3,47	101,9	7,6	15,7	95	153
April	15,4	75,7%	4,58	102,0	6,8	16,2	77	163
May	16,5	77,2%	5,44	102,1	5,9	17,2	47	201
June	18,4	81,1%	5,53	102,3	5,1	19,2	0	252
July	20,7	82,6%	6,01	102,5	4,4	21,8	0	331
August	21,9	80,9%	5,45	102,2	4,6	23,2	0	368
September	21,4	78,3%	4,17	102,0	5,4	22,6	0	343
October	19,7	74,1%	2,74	101,9	6,4	20,7	0	301
November	18,0	72,6%	1,74	101,9	7,7	18,8	1	239
December	16,6	72,6%	1,35	101,7	8,3	17,3	45	203
Annual	17,9	76,3%	3,71	102,1	6,6	18,7	425	2.866
Measured at (m)					10,0	0,0		

Figure 6.13 Site climate conditions used for simulation/optimization of the wind power plant in Corvo Island (Portugal). Source: RETScreen® International Clean Energy Decision Support Centre (2009)

6.4.4.1 VARIABLES RELATIONSHIP AND RESEARCH BOUNDARY

The variables influencing on cost of energy produced from a wind farm are present at Figure 6.8, which for this Ph.D. research work were analyzed in certain conditions and relationships:

1. The *lifetime of the project* is the period of working of the power plant. We have been considered 25 years of operation∴The lifetime of the wind farm is driven by wind turbines 'lifetime. If it is chosen a wind turbine for 20 years of operation, so the lifetime of the wind farm will be the same period;

2. The *cost of capital* reflects how much the project finance operation is. It is also called *"financial cost"* of the project, as we have already explained in Table 5.1. Usually the cost of capital of a power plant is affected by the lifetime, the initial investment that is driven directly by the power system configuration;

3. The price of wind turbines, access roads, foundations and other facilities can be analyzed as *"capital cost"* or "*initial investment".* The wind turbines chosen are driven by the local wind resources and terrain conditions∴As higher the wind power class, more powerful and bigger the wind turbines have to be adopted;

4. For *power system configuration* (rotor diameter, hub high and other physical features) has been considered the data shown at Figure 6.6. The power system configuration is used to be conditioned to how capital the investor has available, the local wind resources profile and the cost of energy produced;

5. For *mean wind speed and site characteristics* have been considered the data shown at Figures 6.11, 6.12 and 6.13. We easily find a direct relation among wind speed, initial investment, and annual energy production. As higher as wind speed, much as initial investment and the annual production;

6. *O&M costs* were classified into *O&M costs fixed* ($O\&M_{fixed}$) and *O&M variable* ($O\&M_{variable}$). $O\&M_{fixed}$ was determined by a number of fixed hours of work during the operation years of the power plant; however $O\&M_{variable}$ was fit to the annual energy production of the power plant;

7. *Annual Energy Production (AEP)* has been calculated for each year by the $LCPM_{WF}$, which the *capacity factor* (C_F) variable per year of power plant operation∴It seems to be more realistic to the nature of operational aspect for the WECS;

8. For the *annual emissions of GHG*, we consider only CO_2 *emissions* and it was compared with the same amount of electricity produced from fossil fuel technology considering the fuel type, region and P&D losses. The GHG emission of CO_2 ($GHG_{EF_{ff\ co_2}}$) was calculated for Brazil, Canada and Portugal.

When these variables have been considered for all lifetime of the power project how is the case of present Ph.D. research work (25 years), we could get *LCOE* of the power plant. The methodology proposed for simulation and optimization of WECS projects was developed during this research work considering these variables and their relationships. It is important to understand in the new methodology proposed *($LCOE_{wso}$)* which is the most influencing variable(s) on cost of energy produced from the wind farm∴It was also of great importance to define the research boundaries in order to make the results more measureable and transparent, in economic terms.

Economic optimization of wind farm *via LCOE* methodology is a combination of many different disciplines including operational research, economics, accounting, industrial engineering, production management, maintenance costs and others related to. In the present Ph.D. research work we have to consider as WECS boundaries for *LCOE* calculations and evaluations as shown in Figure 6.14.

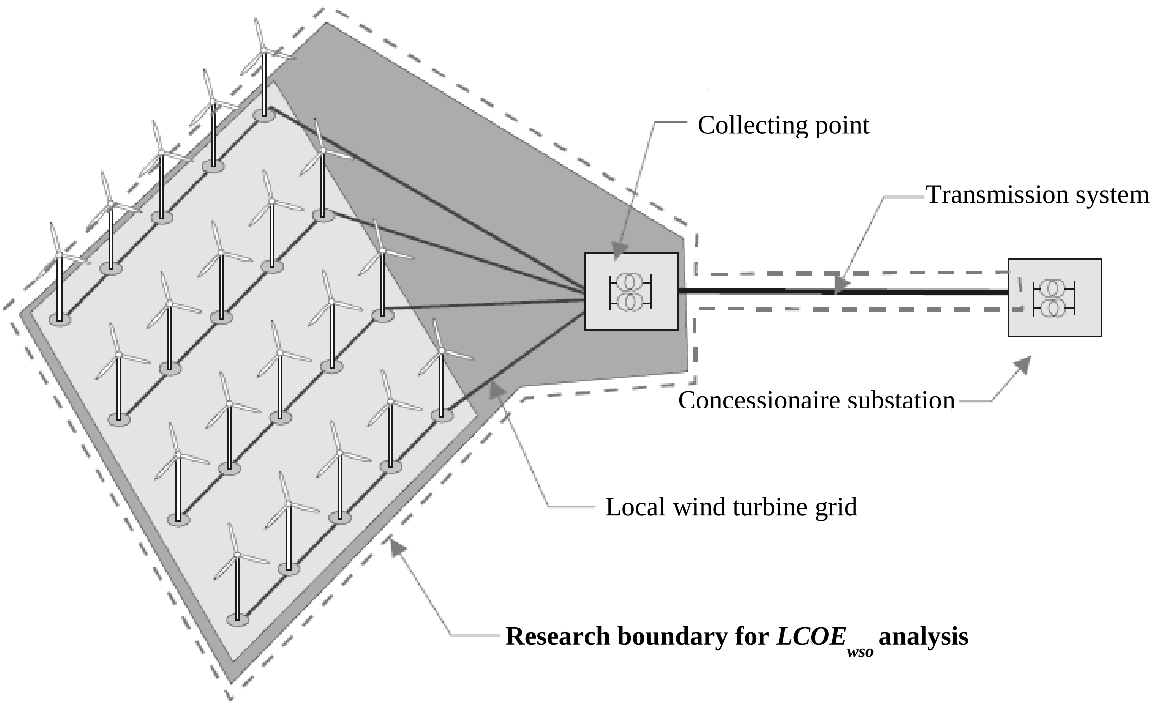

Figure 6.14 Cost and production frontier considered in simulations for optimized $LCOE_{wso}$. Source: Own elaboration

For reasons of system delimitation for the research work, economic evaluation and annual energy production, all analysis done was related to the production and transmission phases[92] of the WECS. The *power plant*, including the *land*, *local wind turbines grid*, *collecting point*[93] and *transmission system* (to the grid of distribution) were included for costs and production analysis∴This implies that the costs and other charges for distribution and commercialization of the electricity produced to the final consumer are not part of the proposed methodology of this Ph.D. research work.

[92] When we refer to energy production in form of electricity, it is used to be analyzed as, *production*, *transmission*, *distribution* and *commercialization* phases. Each of these phases present its aspects and costs associated.

[93] The *collecting point* for a wind farm is the same as an electrical substation. An electrical substation is a part of an electrical production, transmission, and distribution system. Substations transform voltage from high to low, or the reverse, or perform any of several other important functions.

6.4.4.2 MATHEMATICAL MODEL STRUCTURING

As we have already discussed before, a "*model"* is a representation of a system or process of the real world into a theoretical manner (Carson & Maria, 1997). For the present research work, methodologically adopted and approach of operational research, because it is related to a real problem industrializing activity, case of wind power. So the WECS studied has to be analytical analyzed through the "*mathematical modeling"*. Mathematical modeling is to establish a set of mathematical tools that allow making a theoretical analysis of a given situation∴For Banks (1999) the real-world system under investigation is abstracted by a *conceptual model*, a series of mathematical and logical relationships concerning the components (variables) and the structure of the system.

Our conceptual model was based on *LCOE/NREL,* considering the conceptual and operational definitions explained in Table 6.2. The conceptualization of this Ph.D. research work was also driven by the hypotheses formulation (see Table 6.3), which variables were grouped in clusters (see section 6.4.4) to be better studied and mathematically formulated∴The most important relationships were briefly described in section 6.4.4.1 and the size or structure of the system (see Figure 6.14) to be modeling.

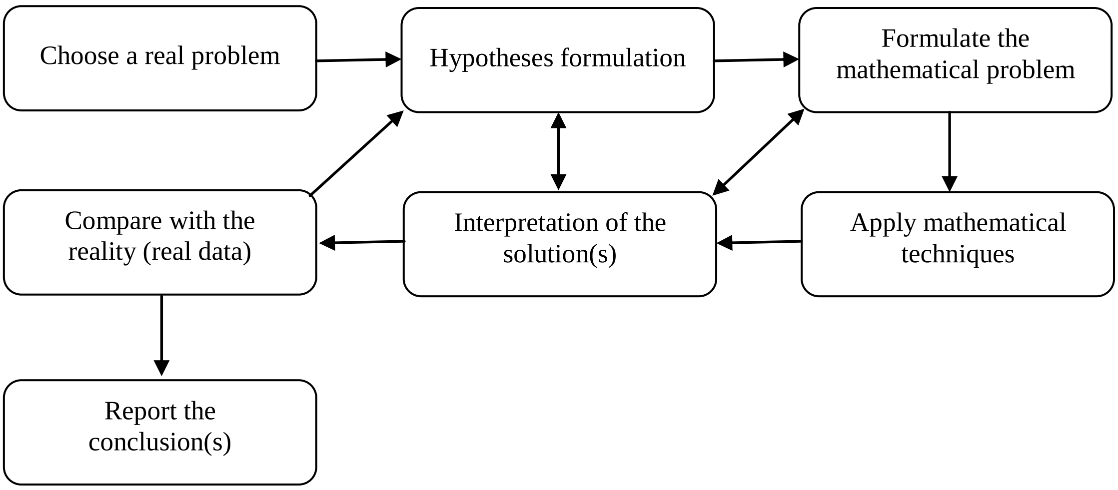

Figure 6.15 Modeling process flowchart. Source: Own elaboration

As we can see in the Figure 6.15 the modeling process is dynamic. The present research modeling process was built since the first and second phases of this research due to the nature of the present Ph.D. research work∴It is related to engineering economic analysis of wind power, so the *mathematical model*[94] was developed through the block diagram structure for wind farm economic optimization (see Figure 6.16) considering these two aspects, the economic and engineering one.

[94] In this section of this Ph.D. thesis a *mathematical model* is defined as a mathematical description — usually in the form of a computer algorithm — of a real system and the ways that phenomena occur within that system, and an energy model is a model with its focus on energy issues, according already explained in the footnote 76 on this same Chapter.

The *Economic Optimization Algorithm Proposed* ($EOAP=>LCOE_{wso}$) developed during this research work was built in models. There are six main modules: *Wind Farm Life-Cycle Capital Cost Model* ($LCCCM_{WF}$); *Wind Farm O&M Cost Model* ($O\&M_{WFCM}$); *Levelized Replacement Cost Model (LRCM)*; *Wind Farm Removal Cost Model* (RCM_{WF}); *Renewable Energy Public Incentive Model (REPIM)* and *Wind Farm Life-Cycle Production Model* ($LCPM_{WF}$). Each of them was integrated into sub-models, as shown in Figure 6.16.

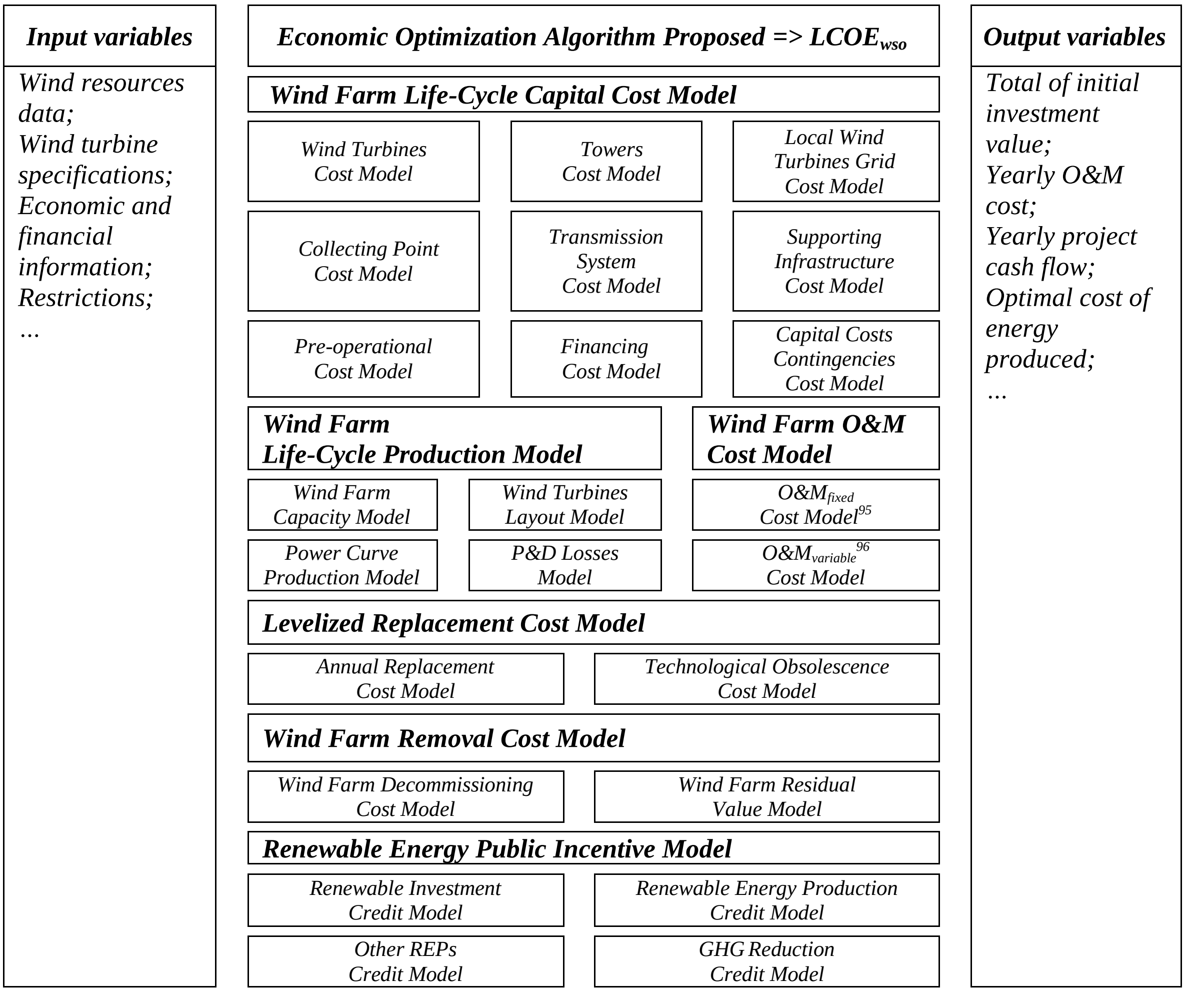

Figure 6.16 Block diagram of the wind farm simulation and optimization algorithm proposed. Source: Own elaboration

Now we have detailed our proposed methodology and new approach for *LCOE* calculations. The following Eqn 6.2 has shown the Ph.D. research algorithm:

[95] In *"$O\&M_{fixed}$"* we have been considered all expenses about insurances, taxes not incidents of revenue, land rents and other expenses related, but not directly to *AEP*, revenue or operational nature in the wind farm.
[96] For *"$O\&M_{variable}$"* we have been considered all expenses and costs related directly proportional to the hours of working and to the operational revenues of the wind farm.

$$LCOE_{wso} = \frac{LCCCM_{WF} + LRCM}{LCPM_{WF}} + O\&M_{WFCM} + RCM_{WF} - REPIM \quad [\$/kWh] \quad \text{Eqn (6.2)}$$

where $LCCCM_{WF}$ = *Wind Farm Life-Cycle Capital Cost Model; LRCM = Levelized Replacement Cost Model;* $O\&M_{WFCM}$ = *Wind Farm O&M Cost Model;* RCM_{WF} = *Wind Farm Removal Cost Model; REPIM = Renewable Energy Public Incentive Model and* $LCPM_{WF}$ = *Wind Farm Life-Cycle Production Model.*

Wind Farm Life-Cycle Capital Cost Model ($LCCCM_{WF}$)

$LCCCM_{WF}$ is an important aspect for the formulation of the *initial investment* (capital cost) of the wind power project, even for onshore or offshore installations. As we already discussed before, these projects are capital-intensive and a great part of the costs were driven to this term $\therefore$ This item represents the sum of the cost of wind power system and the cost structure of the wind farm. This cost measure includes all the planning, equipment acquisition, construction and installation costs of the wind system which makes the wind farm ready to operate. For our proposal methodology, $LCCCM_{WF}$ was built considering the wind turbines, towers, local wind turbines grid, transmission system, collecting point[97], supporting infrastructure (builds and other facilities), pre-operational costs (consulting, surveys, permitting, etc.), financing costs and other contingencies capital costs. The wind turbines and towers have been delivered and installed on site of the wind farm with all maintenance, electrical system and other infrastructure support for the whole wind farm installations. We also emphasize the utilization of *Uniform Capital Recovery Factor*[98] $UCRF = \left[\frac{WACC_{proj}(1+WACC_{proj})^N}{(1+WACC_{proj})^N - 1}\right]$ for cost items which represents the power system (equipment and facilities) of the proposed methodology. $LCCCM_{WF}$ is shown in Eqn 6.2.1.

$$LCCCM_{WF} = WT_{CM} + T_{CM} + LWTG_{CM} + CP_{CM} + TS_{CM} + SI_{CM} + PO_{CM} + F_{CM} + CCC_{CM} \quad [\$/kW] \quad \text{Eqn (6.2.1)}$$

where WT_{CM} = *Wind Turbines Cost Model*; T_{CM} = *Towers Cost Model*; $LWTG_{CM}$ = *Local Wind Turbines Grid Cost Model*; CP_{CM} = *Collecting Point Cost Model*; TS_{CM} = *Transmission System Cost Model*; SI_{CM} = *Supporting Infra-structure Cost Model*; PO_{CM} = *Pre-operational Cost Model*; F_{CM} = *Financing Cost Model* and CCC_{CM} = *Capital Costs Contingencies Cost Model*.

[97] In case of *system of transmission* and *collecting point* of electricity which extends from each wind turbine to the substation and point of interconnection with the grid of distribution.

[98] *UCRF* converts the current value in the flow of equal annual payments over a specified period of time *"t"*, *"i"* the rate specified discount (interest). For $LCOE_{wso}$ model *"t"* is the lifetime of the wind farm ($t=N$) and *"i"* is the weight average costs of capital of the project ($i=WACC_{proj}$) for *UCRF* calculation. In Eqn 5.19 shows *UCRF* calculation, where *"i"* = discount rate and *"t"* = number of periods in years.

The *wind turbines investment costs (WT_{CM})* were developed considering the *wind turbine cost for manufacturer (CM_{WT}), number of turbines in the wind farm (N_{WT}), market cost adjustment (MC_A)* and *uniform capital recovery factor (UCRF)*$\therefore$For George and Schweizer (2008) market cost adjustment *"reflects a number of factors, which are not believed to be fundamentally technology-related to the turbine cost estimate"*. Then, WT_{CM} can be calculated with the Eqn 6.2.1.1:

$$WT_{CM} = \left[N_{WT}\left(CM_{WT} + MC_A\right)\right]UCRF \qquad [\$/kW] \qquad \text{Eqn (6.2.1.1)}$$

where CM_{WT} can be calculated within the *percentage cost for the wind turbine component*, with the *total relative cost (RC_{WT}), cost of kW installed (C_{kW})* and *industrialized product taxes (IPT).* This formulation was shown in Eqn 6.2.1.1.1 as follows:

$$CM_{WT} = \left(RC_{WT}C_{kW}\right)\left(1\text{-}IPT\right) \qquad [\$/kW] \qquad \text{Eqn (6.2.1.1.1)}$$

Another important element of capital cost for wind projects is the wind turbine tower. We called *"Towers Cost Model"*. According to Oliveira and Fernandes (2012a) towers figure 30-65% of WECS weight and 10-25% of the costs. T_{CM} model was based on Fingersh, Hand, and Laxson (2006) which have been considered the scalar relation among, *rotor diameter (D)*, *swept area (A)* and *hub height (H_h)*$\therefore$For a given wind farm, the total towers cost is also the product of the *percentage cost for the wind tower component (RC_T)*, with the *wind turbines investment costs (WT_{CM}), mass of each tower (T_{mass}), cost of steel (C_{steel})* and *uniform capital recovery factor (UCRF)*. The cost of the towers often depends on fluctuations in the cost of steel, which is the main production material for the modern towers (Jamieson, 2011). T_{CM} was written in Eqn. 6.2.1.2:

$$T_{CM} = \left[RC_T\left(T_{mass}C_{steel}\right)\right]UCRF \qquad [\$/kW] \qquad \text{Eqn (6.2.1.2)}$$

The cost of connections for a wind farm is an important initial cost item which has been considered as *"Local Wind Turbines Grid Cost Model"*[99] *($LWTG_{CM}$)*. The internal electrical grid installation of the wind farm comprises the medium voltage grid in the wind farm up to a common point and the necessary medium voltage switch gear at that point. The total costs for this item ranges from 3 to 10 % of the total costs of the complete wind farm. It depends on local equipment prices, technical requirements, soil conditions, the distance between the turbines, the size of the wind farm and

[99] According to research boundary (section 6.4.4.1) was focused only on local (internal) grid of the wind farm, but the costs for grid connection can be split up in two. The costs for the local (internal) electrical installation and the costs for connecting the wind farm to the electrical grid for distribution.

hence the voltage level for the line to the connecting point of existing grid (European Commission, 2001). $LWTG_{CM}$ proposed was formulated as shown in Eqn 6.2.1.3:

$$LWTG_{CM} = \frac{\left[\left(L_g CAB_{cost}\right) + MC_A\right]UCRF}{WF_{cap}} \quad [\$/m/kW] \quad \text{Eqn (6.2.1.3)}$$

Then $LWTG_{CM}$ could be understood as a product of the *local grid length* (L_g) and *cables cost* (CAB_{cost}) including skilled labor. It was also considered the *market cost adjustment* (MC_A) for the cables materials` life-cycle and *uniform capital recovery factor (UCRF)* per *wind farm electric installed capacity* (WF_{cap}). The length of the grid is affected by the wind farm and grid layouts, type of cables, orography and other electrical configurations of the power plant.

The *Collecting Point Cost Model* (CP_{CM}) was developed considering the function of this investment item for the wind farm as a whole to the wind farm, as an *electrical substation* (already explained in footnote 93)$\therefore$The *"collecting point"* also called *"integration system"* manages the voltage from high to low, or the reverse, or performs any of several other important functions for the output power quality. That is why for our CP_{CM} proposed has been considered a fixed part for transformers, and other *electrical facilities* (EF_c) *added the cost* (ς) per *wind farm electric installed capacity* (WF_{cap}) and *uniform capital recovery factor (UCRF)*. CP_{CM} was formulated within Eqn 6.2.1.4:

$$CP_{CM} = \left(EF_c + \varsigma WF_{cap}\right)UCRF \quad [\$/kW] \quad \text{Eqn (6.2.1.4)}$$

The present methodology also has taken into consideration the transmission system. We have called *"Transmission System Cost Model"*. TS_{CM} proposed was based on DeCarolis and Keith (2006) when have been considered the *transmission line cost* (TL_c), *transmission line thermal rating*[100](TL_r), *transmission line length* (L_t) and *substation cost of transmitting* (SB_c). It also has been considered the *market cost adjustment* (MC_A) for the cables materials` life-cycle and *uniform capital recovery factor (UCRF)*. The following Eqn 6.2.1.5 represents TS_{CM}[101]:

$$TS_{CM} = \left[\left(\frac{TL_c}{TL_r} L_t\right) + SB_c + MC_A\right]UCRF \quad [\$/kW_e] \quad \text{Eqn (6.2.1.5)}$$

[100] The current carried by a given transmission line conductor which results in the maximum allowable conductor temperature for a particular set of weather parameters.

[101] The *transmission line cost* (TL_c), *transmission line thermal rating* (TL_r), *transmission line length* (L_t) and *substation cost of transmitting* (SB_c) are measure in m; 1/kW; km and \$/kW, respectively.

A large and medium wind power plant will require a maintenance facility for storing trucks, service equipment, spare parts, lubricants, and other supplies. The maintenance facility may be located on- or off-site. Some wind farms combine control and maintenance functions in one building (see Figure 4.16) $\therefore$ The model developed during this research called *"Supporting Infra-structure Cost Model"* (SI_{CM}) was based on *building cost* (Bld_{cost}), *building area* (Bld_{area}), per *wind farm electric installed capacity* (WF_{cap}) for contingencies and *uniform capital recovery factor (UCRF)*. We have also considered the *wind turbine installation* (WT_{inst}) as the cost of RM_{WT} added the RM_{CT}[102]. The variables[103] used for SI_{CM} were organized as shown in Eqn 6.2.1.6:

$$SI_{CM} = \left[\frac{\left(Bld_{\cos t} Bld_{area} \right)}{WF_{cap}} UCRF + WT_{inst} \right] \quad [\$/m^2/kW] \qquad \text{Eqn (6.2.1.6)}$$

The *pre-operational phase*[104] of the power plant is an important part for life-cycle cost analysis, especially in the case of wind projects. As we have discussed in section 4.6 of this Ph.D. research work, this phase could reach 4 years of activities and resources (see Figures 4.13 and 5.1) and obvious costs associated to the same period $\therefore$ We have developed the *"Pre-operational Cost Model"* (PO_{CM}). PO_{CM} was based on the *Feasibility Studies (FS)*, *Development (DT)* and *Engineering (EG)* per *wind farm electric installed capacity* (WF_{cap}) and *uniform capital recovery factor (UCRF)*. The variables used for PO_{CM} were organized as shown in Eqn 6.2.1.7:

$$PO_{CM} = \left[\left(FS + DT + EG \right) UCRF \right] \quad [\$/kW] \qquad \text{Eqn (6.2.1.7)}$$

Wind projects with its capital-intensive nature, in general, are implemented with project financing operations in the beginning of project´s lifetime. The capital structure of an analyzed wind power project has influenced on the finance cost. Capital structure refers to the mix of debt and equity in the power project. The "*Financing Cost Model"* (F_{CM}) proposed was based on Damodaran (2001) which has been considered the *percentage* ($w_{F_{CM}}$) of *Weighted Average Cost of Capital* calculation of weighted average cost of funding sources, in which the weight of each one is considered for each funding position during the *pre-operational phase* (n_{fin}) of the wind project $\therefore F_{CM}$ was formulated as the product of $w_{F_{CM}}$, $WACC_{proj}$ and the *sum of capital investment cost* (WT_{CM}, T_{CM}, $LWTG_{CM}$, CP_{CM}, TS_{CM}, SI_{CM} and PO_{CM}). The following Eqn 6.2.1.8 represents F_{CM}:

$$F_{CM} = w_{F_{CM}} \left(1 + WACC_{proj} \right)^{n_{fin}} \left[\sum \left(WT_{CM} + T_{CM} + LWTG_{CM} + CP_{CM} + TS_{CM} + SI_{CM} + PO_{CM} \right) \right] \quad [\$/kW] \qquad \text{Eqn (6.2.1.8)}$$

[102] The literature confirm that the same equipment and cost are similar, but considering the effect of time, so the *cost of wind turbine installation* (WT_{inst}) is defined as analogous as the sum of *removal wind turbine* (RM_{WT}) and *concrete* (RM_{CT}), $WT_{inst} = RM_{WT} + RM_{CT}$.

[103] Bld_{cost} ($\$/m^2$) and Bld_{area} (m^2).

[104] The *pre-operational phase* includes all of the activities required before production of the power plant. These activities are usually technical studies, construction and equipment installation, testing and technical adjustments.

The balance of system and miscellaneous costs typically includes a number of items such as building and yard construction, spare parts, transportation, training & commissioning, contingencies and interest during construction (RETScreen® International Clean Energy Decision Support Centre, 2009) $\therefore$ *"Capital Costs Contingencies Cost Model" (CCC_{CM})* proposed was formulated with a *percentage (κ)* of *capital costs* for contingencies of the power project. The following Eqn 6.2.1.9 represents CCC_{CM}:

$$CCC_{CM} = \kappa\left[\sum LWTG_{CM} + CP_{CM} + TS_{CM} + SI_{CM} + PO_{CM} + F_{CM}\right] \quad [\$/kW] \qquad \text{Eqn (6.2.1.9)}$$

Levelized Replacement Cost Model (LRCM)

According to NREL (1995) the *Levelized Replacement Cost (LRC)* is a cost component used as a saving account for the wind power project. Depending on the technical details of the power plant, the major review of the power system occurs every 5, 10 or 15 years $\therefore$ The proposed "*Levelized Replacement Cost Model" (LRCM)* was formulated considering the "*Annual Replacement Cost Model" (AR_{CM})* and *"Technological Obsolescence Cost Model" (TO_{CM})*.

$$LRCM = AR_{CM} + TO_{CM} \quad [\$/kW] \qquad \text{Eqn (6.2.2)}$$

"*Annual Replacement Cost Model" (AR_{CM})* was developed within the principles: *(a) as an economic reserve for future expendures*; *(b) the money cost is influenced by the time* and *(c) AR_{CM} is also affected by $O\&M_{WFCM}$.* We have been considered for AR_{CM} *wind turbines (WT_{CM})* and *towers (T_{CM}) costs*. It was also adopted the *inflation rate (if_r)* to ensure the effect of time on investments and available funds within the present value of annual stream of reserve for major replacements and overhauls over the life of the wind power system when payments for event occurring in *year needed (Y_{RC})*[105] have to be made $\therefore$ When we refer to depreciation[106] of the equipment and installations, the proposed AR_{CM} has been considered the difference of *depreciation of wind turbines with towers ($Depr_{WT_{inst}}$)* and the *depreciation in the year ($Depr_{Y_{RC}}$)* when the major review of the power system was programmed.

$$AR_{CM} = Depr_{WT_{inst}} - Depr_{Y_{RC}} \quad [\$/kW] \qquad \text{Eqn (6.2.2.1)}$$

[105] $O\&M_{WFCM}$ possible can affect the overall turbine availability as well as the downtimes during replacements and overhauls. Economically, if $O\&M_{WFCM} > LCCCM_{WF}$ per kW we consider it is time to make the replacements and overhauls necessary to the power system becomes again economically interesting!

[106] The accounting mechanism for the reduction in value of a capitalized item (tangible assets) due to utilization or loss of usefulness by utilization, action of nature or aging. The precise definition and the schedule of reduction will vary widely, depending on the use. Frequently associated with capital cost deductions for income tax purposes (NREL, 1995).

where $Depr_{WT_{inst}}$ can be calculated by the Eqn 6.2.2.1.1 as follows:

$$Depr_{WT_{inst}} = \left[\left(\frac{WT_{CM} + T_{CM}}{N}\right)\right]\left[(1+if_r)^N\right] \qquad [\$/kW] \qquad \text{Eqn (6.2.2.1.1)}$$

and $Depr_{Y_{RC}}$ can be calculated by the Eqn 6.2.2.1.2 as follows:

$$Depr_{Y_{RC}} = \left[\left(\frac{WT_{CM} + T_{CM}}{N}\right)\right]\left[(1+if_r)^{Y_{RC}}\right] \qquad [\$/kW] \qquad \text{Eqn (6.2.2.1.2)}$$

We also analyzed the *technological obsolescence effect* for the power system as a cost (view of investor), considering during the lifetime of the wind project, the technological option chosen for that specific power plant could not be changed easily, even when the investor decides to repower the system in the end of its lifetime, if it is worth it!! That is why we have aggregated the effect of technological obsolescence to $LRCM \therefore$ The technological obsolescence and improvement can be understood as an inverse relation, so, *LRCM* was formulated within the inverse of technology improvements *(TI)*[107] described by Lund (2006).

$$TO_{CM} = \left[\left(\frac{WT_{CM} + T_{CM}}{N}\right)\right]\left[\left(\frac{1}{TI}\right)(1+if_r)^{Y_{RC}}\right] \qquad [\$/kW] \qquad \text{Eqn (6.2.2.2)}$$

where *TI* can be calculated by the Eqn 6.2.2.2.1 as follows:

$$TI \Rightarrow cv = c_0\left[\frac{V_0}{V}\right]^b \qquad [\$/kW] \qquad \text{Eqn (6.2.2.2.1)}$$

where *"c"* and *"c_0"* are *the current* and *initial costs* (\$/kW); V and V_0 the *current* and *initial cumulative volume* (kW); *"b"* is the *learning parameter*. Moreover, $b = \frac{\ln 2}{\ln PR}$, where *PR* is the *progress ratio*[108].

[107] The unit cost drops by *1- PR* for each doubling of the cumulative volume. In the case of wind power, the cumulative volume is considered the cumulative installed capacity in a region. The learning curve describes the effects *of learning by doing* or by using the new technology and transforms the experiences gained through manufacturing and utilization into cost reductions (Lund, 2006).

[108] According to Junginger, Faaij, and Turkenburg (2005) the progress ratio (*PR*) is a parameter that expresses the rate at which costs decline each time the cumulative production doubles.

As discussed by Pan and Köhler (2007) the learning effect (technology improvements) as described by a learning curve combines the effects of both real price and technological change. If a learning curve is measured at constant prices, the price effect is cancelled out and the curve reflects technological change only $\therefore$ This situation justified the adoption of *inflation effect* (if_r) on the TO_{CM} which usually both effects of real price change and technological change are included in the cost reduction — both effects imply or reflect the technology cost reductions as the number of physical installations has increased.

Wind Farm O&M Cost Model ($O\&M_{WFCM}$)

The *operations and maintenance* (*O&M*) of a wind farm is driven by its size, model of turbines, location and other technical and economic conditions. The objective of *O&M* is to enable desired component performance by maintaining or returning the component's ability to function correctly (Nilsson & Bertling, 2007). The *Wind Farm O&M Cost Model* ($O\&M_{WFCM}$) has been developed considering a *fixed* ($O\&M_{fixed_{CM}}$) and *variable* ($O\&M_{variable_{CM}}$) part, as shown in Eqn 6.2.3:

$$O\&M_{WFCM} = O\&M_{fixed_{CM}} + O\&M_{variable_{CM}} \quad [\$/kWh] \qquad \text{Eqn (6.2.3)}$$

$O\&M_{fixed_{CM}}$ was oriented to those costs incurred during the operation phase of the project and are constant at all scales of production, even when the wind farm is stopped $\therefore$ We have proposed a *percentage* (ϖ) of *wind farm life-cycle capital cost model* ($LCCCM_{WF}$) and *land lease cost (LLC)* per kWh. We also have considered the *effect (rate) of inflation* (if_r) during *the lifetime of the wind farm (N)*. $O\&M_{fixed_{CM}}$ was written in Eqn 6.2.3.1:

$$O\&M_{fixed_{CM}} = \varpi LCCCM_{WF} + LLC(1 + if_r)^N \quad [\$/kWh] \qquad \text{Eqn (6.2.3.1)}$$

Meanwhile $O\&M_{variable_{CM}}$ was driven to those costs incurred during the production phase and varies according to the scale of production. This part of $O\&M_{WFCM}$ includes staffing, operations, planned (predictive) unplanned maintenance[109], materials and other consumables, operation services, revenues taxes, and unforeseen expenses. $O\&M_{variable_{CM}}$ was formulated based on Zhang et al. (2010), have been considered the *costs covered by manufacturer* ($O\&M_{ccm}$), *period of warranty* (n_w), *maintenance labor cost (MLC) per hour, number of hours for maintenance labor* (n_{mlh}), *number of hours for technical labor* (n_{tlh}), *technical labor cost (TLC) per hour* and *revenue taxes*

[109] For more details about wind farm maintenance, please see at Endrenyi et al. (2001).

(R_{taxes}). We also have considered the *effect (rate) of inflation (if_r)* during *lifetime of the wind farm (N)*, as shown in Eqn 6.2.3.2:

$$O\&M_{variable_{CM}} = \left(\left(\frac{(MLC \times n_{mlh}) + (TLC \times n_{tlh})(1 + if_r)^{N-n_w}}{AEP_{avail}} \right)(1 - O\&M_{ccm}) + R_{taxes}\left(\frac{AAR}{AEP_{avail}} \right) \right) \quad [\$/kWh] \qquad \text{Eqn (6.2.3.2)}$$

For Schreck and Laxson (2005) *O&M* costs for wind power plants shall include, and be supported by, a tabular listing of the following annual costs:

- Labor, parts and supplies for scheduled maintenance;
- Labor, parts and supplies for unscheduled maintenance;
- Parts and supplies for equipment and facilities maintenance;
- Labor for administration and support.

In the proposed $O\&M_{WFCM}$ was done a separation of *O&M* costs because we believe that the costs for *O&M* could have two types of behavior, one related to the power plant itself (size, land area, and other administrative expenses) and other related to the production of the wind farm. Christopher (2003) has highlighted the effort to minimize wind turbine *O&M* costs must start with a better understanding of the current costs and other factors that drive these costs. This first step could allow development of a sound cost model for evaluating the performance of existing wind farms and enable estimating the cost of proposed projects with reasonable certainty $\therefore$ Some of the factors that have been driven the costs would be common to wind power projects in general, but other factors would be site specific. Detailed information about specific failure types, along with the operating conditions, would allow for an accurate model that could be adapted to different machine types and environments.

The *maintenance and technical labor costs (MLC* and *TLC)* could be determined considering the relation of *Annual Failure Frequency (AFF)* and *Repair Costs (RC).* Determining the maintenance costs of a wind farm could be similar to the approach for asset management and risk analyses have been used in many branches of industry in general $\therefore$ For Obdam, Braam, Rademakers, and Eecen (2007) this approach[110] could be written as:

$$Annual\ O\&M\ costs = AFF \times RC \qquad [\$/kWh] \qquad \text{Eqn (6.2.3.3)}$$

[110] In the proposed $O\&M_{WFCM}$ this approach has not been considered because the focus and objective of the Ph.D. research work, therefore this approach is directly applied *corrective maintenance*, so in the case of wind power plants would not be enough for expressing the *O&M* costs totally.

Wind Farm Removal Cost Model (RCM_{WF})

As we have already stated a wind farm as a project there must have an end of its economic lifetime of operation. The removal phase of WECS, when it was decided to repower the wind farm, is as important as the installation phase $\therefore$ There is not too much literature about uninstalling phase of WECS within its costs associated.

The wind farm removal costs depend a great deal on permit requirements and turbine and site-specific aspects such as how deep the foundations are poured, capacity, and other. For wind developers the cost to remove a wind farm is usually an estimation during the planning stages, but rather assume that salvage value of the wind farm, specific the turbines, would really cover those expenses when the time comes at the end of the project operation phase[111]. The most common way to estimate removing costs is to assume that the future residual value of the turbines will be 5-10% of the initial equipment cost, or to guess what the value of steel and copper and the other metals in the turbine would be in 20-25 years (Botterud, 2003).

"*Wind Farm Removal Cost Model" (RCM_{WF})* was developed within the main principles: *(a) assure funds enough at the end of operational phase to remove or repower the power plant* and *(b) reduce as most as possible the local microenvironment impact caused by the wind farm.* We have been considered for RCM_{WF} the *Wind Farm Decommissioning Cost Model (DCM_{WF})* and *Wind Farm Residual Value Model (RVM_{WF})* $\therefore$ For both sub-models were also adopted the *inflation rate (if_r)* and *UCRF* to ensure the effect of time on investments and available funds within the present value of annual stream of monetary reserve. RCM_{WF} could be formulated by Eqn 6.2.4:

$$RCM_{WF} = DCM_{WF} - RVM_{WF} \qquad [\$/kW] \qquad \text{Eqn (6.2.4)}$$

DCM_{WF} was formulated per wind turbine, considering *man-hour (M_{hr})*, *cost of man-hour (C_{Mhr})*, *number of machines/equipment (N_m)*, time of utilization for machines/equipment in days *(D_m)*, cost per day *(C_{md})* and *wind farm electric installed capacity (WF_{cap})* $\therefore$ We have also considered the following activities: *(1) Removal of wind turbines (RM_{WT}); (2) Removal of concrete (RM_{CT})* and *(3) Seeding and re-vegetation (S&RV)*[112]. RCM_{WF} could be calculated by Eqn 6.2.4.1:

$$DCM_{WF} = RM_{WT} + RM_{CT} + S\&RV \qquad [\$/kW] \qquad \text{Eqn (6.2.4.1)}$$

then,

[111] Many wind farms are not decommissioned, but are repowered. If a site is proven to have good wind resources, in many instances it makes more sense to replace turbines as needed rather than remove the entire facility. A decommissioning fund could be directed to repowering at the appropriate time.
[112] Average of ~2 acres (0.8093712844 ha)/turbine including collection system.

$$RM_{WT} = \frac{N_{WT}\left[\left(M_{hr_{RM_{WT}}} C_{Mhr_{RM_{WT}}}\right) + \left(N_{m_{RM_{WT}}} D_{m_{RM_{WT}}} C_{md_{RM_{WT}}}\right)\right]}{WF_{cap}} \left(1 + if_r\right)^{N+1} \quad [\$/kW] \quad \text{Eqn (6.2.4.1.1)}$$

where $M_{hr_{RM_{WT}}}$ is the *man-hour* for RM_{WT}; $C_{Mhr_{RM_{WT}}}$ is the *cost of man-hour* for RM_{WT}; $N_{m_{RM_{WT}}}$ the *number of machines/equipment* for RM_{WT}; $D_{m_{RM_{WT}}}$ *time (days) of utilization for machines/equipment* for RM_{WT} *and* $C_{md_{RM_{WT}}}$ *cost per day* for RM_{WT}.

and,

$$RM_{CT} = \frac{N_{WT}\left[\left(M_{hr_{RM_{CT}}} C_{Mhr_{RM_{CT}}}\right) + \left(N_{m_{RM_{CT}}} D_{m_{RM_{CT}}} C_{md_{RM_{CT}}}\right)\right]}{WF_{cap}} \left(1 + if_r\right)^{N+1} \quad [\$/kW] \quad \text{Eqn (6.2.4.1.2)}$$

where $M_{hr_{RM_{CT}}}$ is the *man-hour* for RM_{CT}; $C_{Mhr_{R_{CT}}}$ is the *cost of man-hour* for RM_{CT}; $N_{m_{RM_{CT}}}$ the *number of machines/equipment* for R_{CT}; $D_{m_{RM_{CT}}}$ *time (days) of utilization for machines/equipment* for RM_{CT} *and* $C_{md_{RM_{CT}}}$ *cost per day* for RM_{CT}.

and,

$$S\&RV = \frac{N_{WT} A_{WT}\left[\left(M_{hr_{S\&RV}} C_{Mhr_{S\&RV}}\right) + \left(N_{m_{S\&RV}} D_{m_{S\&RV}} C_{md_{S\&RV}}\right)\right]}{WF_{cap}} \left(1 + if_r\right)^{N+1} \quad [\$/kW] \quad \text{Eqn (6.2.4.1.3)}$$

where A_{WT} is the *area per wind turbine*; $M_{hr_{S\&RV}}$ is the *man-hour* for *S&RV*; $C_{Mhr_{S\&RV}}$ is the *cost of man-hour* for *S&RV*; $N_{m_{S\&RV}}$ the *number of machines/equipment* for *S&RV*; $D_{m_{S\&RV}}$ *time (days) of utilization for machines/equipment* for *S&RV and* $C_{md_{S\&RV}}$ *cost per day* for *S&RV*.

Wind Farm Residual Value Model (RVM_{WF}) was formulated within the main considerations: *(a) scrap value of wind turbine* and *(b) scrap value of steel tower* $\therefore$ We have considered for RFM_{WF} the *Wind Turbine Scrap Value Model* (WTS_{VM}) and *Tower Scrap Value Model* (TS_{VM}). RVM_{WF} could be formulated by Eqn 6.2.4.2:

$$RVM_{WF} = N_{WT}(WTS_{VM} + TS_{VM}) \quad [\$/kW] \quad \text{Eqn (6.2.4.2)}$$

where WTS_{VM} was formulated taking into consideration the *weight of a wind turbine* (WT_{weight}) and the *cost of steel* (C_{steel}) $\therefore$ As we have thought about the wind farm lifetime, for RCM_{WF} was considered one more year for total removal process for the wind farm in question. It was also adopted the *inflation rate* (if_r) during this period. WTS_{VM} can be written as Eqn 6.2.4.2.1:

$$WTS_{VM} = \left[\frac{(WT_{weight}C_{steel})}{WF_{cap}}\right](1 + if_r)^{N+1} \quad [\$/kW] \quad \text{Eqn (6.2.4.2.1)}$$

and TS_{VM} was also formulated taking into consideration the *mass*[113] *of each tower* (T_{mass}) and the *cost of steel* (C_{steel}) $\therefore$ As we have thought about the wind farm lifetime, for RCM_{WF} was considered one more year for total removal process for the wind farm in question. It was also adopted the *inflation rate* (if_r) during this period. TS_{VM} can be written as Eqn 6.2.4.2.2:

$$TS_{VM} = \left[\frac{(T_{mass}C_{steel})}{WF_{cap}}\right](1 + if_r)^{N+1} \quad [\$/kW] \quad \text{Eqn (6.2.4.2.2)}$$

If the wind farm was built with different wind turbines and towers in relation to the sizes, weights (both wind turbines and towers) and technologies, it will be necessary consider individually $\therefore$ We have to make the calculations for WTS_{VM} *and* TS_{VM} one-by-one and sum all for finding RVM_{WF}. Eqn 6.2.4.3 has expressed it:

$$RVM_{WF} = \sum(WTS_{VM\,a} + ... + WTS_{VM\,n} + TS_{VM_a} + ... + TS_{VM_n}) \quad [\$/kW] \quad \text{Eqn (6.2.4.3)}$$

But the most common situation is the wind farm has been settled-up with a homogeneous technology, both for wind turbines and towers, so the Eqn 6.2.4.2 can easily find RVM_{WF} for a specific wind farm.

[113] The mass of a wind tower can be calculated by the relation $A \times H_h$, where A is the swept area and H_h the hub height. For more details, see at Fingersh et al. (2006).

Renewable Energy Public Incentive Model (REPIM)

Globally, governments tend to appreciate the advantages of renewable energy production more than conventional energy production∴Therefore, the support for expansion of production capacity of renewable energy in many ways, which basically aim to reduce the disadvantages of most technologies for renewable energy production: the cost and the lack of controllability. The disadvantage of the cost is in most cases decreased through the socialization of the burden by some form of subsidy or incentive. An example is forcing electricity companies to buy energy from renewable sources at a price that is not based on the actual cost of this energy, but it is calculated in such a way that the renewable energy project become profitable for the investor (Oliveira, 2010). In Figure 6.17 are briefly the main policy instruments for the promotion of renewable energy.

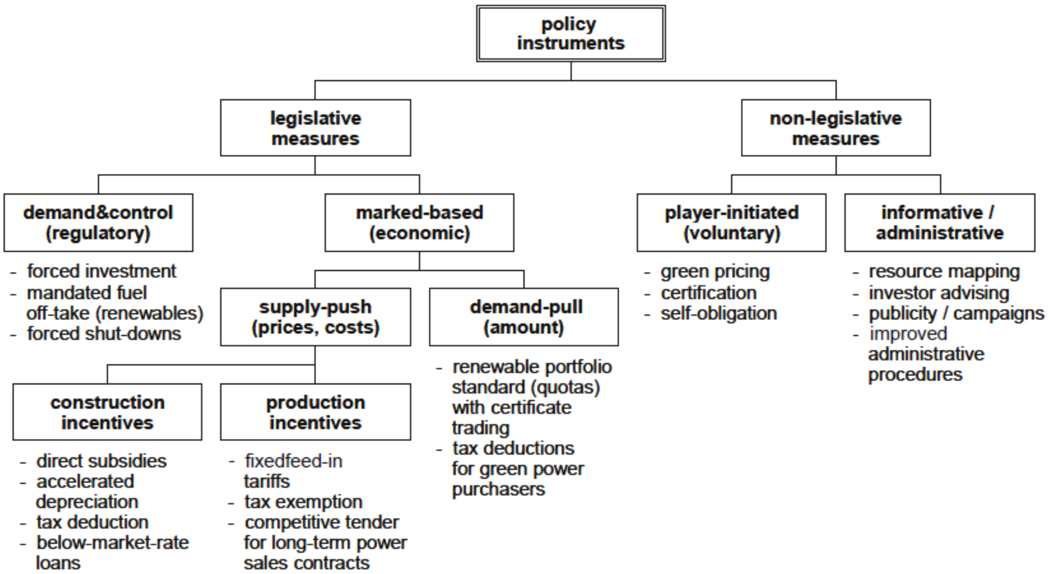

Figure 6.17 Typology of energy policy instruments. Source: Enzensberger et al. (2002)

We has followed the classification of Enzensberger et al. (2002) for *Renewable Energy Public Incentive Model* (*REPIM*) when we have considered the *market-based (economic)* instruments conception (see Figure 6.17). We have taken a look into the current market status and trends, e.g. electricity market liberalized[114] as result *REPIM* was orientated by *supply* and *demand-push approach*[115] into the following sub-models: *(1) Renewable Energy Investment Credit Mode* (REI_{CM}); *(2) Renewable Energy Production Credit Mode (REP_{CM}); (3) Other REPs Credit Mode ($OREP_{CM}$)* and *(4) GHG Reduction Credit Model ($GHG.R_{CM}$)*. So, *REPIM* could be formulated as shown in Eqn 6.2.5:

[114] For Menz and Vachon (2006) if the renewable energy market continuing rise fossil fuel prices, renewable energy technologies will become more economically attractive to consumers. In that context, market-based voluntary measures might play an increasingly important role in future wind power development.

[115] For more details about *supply and demand-push approaches*, see at Grubb (2004); Jamasb (2007).

$$REPIM = REI_{CM} + REP_{CM} + OREP_{CM} + GHG.R_{CM} \quad \text{[\$/proj]} \qquad \text{Eqn (6.2.5)}$$

Then, as we have said *REPIM* and sub-models as REI_{CM} were also orientated by *supply-push approach* for initial investments in order to reduce the huge amount of capital in the initial life of the project, and consequently, reduce de final cost of energy produced from the wind power plant. REI_{CM} has been impacted on *investments* ($LCCCM_{WF}$) and *overhaul expenses (LRCM)*. Mathematically, Eqn 6.2.5.1 is shown this relation:

$$REI_{CM} = \frac{\psi_{total}\left(LCCCM_{WF} + LRCM\right)}{n_{\psi}}\left(1 + ifr\right)^{n_{\psi}} \quad [\$/kW_e] \qquad \text{Eqn (6.2.5.1)}$$

where (ψ_{total}) is the *total investment tax credit* given by government during the *time of policy energy instrument* (n_{ψ}) and also considering the *inflation rate* (if_r) for the same time of instrument effect. It also must be calculated year by year, until be concluded the whole period of n_{ψ}.

For REP_{CM} were also orientated by *demand-push approach* for wind farm production in order to reduce the final *LCOE*. REP_{CM} have been impacted on AEP_{avail}/H_{prod} sold to the distribution grids per *wind farm electric installed capacity* (WF_{cap}) $\therefore$ Eqn 6.2.5.2 has been shown this instrument:

$$REP_{CM} = \varepsilon\left(\frac{AEP_{avail}}{H_{prod}} WF_{cap}\right) \quad [\$/kW_e h] \qquad \text{Eqn (6.2.5.2)}$$

where (ε) must be calculated considering *initial value paid by government* (ε_0), *time of policy energy instrument* (n_{ε}) and *inflation rate* (if_r) for the same time of instrument effect. So, the *final value paid by government* (ε) can be found by Eqn 6.2.5.2.1:

$$\varepsilon = \varepsilon_0\left(1 + ifr\right)^{n_{\varepsilon}} \quad [\$/kW_e h] \qquad \text{Eqn (6.2.5.2.1)}$$

Many types of energy policy instruments can be adopted by governments worldwide, but fundamentally these instruments are divided into *investment focused* and *production based* (Haas et al., 2004)$\therefore$The *Other REPs Credit Model ($OREP_{CM}$)* was developed considering a *cover risk factor (CR_f)*[116]*, time of policy energy instrument (n_ψ)* and *discount given by the government (ψ_{total})* for *capital cost of the project ($WACC_{proj}$)*. Eqn 6.2.5.3 has shown $LCCCM_{WF_{OREG_{CM}}}$ calculation:

$$LCCCM_{WF_{OREP_{CM}}} = \left[\frac{\left(LCCCM_{WF} WACC_{proj} \psi_{total}\right)\left(1 - CR_f\right)}{\left(1 + ifr\right)^{n_\psi}} \right] \text{ [\$/kW}_e\text{]} \qquad \text{Eqn (6.2.5.3)}$$

where *(CR_f)* is the *financing risk*[117]for a given wind power project, *(ψ_{total})* is the *total investment tax credit* given by government during the *time of policy energy instrument (n_ψ)* and also considering the *inflation rate (if_r)* for the same time of instrument effect. It also can be calculated year by year, until be concluded the whole period of n_ψ.

$OREP_{CM}$ was developed to show how much the government incentive for this energy instrument is, we also could find it by the relation among the initial $LCCCM_{WF}$, $LCCCM_{WF_{OREP_{CM}}}$ and AEP_{avail}/H_{prod}, so the equation can be written as Eqn 6.2.5.3.1:

$$OREP_{CM} = \left[\left(\frac{LCCCM_{WF_{OREP_{CM}}}}{LCCCM_{WF}} \right) \left(\frac{AEP_{avail}}{H_{prod}} \right) \right] \text{ [\$/kW}_e\text{]} \qquad \text{Eqn (6.2.5.3.1)}$$

Finally, to complete *REPIM* was developed *$GHG.R_{CM}$* or *GHG Reduction Credit Model* for also associate the effect of GHG reduction in function of RET for producing green electricity. According to El-Kordy et al. (2002) external cost for electricity production are expressed by emissions from electric power plants which are generally evaluated based on the plant specifications, although, it could be hard to estimate a *"typical"* set of emissions for any resource type.

$GHG.R_{CM}$ was developed considering *Life-Cycle Emission Reduction for CO_2 ($LCER_{CO_2}$)* which can be found by the difference of *GreenHouse Gas Emission of CO_2 from fossil fuel ($GHG_{EM_{ff\ co_2}}$)* and *GreenHouse Gas Emission of CO_2 from WECS ($GHG_{EM_{wecs\ co_2}}$).*

[116] We have considered a risk factor for $OREP_{CM}$ energy policy instrument in order to be more realistic to the wind power market and developed an instrument which associates the importance and impact of the risk in the projects, usually supported by government's actions. The *Cover Risk Factor (CR_f)* can be classified into *price*, *technical* and *financial risks*. CR_f works as a project security. For more details, please see at Gross, Blyth, and Heptonstall (2010); Gross, Heptonstall, and Blyth (2007).

[117] If $r_{debt} > WACC_{prof}$, then $CR_f = 100\%$; If $r_{debt} \cong WACC_{prof}$, then $CR_f = 50\%$; If $r_{debt} < WACC_{prof}$, then $CR_f = 25\%$.

We have also considered the product from the difference from these *CO_2 emissions*[118] and the sum of the whole lifetime of the wind farm production ($\sum AEP_{avail_{yr_{1+...+yr_n}}}$). Eqn 6.2.5.4 has shown how $LCER_{CO_2}$ was written mathematically:

$$LCER_{CO_2} = \left(GHG_{EM_{ff\ co_2}} - GHG_{EM_{wecs\ co_2}} \right) \sum AEP_{avail_{yr_{1+...+yr_n}}} \quad [tCO_2/MW_eh] \quad \text{Eqn (6.2.5.4)}$$

so $GHG.R_{CM}$ was created considering *a carbon credit (ε_c)* for each MW_eh of $LCER_{CO_2}$ given to the producer within an annual basis $\therefore$ This credit must be updated within the same formula as shown in Eqn 6.2.5.2.1. $GHG.R_{CM}$ was formulated as Eqn 6.2.5.4.1:

$$GHG.R_{CM} = \varepsilon_c LCER_{CO_2} \quad [\$/tCO_2] \quad \text{Eqn (6.2.5.4.1)}$$

It is important to highlight each of these energy policy instruments suggested by *REPIM* could be adopted more than one type for the same wind power project. In $LCOE_{wso}$ we have considered four types of wind energy policy instruments *(REI_{CM}; REP_{CM}; $OREP_{CM}$* and *$GHG.R_{CM}$)* $\therefore$ Depend on specific legislation where wind farm is located or will be located, is crucial to understand what is acceptable, due to one of the fundamental condition is the public and local authorities to approve the wind farm operation and licenses. So, if we adopt more than one instrument for the same project, we could possible suggest a percentage[119] *(ξ_n)* for each one, as shown in Eqn 6.2.5.5:

$$REPIM = \xi_1 REI_{CM} + \xi_2 REP_{CM} + \xi_3 OREP_{CM} + \xi_4 GHG.R_{CM} \quad [\$/proj] \quad \text{Eqn (6.2.5.5)}$$

[118] According to Hondo (2005) the life-cycle emission factor of CO_2 for wind power could be about *30 g CO_2/kWh (29.5 g CO_2/kWh)* and for fossil fuel (Oil-fired) about *742 g CO_2/kWh (742.1 g CO_2/kWh)* within both lifetimes of 30 years and capacity factor of 20% and 70%, respectively. It is also possible to calculate it through *Electricity Emission Factors (EF_{el})* specific by country. For more details, please see at IEA (2011).

[119] The sum ($\sum \xi_{1+..+4}$) of ξ_n has to totalize 100%.

Wind Farm Life-Cycle Production Model ($LCPM_{WF}$)

When we have proposed to develop a different approach to calculate and simulate the electricity production of a wind farm, first of all it was necessary understand how a wind farm works. In other words, how WECS works, so we have understood according to what was discussed in Chapter 4 that wind has presents power in itself, so WECS extracts its kinetic energy into mechanical and finally into electricity. Therefore, *Wind Farm Life-Cycle Production Model* ($LCPM_{WF}$) was based on Moran and Sherrington (2007) when were also considered the wind farm installed capacity which was called *Wind Farm Capacity Model* (WF_{CM}); wind turbines layout effect to be analyzed by *Wind Turbines Layout Model* (WT_{LM}); *Power Curve Production Model* (PC_{PM}) in function of the full load hours of Production (FLH_{wf}) *and hours of effective Production* (H_{prod}) in a year and *P&D*[120] *Losses Model* ($P\&D_{LM}$) for determination of wind farm capacity factor (CF_{wf}). $LCPM_{WF}$ could be mathematically written by Eqn 6.2.6:

$$LCPM_{WF} = f\left(WF_{CM}; PC_{PM}; WT_{LM}; P\&D_{LM}\right) \quad \text{[kWh/yr]} \qquad \text{Eqn (6.2.6)}$$

The *Wind Farm Capacity Model* (WF_{CM}) was developed considering the *electrical installed capacity of a wind farm* (WF_{cap}). We can find WF_{cap} through the relation between the *number of wind turbines*[121] (N_{WT}) and *wind turbine rated capacity* (WT_{rated})$\therefore$ In other words, for a certain year a wind farm could be expressed its installed capacity as shown in Eqn 6.2.6.1:

$$WF_{CM} \Rightarrow WF_{cap} = N_{WT} WT_{rated} \quad \text{[kW}_e\text{/yr]} \qquad \text{Eqn (6.2.6.1)}$$

We have also considered the effect of layout for $LCPM_{WF}$ development as a sub-model the *Turbines Layout Model* (WT_{LM}) in a linear configuration as have already explained in Chapter 4, section 4.5.1. So we have determined N_{WT} based on Mustakerov and Borissova (2010) when was taken into consideration the total number of turbines N_{WT} as the result from a multiplication of rows (N_{row}) and columns (N_{col}) turbines number[122]. Mathematically, N_{WT} can be written as Eqn 6.2.6.1.1:

$$WT_{LM} \Rightarrow N_{WT} = N_{row} N_{col} \quad \text{[–]} \qquad \text{Eqn (6.2.6.1.1)}$$

[120] *P&D = Production and Distribution*

[121] The number of wind turbines for WF_{CM} must be count with operationing ones, which can change from year to year, depending on $O\&M_{manag}$, natural disaster (e.g. earthquake, floods, etc.), repowering process and other. The number of wind turbines for a given wind farm could be variable during the wind power plant lifetime.

[122] It is applied to layout configuration as shown in Figure 4.19.

As we could notice N_{row} and N_{col} must be calculated in function of the land area[123] available, *land lease cost (LLC)* and depending on orography of specific project $\therefore$ The predominant wind direction also has to be taken into consideration when positioning wind turbines. For WT_{LM} we have already considered wind-oriented turbines. For Johnson (2001) N_{row} can be found as Eqn 6.2.6.1.2:

$$N_{row} = \frac{L_{x_{row}}}{SD_{x_{row}}} + 1 \qquad [–] \qquad \text{Eqn (6.2.6.1.2)}$$

where $L_{x_{row}}$ is the *area with length (for row)* and $SD_{x_{row}}$ the *separation distances between wind turbines*. SD_x can be calculated by the turbine rotor diameter $\therefore$ Then, $SD_{x_{row}}$ can also be a result from the *coefficients (k_{row} and k_{col})* and *rotor diameter (D)*. Eqn 6.2.6.1.2 has expressed this relation:

$$SD_x = k_{row} D \qquad [–] \qquad \text{Eqn (6.2.6.1.3)}$$

therefore, Eqn 6.2.6.1.2 can be rewritten as:

$$N_{row} = \frac{L_{x_{row}}}{k_{row} D} + 1 \qquad [–] \qquad \text{Eqn (6.2.6.1.3)}$$

and then the same analogy can be taken into the *number of wind turbines in a column* with the $(SD_{xcol} = k_{col} D)$, as written in Eqn 6.2.6.1.4:

$$N_{col} = \frac{L_{x_{col}}}{SD_{xcol}} + 1 \qquad [–] \qquad \text{Eqn (6.2.6.1.4)}$$

Another important aspect for wind farm production is the *hours of production in a year (H_{prod})*. The hours of production for a wind farm depend on several factors $\therefore$ First of all, as Krokoszinski (2003) has introduced the concept of *Layout Factor (LF)* as the difference between *theoretical electrical energy* (*E_{theo}(park)*) and *available electrical energy (E_{avail})*. *E_{theo}(park)* is result from *full load hours of production* which is the same of *theoretical production time*. Full load hours of production for a wind farm *(FLH_{wf})* are the total hours available for wind farm generate electricity. In general, FLH_{wf} can be found by:

$$FLH_{wf} = 24_{hours} \times 365_{days} \Rightarrow 8760_{hours/year} \qquad \text{[h/yr]} \qquad \text{Eqn (6.2.6.2)}$$

[123] According to Bansal, Bhatti, and Kothari (2002) 10 ha/MW is the *"rule of thumb"* for land area for wind power plants, including infrastructure.

So we have considered the difference between E_{theo}*(park)* and E_{avail} as *Wind Farm Production Efficiency* (WF_{PE}) which is affected by human, climate and technological factor. Then, human factor refers how operations and maintenance of wind farm are $(O\&M_{manag})$. $O\&M_{manag}$ symbolized the frequency for *scheduled maintenance* $(SC_{O\&M})$ and *unscheduled maintenance* $(USC_{O\&M})$; within each *repair duration* (hours) and *costs ($/kWh)* associated. In other hand, the climate factor is associated to wind direction, intensity and speed; relative humidity, air pressure, site orography. So as we have considered the *hours of effective production in a year* (H_{prod}) for wind farm production, we could write it as Eqn 6.2.6.2.1:

$$H_{prod} = FLH_{WF} - \sum SC_{O\&M} + USC_{O\&M} \qquad \text{[h/yr]} \qquad \text{Eqn (6.2.6.2.1)}$$

$SC_{O\&M}$ and $USC_{O\&M}$[124] were developed based on Mabel and Fernandez (2008) when were considered the inclusion of hours for *wind turbine maintenance* (WT_{main}), *turbine breakdown* (WT_{bd}), *grid maintenance* (G_{main}) and *grid breakdown* (G_{bd}) to determine the effective hours of production of a wind farm. For $LCPM_{WF}$ we have also taken into consideration the full (see Figure 6.18, *blue line*) and available load hours of production per month (see Figure 6.18, *red line*); different *wind speed per period* (v_{w_p}), *air density* (ρ), which resulted into the *Power Curve Production Model* (PC_{PM}). It was necessary to understand how the production could be fit to the wind turbine power curve. We have taken into consideration the hours of production per period (month) for determining the best period for $O\&M_{manag}$ *as*:

- ✡ the frequency for *scheduled maintenance* $(SC_{O\&M})$ to be adopted in the wind farm (we have considered the period with less hours of production *(february, april, june, september* and *november*);
- ✡ the *wind speed for each period* (v_{w_p}) was the main criteria for determining the period for $SC_{O\&M}$ activities. If the *mouth mean speed* is lower than the *annual mean wind speed*, the loss of production would be reduced, in a contrary situation, the availability of the wind farm could be decreased;
- ✡ if both situation occurs, we have possible optimized the power curve of the wind farm in relation to *O&M* activities and FLH_{wf}.

For WECS the local wind resources can determine the technical and economic viability for a power plant, although for any wind project, theoretically, we have the same time distribution for electricity production. If we have considered in a monthly basis, the wind resources could be represented by a graph as shown in Figure 6.18. The effect of $O\&M_{manag}$ has influenced directly on wind farm *availability* (see Figure 6.18, *red line*).

[124] When necessary, a possible way for calculation the total hours and costs for both $SC_{O\&M}$ and $USC_{O\&M}$. For hours calculation we just do $SC_{O\&M(h)} = freq. \times hours$ and for costs $SC_{O\&M(\$)} = SC_{O\&M(h)} \times \$/\text{kWh}$.

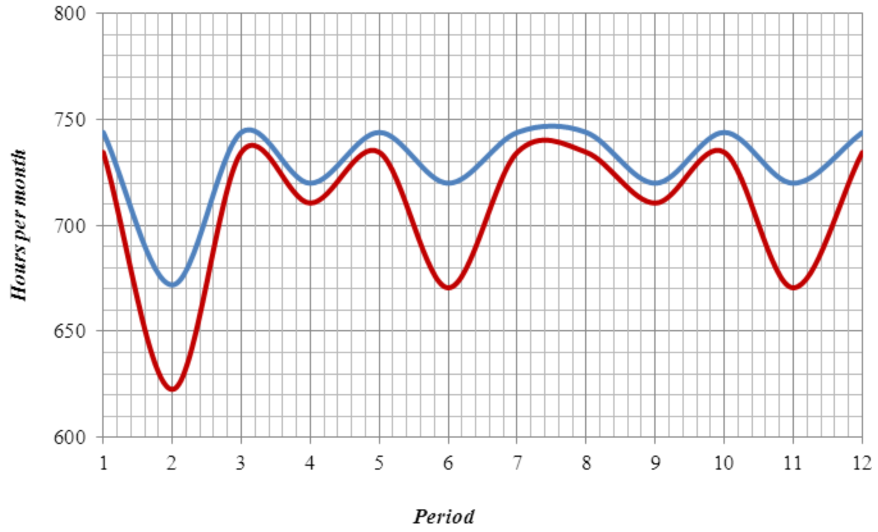

Figure 6.18 FLH_{wf} (blue line) and H_{prod} (red line) distribution during a year with $O\&M_{manag}$ effect. Source: Own elaboration

For example, if we have considered an $O\&M_{manag}$ for $SC_{O\&M}$ and $USC_{O\&M}$. For $SC_{O\&M}$ we have programmed *3 work days* of downtime in *february*, *june* and *november* which resulted in *72 hours of downtime* for the wind farm. And for $USC_{O\&M.}$ was considered a failure frequency of 1.5 per year, with *3 hours/wind turbine*, which resulted into *112.5 hours* and a total *184.5 hours of downtime per year*. The *availability* has resulted into *97.9%*, in other words, approximately *8 days/year* of downtime. We must remember that the *availability* represents the hours able to be used for electricity production by WECS. As we could see the $O\&M_{manag}$ is an important factor for wind farm electricity production. Technological factors are related to machinery and equipment for electricity production by WECS, *e.g. power curve of wind turbines*, *cut-in* and *cut-off* speeds (see Figure 6.19).

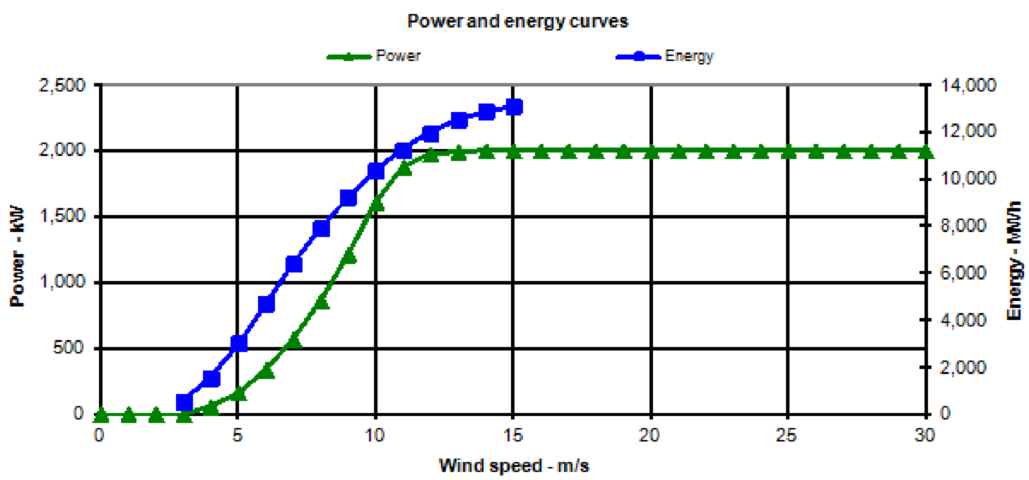

Figure 6.19 Wind turbine VESTAS V90 - 2 MW power curve. Source: RETScreen® International Clean Energy Decision Support Centre (2009)

The *production and distribution* of electricity produced from WECS has influence due to the natural losses during the production and distribution of electricity. We have taken into consideration the same methodology adopted by RETScreen® International Clean Energy Decision Support Centre (2009) for losses categorization: *array losses* (λ_a), *airfoil soiling and icing losses* ($\lambda_{s\&i}$), *downtime losses* (λ_d) and *miscellaneous losses* (λ_m)[125]. We have also taken into consideration the $\eta_{wecs_{(factor)}}$ as the basis for losses calculation. So, *P&D Losses Model factor* ($P\&D_{LM_{factor}}$) could be written as Eqn 6.2.6.3:

$$P\&D_{LM_{factor}} = \eta_{wecs_{(ref)}}\left[(1-\lambda_a)(1-\lambda_{s\&i})(1-\lambda_d)(1-\lambda_m)\right] \quad [-] \qquad \text{Eqn (6.2.6.3)}$$

then, the relation between AEP_{gross} and $P\&D_{LM_{factor}}$ is $LCPM_{WF}$ was developed for analyzing the wind farm production during the lifetime of the wind power plant. As we have developed for the whole lifetime of the wind farm, it was needed to calculate the *AEP* per year of operation. According to Albadi, El-Saadany, and Albadi (2009) *capacity factor* of a wind farm (CF_{wf}), in general, *is defined as the ratio of the average output power to the rated output power*. As we can notice in Eqn 6.2.6.4:

$$CF_{wf} = \frac{AEP_{avail}}{WF_{cap}\times 8760} \Rightarrow \frac{AEP_{avail}}{AEP_{rated}} \quad [-] \qquad \text{Eqn (6.2.6.4)}$$

the *Annual Energy Production Available* (AEP_{avail}). Downtime losses are influenced directly by the $O\&M_{manag}$ program adopted by the wind farm manager. For $LCPM_{WF}$ was considered the AEP_{avail} ($AEP_{avail} = WF_{cap}\left(1-\sum\lambda_{a;s\&i;d;m}\right)H_{prod}$), so we have taken into account H_{prod} for CF_{wf}, and possible rewrite the Eqn 6.2.6.4.1 as follows:

$$CF_{wf} = \frac{WF_{cap}H_{prod}\left(1-\sum\lambda_{a;s\&i;d;m}\right)}{WF_{cap}\times 8760} \quad [-] \qquad \text{Eqn (6.2.6.4.1)}$$

then, if WF_{cap} is the same and constant during wind farm lifetime, Eqn 6.2.6.4.1 could be expressed mathematically as shown in Eqn 6.2.6.4.2:

[125] According to RETScreen® International Clean Energy Decision Support Centre (2009) the typical values for a well designed wind farm for *array losses* range from 0 to 20% of AEP_{gross}, for *airfoil soiling and icing losses* range from 1 to 10% of AEP_{gross}; for *downtime losses* range from 2 to 10% of AEP_{gross} and for *miscellaneous losses* range from 2 to 6% of AEP_{gross}.

$$CF_{wf} = WF_{cap} H_{prod} \left(1 - \sum \lambda_{a;s\&i;d;m}\right) \frac{1}{8760} \qquad [–] \qquad \text{Eqn (6.2.6.4.2)}$$

As we have shown in Eqn 6.2.6.4, the product of WF_{cap} and FLH_{wf} is the maximum annual energy production *(AEP_{rated})*. The relation between AEP_{avail} and AEP_{rated} can be understood as *Wind Farm Production Efficiency (WF_{PE})*. We finally can obtain from Eqn 6.2.6.4, 6.2.6.4.1and 6.2.6.4.2 an equivalent term related to CF_{wf} which was named as *Wind Farm Production Efficiency (WF_{PE})*, considering the *Betz Limit`s coefficient of performance (C_{PBetz})*. This generator indicator as closer to *Betz Limit* ($\frac{16}{27}$ or 59.3%), better wind farm production efficiency the power plant is. WF_{PE} was formulated as shown in Eqn 6.2.6.5:

$$WF_{PE} = \frac{AEP_{avail}}{AEP_{rated}} \qquad [–] \qquad \text{Eqn (6.2.6.5)}$$

$LCPM_{WF}$ can be rewritten from Eqn 6.2.6 into two parts when we have taken into consideration AEP_{rated} and WF_{PE}.

$$LCPM_{WF} = AEP_{rated} WF_{PE} \qquad [\text{kW}_e\text{h/yr}] \qquad \text{Eqn (6.2.6.6)}$$

In order to make $LCPM_{WF}$ more realistic we have decided to adopt the principles of aerodynamics applied to WECS from Eqn 4.7 and Figure 4.12 to calculate AEP_{avail} and consequently WF_{PE}. We have considered AEP_{avail} equivalent to *Power Delivered (P_D)*. So, if we have added the effective hours of production for each year *(H_{prod})* of wind farm lifetime, then, we found the Eqn 6.2.6.6.1:

$$AEP_{avail} \Leftrightarrow C_{P\,Betz} WF_{cap} H_{prod} = \left[\frac{16}{27}\frac{1}{2} 10^{-3} \rho v_w^3 A N_{WT} \eta_{wecs}\right] H_{prod\; yr_{1+\ldots+yr_n}} \qquad [\text{kW}_e\text{h/yr}] \qquad \text{Eqn (6.2.6.6.1)}$$

As we could noticed AEP_{avail} for each year of the wind farm lifetime is variable due to *annual mean wind speed (v_w), air density (ρ), wind power plant efficiency (η_{wecs})* and *hours of effective production (H_{prod})*. The *overall efficiency*[126] for the power plant (equivalent to WF_{PE}) can also be understood as a result from *electrical transmission efficiency (η_e)* and *mechanical transmission efficiency (η_m).*

$$\eta_{wecs} = \eta_e + \eta_m \qquad [\%] \qquad \text{Eqn (6.2.6.6.1.1)}$$

[126] For Evans, Strezov, and Evans (2009) the efficiency of electricity production by WECS range from 24 to 54%.

6.4.4.3 NUMERICAL SIMULATION AND VALIDATION PROCESS

A simulation is a technique applied to systematic studies in order to understand *complex system*[127] and its interactions. The simulation process should follow some standard steps. For numerical simulation process we have found some common steps in the specialized literature (Andradóttir, 2007; Axelrod, 2003; Azadivar, 1999; Banks, 1999; Billinton, Hua, & Ghajar, 1996; Carson & Maria, 1997; Chang & Yu, 2009; Davis & Bingham, 2007; Delarue, Bouscayrol, Tounzi, Guillaud, & Lancigu, 2003; Fu, 1994; Fu, 2002; Hobbs, 2008; Law & Kelton, 2007; Olafsson & Jumi, 2002; Roberts, Andersen, Deal, Garet, & Shaffer, 1983; Shannon, 1992; Wang, Liu, & Zeng, 2009), for general proposals and applied to power systems, case of WECS. These steps are shown in Figure 6.20.

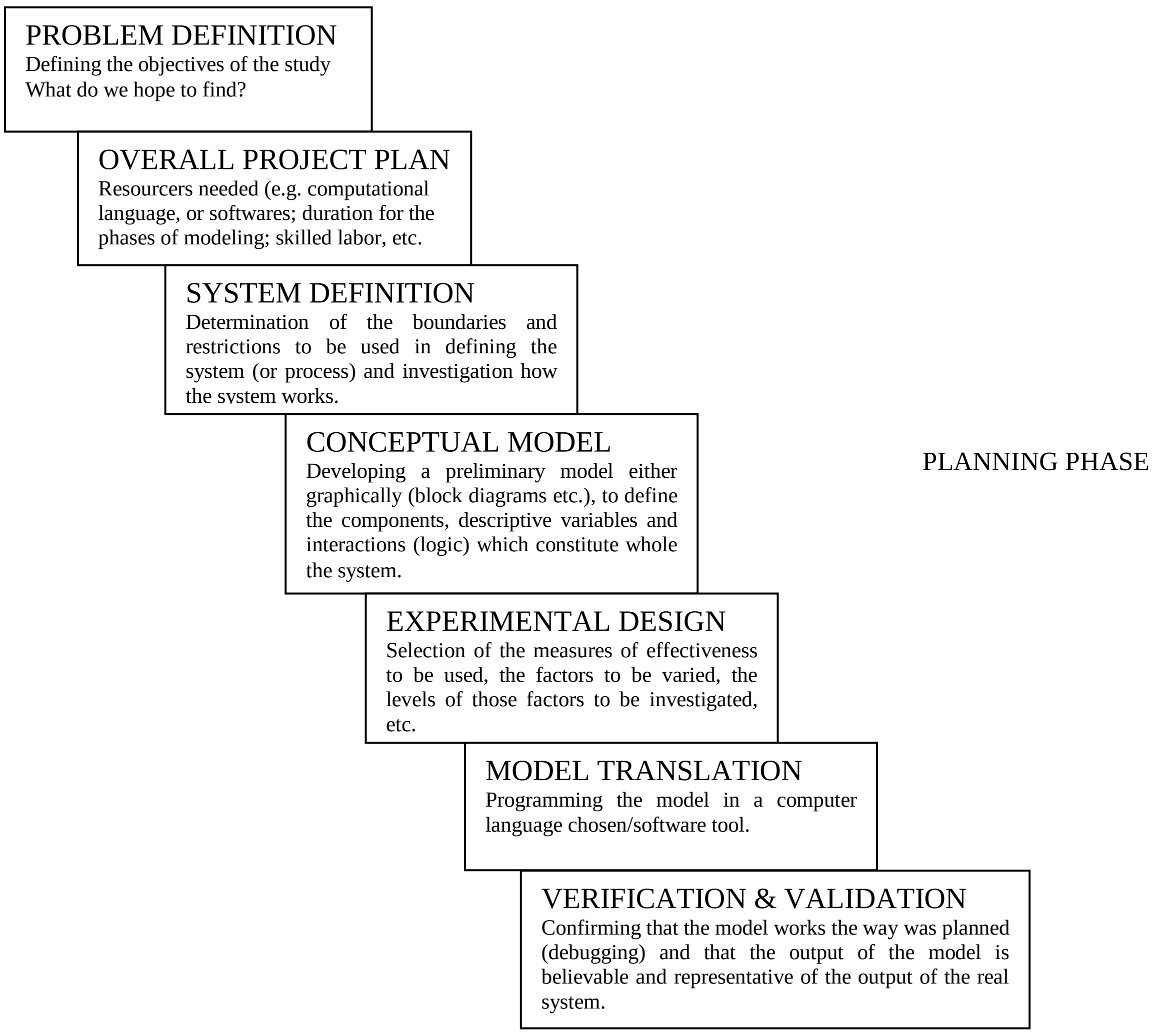

Figure 6.20 Planning phase for simulations studies. Source: adapted from Shannon (1992) and Banks (1999)

[127] We understand as a *complex system* when this same system has multiple interactions and one action implies into several responses from the system. It is the case of WECS and the LCOE approach.

For some researchers in simulation studies we must include more phases or steps, as the case of "*INPUT DATA PREPARATION"* (if the model to be simulated required several data) and "*FINAL EXPERIMENTAL DESIGN"*. Meanwhile, we understand a simulation process possible never is totally concluded in function of its nature and the process could be in evolutive stages of improving. For Shannon (1992) the process for simulation studies could be classified into planning and operational phase, and the operational one must include the following steps (see Figure 6.21):

EXPERIMENTATION/OPERATIONALIZATION
Execution of the simulation to produce the desired data and to perform sensitivity analysis.

ANALYSIS & INTERPRETATION
Drawing inferences from the data produced from the simulation. Interpretation of inter-relations among variables.

IMPLEMENTATION & DOCUMENTATION
Publishing the results, recording the findings as well as documenting the model and its use.

OPERATIONAL PHASE

Figure 6.21 Operational phase for simulations studies. Source: adapted from Shannon (1992) and Banks (1999)

The numerical simulation was run considering the variables and the impacts on the values of $LCOE_{wso}$ found. Remember that there is no standard *LCOE* value for WECS, both onshore and offshore applications. Table 6.5 has summarized the variables and their variations expected in the numerical simulation done.

Table 6.5 Main variables within expected values for $LCOE_{wso}$ algorithm simulation

Variables	Variations
Annual mean wind speed calculated (v_{wc})	7.4m/s; 9.1m/s; 12.5m/s
Operations and Maintenance management ($O\&M_{manag}$)	$O\&M_{manag(STD)}$; $O\&M_{manag(A)}$; $O\&M_{manag(B)}$
Wind turbines layout (L_{wt})	*5D/4D; 5D/7D; 5D/10D; 6D/12D*
Energy policy instruments (E_{pi})	*REPIM* (all instruments)

Source: Own elaboration

As we could noticed the model proposed by this Ph.D. research work ($LCOE_{wso}$) were needed many independent variables for running the algorithm developed. We have divided these variables into two large groups. The first group we reserve for economic variables and the second group is driven to engineering variables of the model (see Table 6.6).

Table 6.6 Independent variables of equations for $LCOE_{wso}$ algorithm

Equations	Variables		Sources
	Economic	Engineering	
Eqn 6.2.1.1; Eqn 6.2.1.1.1	MC_A; RC_{WT}; C_{kW}; IPT	N_{WT}	George and Schweizer (2008); Oliveira and Fernandes (2012a)
Eqn 6.2.1.2; Eqn 6.2.1.3	C_{steel}; CAB_{cost}	A; H_h; L_g	Nandigam and Dhali (2008); Dicorato, Forte, Pisani, and Trovato (2011); Jamieson (2011); RETScreen® International Clean Energy Decision Support Centre (2009); Bolinger (2012); Bolinger and Wiser (2012)
Eqn 6.2.1.4; Eqn 6.2.1.5	EF_c; ς ; SB_c	TL_r; L_t;	DeCarolis and Keith (2006); Hrayshat (2009); Alam, Rehman, Meyer, and Al-Hadhrami (2011)
Eqn 6.2.1.6; Eqn 6.2.1.7	Bld_{cost}; WT_{inst};FS; DT; EG	Bld_{area}	Alam et al. (2011); Rehman, Ahmad, and Al-Hadhrami (2011); Himria, Boudghene, and Draouic (2009); Oliveira and Fernandes (2012b); Ozerdem, Ozer, and Tosun (2006)
Eqn 6.2.1.9; Eqn 6.2.2.1.1; Eqn 6.2.2.1.2	if_r; Y_{RC}	N	RETScreen® International Clean Energy Decision Support Centre (2009); Nilsson and Bertling (2007); Saidur, Islam, Rahim, and Solangi (2010)
Eqn 6.2.3.1; Eqn 6.2.3.2; Eqn 6.2.4.1; Eqn 6.2.4.1.1	MLC; TLC; R_{taxes}; $C_{Mhr_{RM_{WT}}}$; $C_{md_{RM_{WT}}}$	$M_{hr_{RM_{WT}}}$; $N_{m_{RM_{WT}}}$; $D_{m_{RM_{WT}}}$	Nilsson and Bertling (2007); Rademakers, Braam, and Verbruggen (2003); Martin-Tretton, Reha, Drunsic, and Keim (2012); Bolinger (2012); Bolinger and Wiser (2012)
Eqn 6.2.4.1.2; Eqn 6.2.4.1.3	$C_{Mhr_{RM_{CT}}}$; $C_{md_{RM_{CT}}}$; $C_{Mhr_{S\&RV}}$; $C_{md_{S\&RV}}$	$M_{hr_{RM_{CT}}}$; $N_{m_{RM_{CT}}}$; $D_{m_{RM_{CT}}}$; A_{WT}; $M_{hr_{S\&RV}}$; $N_{m_{S\&RV}}$; $D_{m_{S\&RV}}$	Zhang, Chowdhury, Messac, and Castillo (2012a) ;Martin-Tretton et al. (2012); Rehman et al. (2011)
Eqn 6.2.4.2.1; Eqn 6.2.4.2.2; Eqn 6.2.5.1; Eqn 6.2.5.2; Eqn 6.2.5.2.1	ψ_{total} ; n_{ψ} ; ε ; n_{ε}	T_{mass}	Barradale (2010); Martinez, Sanz, Pellegrini, Jimenez, and Blanco (2009a, 2009b)
Eqn 6.2.5.3; Eqn 6.2.5.4.1; Eqn 6.2.5.5; Eqn 6.2.6.1.2; Eqn 6.2.6.1.4	CR_f; ε_c ; ξ_n	$L_{x_{row}}$; $L_{x_{col}}$; $SD_{x_{row}}$; $SD_{x_{col}}$ k_{row}; k_{col} ;D	BNDES (2012); IEA (2011); Green and Schellstede (2007); Hondo (2005); RETScreen® International Clean Energy Decision Support Centre (2009)
Eqn 6.2.6.1; Eqn 6.2.6.3; Eqn 6.2.6.6.1		λ_a; $\lambda_{s\&i}$; λ_d; λ_m ρ ; v_w; A; $\eta_{wecs(ref)}$	RETScreen® International Clean Energy Decision Support Centre (2009); IEA (2010)

Source: Own construction

For Kleindorfer et al. (1998) the fundamental difficulty in warranting *simulation models* and scientific methodologies has to do with the problem of induction. Since a researcher has direct access only to his or her own peculiar and limited set of experiences and knowledge, how can be justified the generalizations beyond the particular and personal empirical domain? The same situation arises in *simulations researches*. How can we infer from our observations (experience) of a system that the model we have idealized captures its essential structure and parameters?

As we could see, the validation process could be a hard way to find it and be adequate to the model itself. First of all, the system to be simulated must be modeled, so, a conceptual model has to be formulated and applied by a computerized model. As shown in Figure 6.22 the real and simulation worlds are linked by system theories through the *hypothesizing* and *modeling* process. Create hypotheses about what is studied is the same as create conceptions about relation among things (parts) of a system functioning phenomena (Sargent, 2009). For WECS, as a system, was already discussed in Chapter 4, is a chain of energy conversion that results in a final product, *electricity*. So the conceptual model was developed considering WECS mechanism and laws.

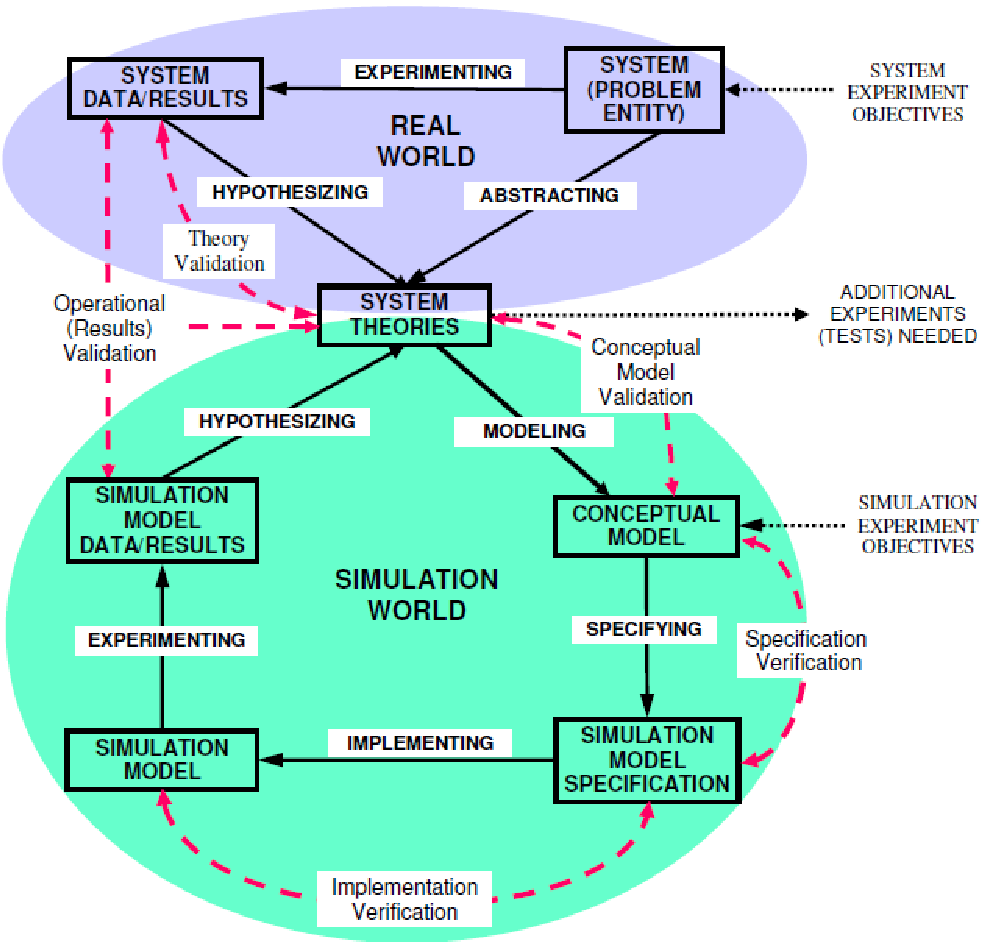

Figure 6.22 Relationship between real and simulation worlds through the verification and validation process. Source: Sargent (2009)

The *experimenting* and *specifying* process were done by adding the conceptual model (simulation model), which includes programming the conceptual model whose specifications are contained in the simulation model specification. The results obtained are compared within the data of the real world, taking into consideration "*mutatis mutandis"* condition in the comparison process done in the validation process.

For this Ph.D. research work we have chosen as validation technique the *"Comparison to Other Models"* and the other model to be compared with was *LCOE/NREL*. We also have considered the following possible equivalence for each part of the algorithm, as shown in Tables 6.7, 6.8, 6.9, 6.10 and 6.11.

Table 6.7 Numerical validation and reference parameters for $LCOE_{wso}$ and $LCCCM_{WF}$

Terms	Equivalent to	Values range	Sources/Notes
$LCOE_{wso}$	*LCOE/NREL*	\$ 50/MWh[(a)] to \$ 150/MWh[(b)] \$ 71/MWh (mean)	Lantz, Wiser, and Hand (2012); [(a)] Wind class 5; [(b)] Wind class 2; IEA (2005, 2010)
$LCCCM_{WF}$	*ICC*	869 €/kW to 1,559 €/kW	Milborrow (2006); IEA (2007); Ertürk (2012); See Table 5.3
WT_{CM}		\$ 780,000 to \$ 1,326,600[(c)] 700 to 1,600 cost/kW	Rehman et al. (2011); [(c)]Wind turbine cost represents 73.7% of wind turbine overall cost (Blanco, 2009); Adaramola, Paul, and Oyedepo (2011)
T_{CM}		\$ 205,000 to \$ 473,400[(d)]	Keith (2004); Rehman et al. (2011); [(d)] Tower cost represents 26.3% of wind turbine overall cost (Blanco, 2009)
$LWTG_{CM}$		3 to 10 % of the total costs of the complete wind farm	European Commission (2001)
	CAB_{cost}	\$ 80,000/km to \$ 133,000/km	Keith (2004); Rehman et al. (2011)
CP_{CM}		\$ 608/kW[(c)]	Rehman et al. (2011); [(c)] This approximation was done excluding underground cable (4.5 km) and overhead line (5 km)
	EF_c	\$ 400/kW to \$ 500/kW	Rehman et al. (2011); IEA (2005, 2010)
TS_{CM}			
	TL_c	\$ 0.04 to \$ 0.07/kWh	Delucchi and Jacobson (2011)
	Sb_c	\$ 113/kW to \$ 200/kW	Keith (2004); IEA (2005, 2010)
SI_{CM}	Bld_{cost}	\$ 500/m^2	Rehman et al. (2011)
	Bld_{area}	300 to 700 m^2	
PO_{CM}			
	FS	15 €/kW to \$ 97.60/kW	Himria et al. (2009); Oliveira and Fernandes (2012b); Ozerdem et al. (2006)
	DT	\$ 87.22/kW to \$ 385.25/kW	
	EG	\$ 305.25/kW	
F_{CM}	*FCR*	*calculated*	Depending on capital structure and project finance conditions
	w_{cc}	*estimated*	
CCC_{CM}	*Miscellaneous*	3 to 5% of *ICC*	Harper, Karcher, and Bolinger (2007) figure based on industry review
	κ	*estimated*	The estimation was done considering the final range from 3 to 5% of *ICC*

Source: Own construction

Table 6.8 Numerical validation and reference parameters for *LRCM*,$O\&M_{WFCM}$ and RCM_{WF}

Terms	Equivalent to	Values range	Sources/Notes
LRCM	*LRC*	$ 10 to $ 15/MWh	Tegen et al. (2012)
Y_{RC}		5 to 15 years	NREL (1995)
b		*calculated*	$b = \frac{\ln 2}{\ln PR}$
PR		0.7 to 0.9	Lund (2006); Junginger et al. (2005)
c_0		1 100 €/kW to 1 400€/kW; $ 1 700/kW to $ 2 400/kW	Blanco (2009); See Table 5.3 IRENA (2012); Lantz et al. (2012)
c		$ 6 800/kW to $ 9 600/kW	Valentine (2011); Wiser (1997)
V		237 699 000 kW (2011)	GWEC (2012)
V_0		6 100 000 kW (1996)	GWEC (2012)
$O\&M_{WFCM}$	*O&M*	3.5 to 6 cents/kWh 10 to 20% of *LCOE*	Christopher (2003); Ertürk (2012); See Table 5.4
$O\&M_{fixed_{CM}}$	*Fixed O&M*	11.5 cents/kW-yr	Harper et al. (2007)
	LLC	0.04 to 0.088 €/kWh $0.00108/kWh	Fueyo, Sanz, Rodrigues, Montanes, and Dopazo (2011); Fingersh et al. (2006)
$O\&M_{variable_{CM}}$	*Variable O&M*	6 cents/MWh	
	Preventive maintenance	0,003 to 0,009 €/kWh	Rademakers et al. (2003)
	Corrective maintenance	0,005 to 0,010 €/kWh	
ϖ		*estimated*	The estimation was done considering the final range from 10 to 20% of *LCOE*
MLC		54 €/h to 60 €/h	Nilsson and Bertling (2007); Rademakers et al. (2003)
N		20 to 30 years	RETScreen® International Clean Energy Decision Support Centre (2009)
TLC[128]		94 €/h to 106 €/h	Nilsson and Bertling (2007); Rademakers et al. (2003)
RCM_{WF}		30.43 $/kW	According to Ferrell and DeVuyst (2012); they have considered $ 70,000 for a 2.3MWcapacity turbine
DCM_{WF}		$ 27,285 to $ 148,600/turbine	Ferrell and DeVuyst (2012)
	if_r	2.5 to 4.5%/year	IMF (2012)
RM_{WT}			
	$M_{hr_{RM_{WT}}}$	100 to 300 man-hour	Doyle (2008); LVI Environmental Services (2009); Zhang et al. (2012a); Martin-Tretton et al. (2012); Rehman et al. (2011)
	$C_{Mhr_{RM_{WT}}}$	$ 85/h to $ 90/h	
	$N_{m_{RM_{WT}}}$	2 to 3 Cranes	
	$D_{m_{RM_{WT}}}$	3 to 5 days	
	$C_{md_{RM_{WT}}}$	$ 4,000 to $ 6,000/day	

Source: Own construction

[128] Minor maintenance takes about *4h for two people* and major maintenance takes about *7h for two people* (Nilsson & Bertling, 2007).

Table 6.9 Numerical validation and reference parameters for RCM_{WF} *(cont)*

Terms	Equivalent to	Values range	Sources/Notes
RM_{CT}			
	$M_{hr_{RM_{CT}}}$	100 to 150 man-hour	Doyle (2008); LVI Environmental Services (2009); Zhang et al. (2012a); Martin-Tretton et al. (2012); Rehman et al. (2011)
	$C_{Mhr_{RM_{CT}}}$	$ 85/h to $ 90/h	
	$N_{m_{RM_{CT}}}$	3 Equipment	
	$D_{m_{RM_{CT}}}$	2 to 3 days	
	$C_{md_{RM_{CT}}}$	$ 2,500/day	
$S\&RV$			
	A_{WT}	43 to 60 m^2/wt	Doyle (2008); LVI Environmental Services (2009); Zhang et al. (2012a); Martin-Tretton et al. (2012); Rehman et al. (2011)
	$M_{hr_{S\&RV}}$	3 to 5 man-hour	
	$C_{Mhr_{S\&RV}}$	$ 85/h to $ 90/h	
	$N_{m_{S\&RV}}$	3 Equipment	
	$D_{m_{S\&RV}}$	2 days	
	$C_{md_{S\&RV}}$	$ 3,500/day	
RVM_{WF}			
	WT_{weight}	200 to 273 t[(a)]	Doyle (2008); LVI Environmental Services (2009); [(a)] We considered the proportional relation (kg/kW) as used by Bolinger (2012); Bolinger and Wiser (2012) for 2 MW wind turbine.
	C_{steel}	$190 to $ 220/t	LVI Environmental Services (2009); Doyle (2008)
TS_{VM}			
	T_{mass}	138 to 143 t	LVI Environmental Services (2009); Martinez et al. (2009a, 2009b); Three sections

Source: Own construction

We have adopted general values for simulation and validation procedures. We have in mind that real values were obtained from specialized literature. A different methodology proposed for LCOE/NREL calculation only make sense for comparison reasons, if credible sources of data have be used for input and parameters for this different methodology *($LCOE_{wso}$)*. All data related to monetary values in the model were considered the following aspects:

1. The effect of time on money, *"the inflation"*, that is why all the values which mean *"money"* for the $LCOE_{wso}$ were updated considering the inflation of the period until *2012 year*.

2. As we have different currencies (US$, CAD $ and Euro), a standardization of currencies was applied through the exchange rates taking into consideration the published year and converted to year 2010. The currencies standardization was done for monetary values considered and shown in Chapter 7 and 8.

Table 6.10 Numerical validation and reference parameters for *REPIM*

Terms	Equivalent to	Values range	Sources/Notes
REPIM			
REI	*ITC*		
	ψ_{total}	30%[a] of initial capital cost;	[a] According to Bolinger (2009) and Kung (2012)
	n_{ψ}	6 years (5%/year)	
REP_{CM}	*PTC*		
	ε_0	88.20 €/MWh[b]; $75.00/MWh[c]; CAD $10/MWh[d]	[b] For Portugal (DRE, 2012); [c] For Brazil (Azuela & Barroso, 2012); [d] For Canada (Saidur et al., 2010; Valentine, 2010)
	n_{ε}	10-15 years[b]; 15-20 years[c]; 10-15 years[d]	
$OREP_{CM}$			
	CR_f	20 to 80%	BNDES (2012)
$GHG.R_{CM}$			
	$GHG_{EF_{ff}\,co_2}$	16 to 410 g/kWh; 689 to 890 g/kWh; 460 to 1234 g/kWh[e]	[e] Hydraulic, fuel oil and natural gas for Şahin (2004);
	$GHG_{EF_{wecs}\,co_2}$	11 to 75 g/kWh; 48 g/kWh[f]; 12 to 83 g/kWh[g]	[f] Interpolation considering the lifetime effect (25 years) as Hondo (2005) has discussed; [g] Dolan and Heath (2012)
	ε_c	35 €/tCO_2[h]; $13.00/$tCO_2$[i]; $ 30.00/tCO_2[j]	[h] For Portugal (Valles, Reneses, & Campos, 2012); [i] For Brazil (Pereira, Reis, de Araujo, & Gongalves, 2006); [j] For Canada (Monahan & van Kooten, 2010)
	ξ_n	0 to 100% *(if applicable)*	The distribution depends on specific legislation, in case of the same wind project receives more than one incentive or subsidies by government.

Source: Own construction

The *REPIM* was developed to represent the energy policy effect on wind power plant cost, but as Barradale (2010) has discussed about some other policy instruments used to encourage renewable energy investment include:

- *Pricing or tariff mechanisms*: Guaranteed prices for renewable energy. Favorable tariff mechanisms have been used to promote wind energy development in Germany and Denmark.
- *Production cash subsidies*: These can be provided at the national, state, and local levels.
- *Depreciation rules*: Accelerated depreciation for capacity investment can reduce a company’s tax expense during early years, providing a time-value-of-money benefit.
- *Renewable portfolio standards (RPS)*: These require electricity suppliers to meet a certain percentage of their load from renewable energy sources.

Table 6.11 Numerical validation and reference parameters for $LCPM_{WF}$

Terms	Equivalent to	Values range	Sources/Notes
$LCPM_{WF}$	AEP_{avail}	kW_eh/yr	
WF_{CM}			
	WT_{rated}	2,000 kW	RETScreen® International Clean Energy Decision Support Centre (2009)
WT_{LM}	*Wind farm geometry*	*5D/4D; 5D/7D; 5D/10D; 6D/12D*	See Table 6.5
	$L_{x_{row}}$	1 800 to 4 680 m	Nandigam and Dhali (2008); Emami and Noghreh (2010)
	$L_{x_{col}}$	2 430 to 2 790 m	
	$SD_{x_{row}}$	calculated	Wind farm geometry impacts direct on the values of these variables.
	$SD_{x_{col}}$	calculated	
	k_{row} and k_{col}	estimated	
	D	90 m	RETScreen® International Clean Energy Decision Support Centre (2009)
PC_{PM}	*Cut-in*	4 m/s	Vestas Wind Systems A/S (2013)
	Cut-out	25 m/s	
	ρ	*calculated*	It was calculated for Brazil, Canada and Portugal according to Eqn 4.2 within data shown in Figures 6.11, 6.12 and 6.13.
	v_w	5.3 m/s (Brazil); 9.0 m/s (Canada) and 6.6 m/s (Portugal)	RETScreen® International Clean Energy Decision Support Centre (2009); See Table 6.4 and Figures 6.11, 6.12 and 6.13
	A	6,720.1 m^2/turbine	RETScreen® International Clean Energy Decision Support Centre (2009); See Figure 6.6
	$SC_{O\&M}$		$O\&M_{manag(STD)}$; $O\&M_{manag(A)}$; $O\&M_{manag(B)}$
	Days/month	*5 d; 2 d; 3 d*	Ding and Tian (2012)
	Months	*Feb; Jun; Nov*	See Figure 6.18
	$USC_{O\&M}$		
	Freq. failure	*1.5/yr; 1.0/yr; 1.8/yr*	Rademakers et al. (2003)
	Duration	*3 h/repair; 4 h/repair; 2 h/repair*	
	N_{WT}	*calculated*	See Eqn 6.2.6.1.1
	H_{prod}	*calculated*	See Eqn 6.2.6.2.1
$P\&D_{LM}$	λ_a	0 to 20% of AEP_{gross}	RETScreen® International Clean Energy Decision Support Centre (2009)
	$\lambda_{s\&i}$	1 to 10% of AEP_{gross}	
	λ_d	2 to 10% of AEP_{gross}	
	λ_m	2 to 6% of AEP_{gross}	
	$\eta_{wecs(ref)}$	25%	Hansen, Bower, and Studies (2003)
CF_{wf}[129]		21 to 41% *(onshore)*	IEA (2010)

Source: Own construction

All the variables from Tables 6.5 and 6.6 and data from Tables 6.7 to 6.11 were used for parameterization of the proposed $LCOE_{wso}$ through the *simulations procedures* shown and explained in Chapters 7 and 8.

[129] According to IEA (2010), the capacity factor of wind projects range from *21% to 41% for onshore* and *34% to 43% for offshore.*

6.5 SUMMARY AND CONCLUSIONS

This chapter started by briefly presenting some considerations on epistemological and methodological research issues in general, and focused on *operational research* and *optimization concerning*. The rationale of the study and the research framework was also discussed, followed by the outline of the research design, focusing on the main steps related to methodological procedures (section 6.4.2), theoretical framework and hypotheses development (section 6.4.3), research objectives (6.4.3.1), research approach (section 6.4.3.2).

The research design was build considered the *LCOE/NREL* methodology and the variables were grouped into four categories: *(1) Wind speed (v_w); (2) Wind turbines layouts (L_{wt}); (3) Operations and Maintenance management ($O\&M_{manag}$)* and *(4) Energy policy instruments (E_{pi}).* The reason for grouping these variables into these categories was based on research hypotheses presented at Table 6.3. The variables relationship and research boundary (see Figure 6.14) were explained in section 6.4.4.1 which driven the simulation procedures done and shown in Chapter 7.

During this Ph.D. research work a conceptual model was developed based on conceptual and operational definitions explained at Table 6.2. We defined the *Economic Optimization*, a *Simulation Model*, *LCOE*, *AEP* and *COE.* For this research work we considered as *"model" the representation of a system or process of the real world into a theoretical manner* (Carson & Maria, 1997). *LCOE* analyses, therefore, provide important insights into the main cost factors of alternative technologies for producing electricity, in our case, WECS. Since various cost components can vary considerably from place to place and from wind project to wind project, sensitivity analysis was adopted as the key in determining the impacts of changes in costs on the costs of producing electricity (Angevine, Murillo, & Pencheva, 2012).

For the mathematical model structuring we started by building a *Block Diagram* of the algorithm proposed. In Figure 6.16 is shown the six big groups of equations used for *Economic Optimization Algorithm Proposed (EOAP)*, which is equivalent to $LCOE_{wso}$. As we could notice, as wind power technology is capital-intensive, most of equations of this model figure that. So the first one is the *Wind Farm Life-Cycle Capital Cost Model ($LCCCM_{WF}$)* with the sub-models as *Wind Turbines Cost Model (WT_{CM}), Towers Cost Model (T_{CM}), Local Wind Turbines Grid Cost Model ($LWTG_{CM}$), Collecting Point Cost Model (CP_{CM}), Transmission System Cost Model (TS_{CM}), Supporting Infra-structure Cost Model (SI_{CM}), Pre-operational Cost Model (PO_{CM}), Financing Cost Model (F_{CM}) and Capital Costs Contingencies Cost Model (CCC_{CM}).*

For Tegen et al. (2012) *O&M* variables must be focused on understanding current and historical operation and maintenance (*O&M*) costs, including *major component replacement costs (LRCM)*. A better understanding and more precisely analysis O&M costs trends and behavior go through the following aspects:

- ✡ Analysis to estimate the impact of anticipated improvements to *O&M* for both *land-based* and *offshore* wind projects on *LCOE*. Simulation models can be improved and optimization procedures must be applied.

- ✡ Development of models to better represent *non-turbine driven project costs*, *e.g.*, foundations, electrical cabling, and installation, for a range of turbine and project sizes for both *land-based* and *offshore* wind technology.

- ✡ Analysis to quantify the impact of potential technology advances and obsolescence on wind power system reflect into *LCOE* for *land-based* and/or *offshore* wind technology pathways.

The model ($LCOE_{wso}$) also took into consideration the *LRCM* or *Levelized Replacement Cost Model*, related to a cost item treated as "*saving account"* for the wind power project. It was designed two sub-models: the *Annual Replacement Cost Model* (AR_{CM}) (see Eqn 6.2.2.1) and *Technological Obsolescence Cost Model* (TO_{CM}) (see Eqn 6.2.2.2). This model was developed in order to guarantee at a certain period (5, 10 and 15 years) funds enough to make the necessary review in the producing power system.

The operation of a wind farm also needs funds to run the machinery and other facilities, so, we have included a model related to *O&M* named *Wind Farm O&M Cost Model* ($O\&M_{WFCM}$). $O\&M_{WFCM}$ was designed into two part, one is fixed ($O\&M_{fixed_{CM}}$) and the other variable ($O\&M_{variable_{CM}}$). $O\&M_{fixed_{CM}}$ considered a percentage of initial capital cost ($LCCCM_{WF}$) and the *Land Lease Cost (LLC)* within the inflation effect for the lifetime of the power plant (see Eqn 6.2.3.1). The variable part of O&M ($O\&M_{variable_{CM}}$) was developed based on Zhang et al. (2010) and we took into consideration the number of wind turbines, annual energy rated production per turbine, labor cost and revenues taxes (see Eqn 6.2.3.2).

As $LCOE_{wso}$ was designed for lifetime of the wind power project, we thought about the removal phase of the project (project shutdown, removal or repowering) as shown in Figure 4.13 and Figure 5.1. The *Wind Farm Removal Cost Model* (RCM_{WF}) and sub-models *Wind Farm Decommissioning Cost Model* (DCM_{WF}) *Model* and *Wind Farm Residual Value Model* (RVM_{WF}) were developed in order to cover the main costs for *decommissioning process* and the *residual value of a wind farm at the end of its lifetime* (see Eqn 6.2.4.1; 6.2.4.1.1; 6.2.4.1.2; 6.2.4.1.3; 6.2.4.2; 6.2.4.2.1; 6.2.4.2.2; 6.2.4.2.3).

According to GWEC (2012) the wind power worldwide has increased exponentially as shown in Figures 3.12 and 6.1, this fact can be explained by the great attention the governments, enterprises and consumers in general put on RETs, case of wind energy. The hand of government in the renewable energy projects could be seen through the *incentives* given to the investors in this kind of project. That is why we have developed the *REPIM* for $LCOE_{wso}$ for introduce the public incentives forms in order to reduce the cost of this technology. The *Renewable Energy Public Incentive Model (REPIM)* was created within the following sub-models: *(1) Renewable Energy Investment Credit Mode* (REI_{CM}); *(2) Renewable Energy Production Credit Mode* (REP_{CM}); *(3) Other REPs Credit Mode* ($OREP_{CM}$) and *(4) GHG Reduction Credit Model* ($GHG.R_{CM}$).

Each *REPIM* sub-model was explained and respective equation was developed as shown in Eqn 6.2.5.1, 6.2.5.2, 6.2.5.3, 6.2.5.5 and 6.2.5.5. The Eqn 6.2.5.5 could be used for the balance of the incentive given to the same wind power project. The public inventive must consider that costs differ by geographic region to another. The incentive could be tailored to reflect differing costs to encourage locating wind farms throughout the region, according to the wind resources available, both *onshore* and *offshore*, so that wind energy is not just be concentrated in a few windy areas.

According to the *research question* and *LCOE/NREL methodology* used as the basis for the methodology proposed by this Ph.D. research work, the *power production* of the wind farm, in better words, *Annual Energy Production (AEP)* should be considered in our $LCOE_{wso}$ developed and validated. We also called *Wind Farm Life-Cycle Production Model ($LCPM_{WF}$)*. This model was developed with four sub-models: *(1) Wind Farm Capacity Model (WF_{CM}); (2) Wind Turbines Layout Model (WT_{LM}); (3) Power Curve Production Model (PC_{PM})* and *(4) P&D Losses Model ($P\&D_{LM}$)*, as shown in Eqn 6.2.6.

During the elaboration of $LCOE_{wso}$ methodology we notice the necessity to verify if the model and sub-models would be a real *response* to the *research question* and *objectives* designed for this research work, so we have to make the *parameterization*[130] of the data for the *inputs* to feed the $LCOE_{wso}$ calculations. As shown in Figure 6.22 we could compare the *real world* to the *simulation world* for validation if a conceptual model, in fact, represents a real system. In the case of this Ph.D. research work, could be able to calculate the nearest values for the cost of energy produced from 50 MW_e onshore wind farm.

The parameterization process was done considering the data from Figure 6.6 *(wind turbine technology used)*, Figure 6.11 *(climate conditions for Aracati, Brazil)*, Figure 6.12 *(climate conditions for Cape Saint James, Canada)*, Figure 6.13 *(climate conditions for Corvo Island, Portugal)*, Table 6.4 *(locations chosen with criteria and reasons)*, Table 6.5 *(main variables)*, Table 6.6 *(independent variables)*, Table 6.7 *(parameters for $LCOE_{wso}$ and $LCCCM_{WF}$)*, Table 6.8 *(parameters for LRCM,$O\&M_{WFCM}$ and RCM_{WF})*, Table 6.9 *(parameters for RCM_{WF})*, Table 6.10 *(parameters for REPIM)* and Table 6.11 *(parameters for $LCPM_{WF}$)*. All data used as inputs for each independent variable are from a variety of credible industry sources, as scientific journals and proceedings of the global wind energy industry.

The algorithm developed during this Ph.D. research work *($LCOE_{wso}$)* was solved in an environment MS Excel-Matlab®, with Matlab® we have retrieved data from Excel and have made the simulations considering the main variables, such as *wind speed (v_{wc}), operations and maintenance management ($O\&M_{manag}$), wind turbines layout (L_{wt})* and *energy policy instruments (E_{pi})*. The $LCOE_{wso}$ proposed in this research can embody influences of WECS, financing and human factors on COE from the wind farm operation, and can be used to evaluate economic operation of wind farms with different wind resources, investing situations, installed capacities, maintenance situations and so on.

After discussing and justifying the methodological choices for this Ph.D. research work, the next two chapters present the numerical simulation and validation procedures (Chapter 7) with results and discussion (Chapter 8).

[130] In this research work, the "*parameterization*" means the range of values of each independent variable can assume during a numerical simulation.

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Sic Transit Gloria Mundi.
Thomas van Kempen

CHAPTER 7

NUMERICAL SIMULATION AND VALIDATION

This chapter details the WECS and climate numerical parameters considered for simulations procedures. Economic and financial issues to a wind project are also analyzed, within O&M inputs, variables and strategies proposed. General simulations procedures within optimization criteria and sensitivity analysis. Summary and conclusions are presented at the end, with the respective references.

7.1 INTRODUCTION

After developing the $LCOE_{wso}$ model for wind power and presented in Chapter 6, it is necessary to perform its testing. This is important as it will allow validating the $LCOE_{wso}$ model and at the same time carrying out a comparison with other methodologies of basic wind power cost calculations∴This chapter presents the test all tools developed and presented previously. In order to perform the *numerical modeling* and *simulations* we had used a set of *real data*, during the period of one year (see Figures 6.11, 6.12 and 6.13), for wind power energy production in three different sites.

Numerical modeling is an important phase of a simulation research work for designing, evaluation and implementation analysis of power systems. Several models for various types of WECS have been the subject of several studies (see Tables 5.8 and 5.9). We notice that improved analysis techniques are needed in two main areas: *(1) evaluation of operational characteristics of a proposed WECS (technical performance)*, and *(2) determination of the real economic cost of electricity production of a given power system at a right given site (economic performance)* (Ibrahim, Lefebvre, Methot, & Deschenes, 2011)∴Numerical model is used as a strategy for validating the algorithm developed for representation of a real system.

As has stated Molenaar (2003, p. 111) validation is *"the process of determining whether or not a computer simulation model is consistent with the underlying mathematical model to a specified accuracy level".* We understand the validation in a research like this; it is a necessary procedure for a better comprehension of the relations among the set of variables used for the model proposed. We have checked the variable relations that affect each other simultaneously, which can be used for future research needs.

This chapter explains and shows the numerical simulation and validation process utilized in this Ph.D. research work, focused on wind power technology in order to be applied directly on economic evaluation of wind energy cost researches∴*Power system parameters used for simulations* are shown in section 7.2. In this section, detailed *technical features of WECS* (section 7.2.1), within *assumptions, constraints, and limitations* (section 7.2.1.1) considered; *wind turbine technology* (section 7.2.1.2) and *wind farm layout* studied (section 7.2.1.3) are shown. The *climate data considered for simulations* are explained in section 7.2.2, focused on *wind speed* (section 7.2.2.1); *atmospheric pressure* (section 7.2.2.2) and *air temperature* (section 7.2.2.3) for three sites chosen.

Section 7.3 refers to the *economic and financial aspects of the wind project* by describing the *assumptions, constraints, and limitations* (section 7.3.1) and expected *revenue, capital, O&M, and other costs* (section 7.3.2)∴In section 7.4 *O&M assumptions for wind project* simulations are shown and *inputs and variables* (section 7.4.1) and *O&M programs proposed* (section 7.4.2). Section 7.6 is related to *general simulations procedures* within its *steps fallowed* (section 7.6.1), *optimization criteria* (section 7.6.2) and *sensitivity analysis* carried out (section 7.6.3). Finally, *the summary and conclusions* of this chapter (section 7.7) and all *references* (section 7.8) used are present at the end of this chapter.

7.2 POWER SYSTEM PARAMETERS USED FOR SIMULATIONS

7.2.1 TECHNICAL FEATURES OF THE WIND FARM

The hypothetical wind farm will consist of up to 25 wind turbines with 2 MW rated power (see Table 7.3) which will be connected to the national electricity grid through *electrical cables*[131]. The operation of the wind farm will be closely monitored remotely through a sophisticated supervisory control and data acquisition (SCADA) system∴A network of underground electrical cables will transmit the power from the individual turbines to the *point of common connection (PCC).*The principal components of the onshore wind farm considered for simulations:

- ✡ 25 Vestas V90-2MW wind turbines;
- ✡ Access roads;
- ✡ Power cables between the turbines and from the wind farm to the connection point of the transmission public electricity grid;
- ✡ A substation required to house systems to control and monitor the operation of the wind farm as whole and electrical equipment needed to connect the wind farm to the electrical transmission grid.

The wind turbines chosen to be installed at power plant will be technologically updated and economically proposed∴The turbines have minimum maintenance requirements and include the following features as shown in Table 7.1.

Table 7.1 Wind turbines systems added-in

✡ Long term corrosion protection	High quality paints are used to protect the turbine components from the corrosive environment experienced in sites close to the sea
✡ Low noise emissions	Aerodynamic blade and mechanical component design minimize noise emissions. Special control systems are embedded to mitigate noise emissions while maximizing energy production
✡ Safety and accessibility features for service engineers and technicians	The turbines are normally fitted with navigational lights and aerial warning lights meeting the relevant safety standards
✡ Equipped with monitoring and control systems (SCADA)	Predictive maintenance systems are embedded to detect potential technical problems at an early stage allowing for improved maintenance planning and reduced turbine downtime
✡ Lightning protection	A protection system protects the turbine blades and sensitive electrical components from damage caused by lightning strikes

Source: Own elaboration

[131] The electrical cables are used for local wind turbines grid *($LWTG_{CM}$)* and transmission system *(TS_{CM})*. The cables voltage are not detailed, due to the objective of this Ph.D. research work what discard the electrical microscopic analysis of the wind farm for simulations procedures.

7.2.1.1 ASSUMPTIONS, CONSTRAINTS, AND LIMITATIONS

We have considered for numerical simulation and validation process of $LCOE_{wso}$ methodology, the following aspects:

7.2.1.1.1 Assumptions

Table 7.2 Technical parameters of wind power project

✡ Project name	FireStar Wind Farm
✡ Project type	Power (electricity)
✡ Grid type	Central grid
✡ Life time *(N)*	25 yrs
✡ Sites	Araripe (Brazil); Corvo Island (Portugal) and Cape Saint James (Canada)
✡ Number of wind turbines (N_{WT})	25
✡ Wind farm capacity (WF_{cap})	50 MW_e
✡ Wind turbine technology	See Table 7.3
✡ Wind speed measured at (H_0)	10m
✡ Hub height *(H)*	105m
✡ Terrain rugosity factor *(a)*	0.14
✡ Annual mean wind speed (v_{wc})	7.4m/s; 9.1m/s and 12.5m/s

Source: Own elaboration

a) Sites with suitable mean annual wind speed (e.g. greater than 4 m/s) at the hub-height of the WEC system analyzed;

b) We have considered sites are further away from residential settlements than other areas. Therefore any possible impacts that the wind farm might have on such settlements are expected to be small;

c) Annual constant mean wind speed and direction: the annual mean wind speed is constant throughout the simulations and the wind speed direction is fixed with respect to the farm layout∴If another wind direction is wanted, a new simulation model must be produced with a rotated layout;

d) The wind distribution and frequency are variable during the whole lifetime of the power plant;

e) Climate data used for simulations, such as, wind speed, atmospheric pressure and air temperature are constant during the lifetime of the wind farm for the three different sites chosen;

f) The wind turbines are considered to be spaced in a way to minimize turbine-to-turbine interference in the wind flow (wake and array effects);

g) We have considered the same wind turbine technology during 25 years of lifetime of the wind farm operation and for each site chosen the availability of the same product (wind power plant equipment);

h) Proximity of the site to the electric grid should preferably not exceed 3km; and accessibility of the site, in order to avoid expensive road construction etc., must be guaranteed;

i) For each year of operation, different *capacity factors* are expected, due to the dynamic nature of WECS, and in particular, a wind farm analyzed in three different sites, during the simulations procedures;

j) The wind farm production are defined in *Wind Farm Life-Cycle Production Model* ($LCPM_{WF}$) and information/data are based on Table 6.11;

k) The Power Delivered (P_D) is exported (sold) to the grid, so AEP_{avail} (Annual Energy Production available) is the total power output from the hypothetical wind farm simulated;

l) Wind farm losses (for production phase) changes linearly with power level output (AEP_{avail});

m) We considered the environmental impacts as minimal as possible for the wind farm projected, specially related to the local *fauna* and *flora*.

7.2.1.1.2 Constraints

a) We have considered constant the annual mean wind speed for all simulations at each chosen site during this Ph.D. research work;

b) As we have considered only the production and transmission phases of the power plant (see Chapter 6, section 6.4.4.1; Figure 6.14), the distribution costs and investment infrastructure are not included in the $LCOE_{wso}$ methodology;

c) The wind farm production is analyzed annually, but monthly production variation is considered for wind farm production management;

d) The effect of technology innovation for this power plant is not considered for cost of energy reduction, because the model consider the same wind turbine technology for entire lifetime of the wind project;

e) We have considered only linear wind turbines layouts, in order to simplify the $LCOE_{wso}$, other possible wind turbines layouts are not considered which in such way, limits this proposed methodology for other cases of layouts;

f) For WECS, we have taken into consideration an autonomous system, which exclude any kind of energy production planning, so the variability can easily possible be more intense than done in the simulations studies.

7.2.1.1.3 Limitations

a) The suitable mean annual wind speed and direction are considered fixed during 25 years of lifetime of the wind farm operation, so the effect of variation due to climate change are not considered;

b) Due to the lack of availability of data, in particular sites with wind data at Canada, Brazil and Portugal for high elevations above the ground (at least 50m above ground level), it is presently difficult to establish an accurate estimate for the wind energy production as supposed to be this hypothetical wind farm (105m);

c) When we have considered the same technology (wind turbine) for the power plant, we have discard the possibility the effect of updating the machineries and lower much more the cost of production;

d) As we have consider the availability of wind turbines ‘suppliers (Vestas V90-2MW) for the sites analyzed, it was not considered the cost of transportation in these three different sites used for simulations;

e) The cost of transmission reflects the cost for a maximum distance of 3km (from wind farm to the distribution point), so the $LCOE_{wso}$ calculated is applicable for this distance only, when this indicator is used for comparison among different wind farms.

7.2.1.2 WIND TURBINE TECHNOLOGY

Table 7.3 Technical data of wind turbines

✡	Model/type	Vestas V90-2MW
✡	Rated power	2 000 kW
✡	Cut-in speed	4.0 m/s
✡	Rated wind speed	12.0 m/s
✡	Cut-out speed	25.0 m/s
✡	Type class	IEC IIIA
✡	Diameter	90.0 m
✡	Rotor swept area	6 361.7 m^2
✡	Rated rotor speed	14.9 rpm
✡	Rotor speed range	9.0 - 14.9 rpm
✡	Generator type	Double-fed asynchronous generator
✡	Controls	Pitch regulated with variable speed
✡	Tower type	Tubular steel tower

Source: Vestas Wind Systems A/S (2013) and RETScreen® International Clean Energy Decision Support Centre (2009)

According to Vestas Wind Systems A/S (2013) this wind turbine is designed for operating at certain conditions:

1. Ambient temperatures ranging from -20°C to +30°C. Special precautions must be taken outside these temperatures;

2. The placement of wind turbines have to operate at a distance of at least 5 rotor diameters (5D=450m) between the wind turbines themselves. If the wind turbines are placed in one row, perpendicular of the predominant wind direction, the distance between the wind turbines must be at least 4 rotor diameters (4D=360m).

Vestas V90-2MW model uses gearboxes with one planetary and two parallel stages from which the torque is transmitted to the generator through a composite coupling∴This model also contains a 4-pole Doubly-Fed Asynchronous Generator (DFIG) with wound rotor (see Chapter 4, Figure 4.8 and Table 4.3). A partially rated converter controls the current in the rotor circuit of the generator, which allows control of the *reactive power*[132] and serves for smooth connection to the electric power grid.

7.2.1.3 WIND FARM LAYOUT

In the present Ph.D. research work, a flat area was considered for the development of hypothetical wind farm in sites in *Brazil*, *Canada* and *Portugal*. A total of $15km^2$ area is considered for the development of wind farm of $50MW_e$ capacity∴The wind farm is designed using 2000kW size wind machines by Vestas at a maximum hub-height of 105m high (see Table 7.3).

Different wind farm layout conditions are defined and considered for simulations:

1. The <u>5D/4D layout (see Figure 7.1)</u>: the default wind farm layout with 5 rotor diameters (5D) distance (450m) between the turbines and 4D between the rows (360m);

2. The <u>5D/7D layout (see Figure 7.2)</u>: an alternative wind farm layout with 5 rotor diameters (5D) distance (450m) between the turbines and 7D between the rows (630m);

3. The <u>5D/10D layout (see Figure 7.3)</u>: another alternative wind farm layout with 5 rotor diameters (5D) distance (450m) between the turbines and 10D between the rows (900m);

4. The <u>6D/12D layout (see Figure 7.4)</u>: the final alternative wind farm layout with 6 rotor diameters (6D) distance (540m) between the turbines and 12D between the rows (1080m).

The wind turbines will be spaced in a way to minimize turbine-to-turbine interference in the wind flow∴The exact spacing required depends on the size of the turbine selected, with increased spacing used for the larger turbines.

[132] For Ackermann (2005) is a concept used by engineers to describe the electrical energy that circulates continuously among the various electrical and magnetic fields of alternating-current (AC) system, without producing work. These fields store energy which changes through each AC cycle.

In an onshore wind farm, interspacing between individual turbines is around 6 to 10 times the rotor diameter in the prevailing wind direction∴The interspacing distance in the cross prevailing wind direction is around 2 to 5 diameters. The exact spacing will be determined after a detailed micro-siting flow analysis. The micro-sitting analysis leads to an acceptable balance between yield maximization and making efficient use of the limited space available (Rehman, Ahmad, & Al-Hadhrami, 2011). The schema (5D/4D) is used as base-case for wind farm layout simulations.

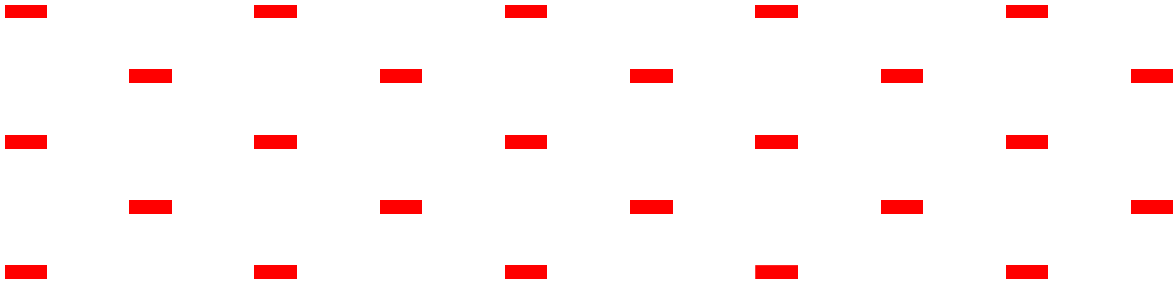

Figure 7.1 Representation of 5D/4D layout used for simulations. Source: Own elaboration

The scheme of 5D/4D requires 4 374km^2 and represents 29.2% of the total area available for the wind farm (see Figure 7.1).

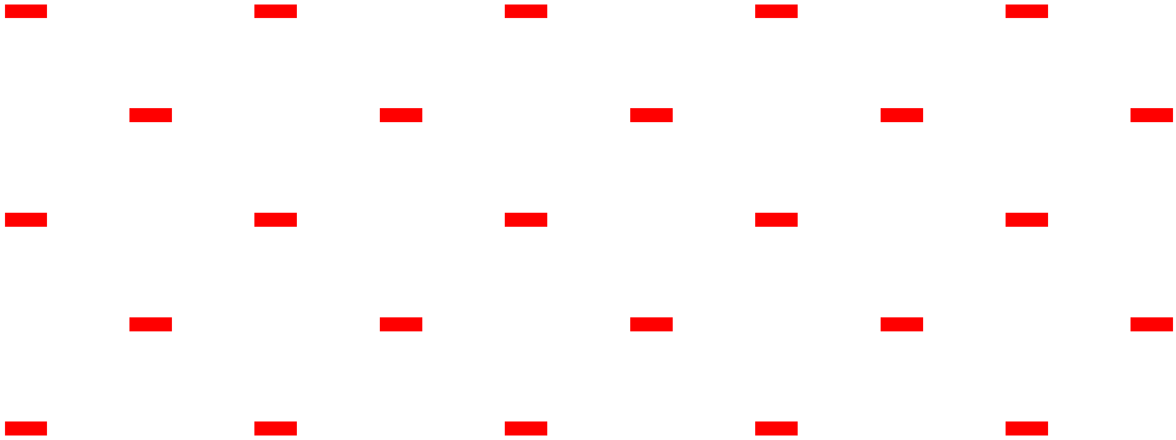

Figure 7.2 Representation of 5D/7D layout used for simulations. Source: Own elaboration

This alternative scheme of 5D/7D requires 6 998km^2 and represents 46.7% of the total area available for the wind farm (see Figure 7.2).

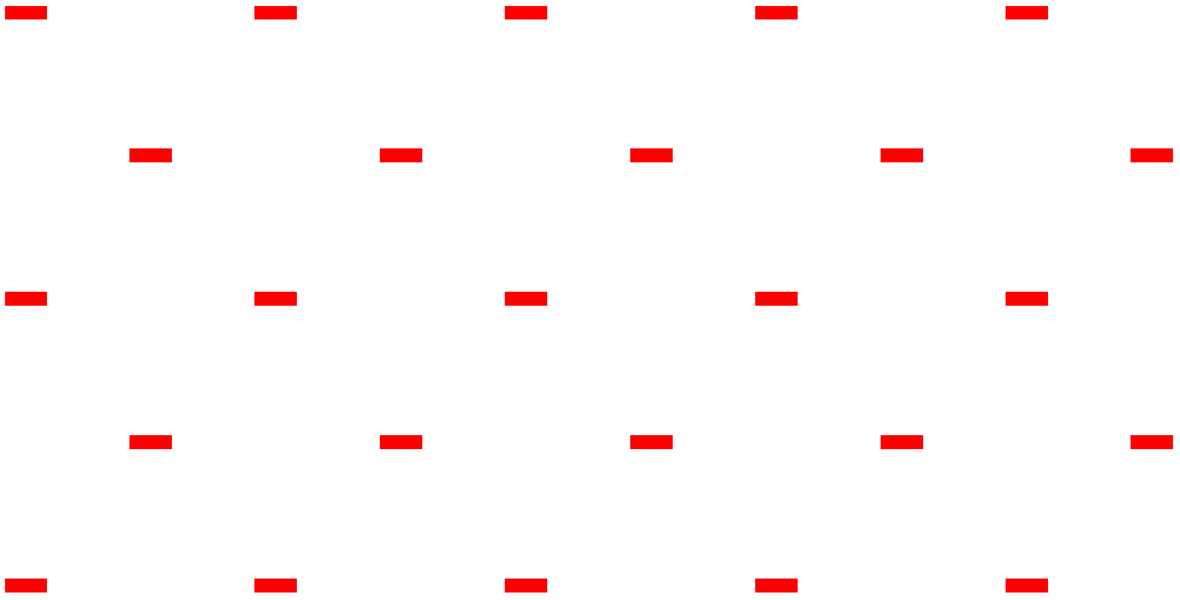

Figure 7.3 Representation of 5D/10D layout used for simulations. Source: Own elaboration

This alternative scheme of 5D/10D requires 9 623km^2 and represents 64.2% of the total area available for the wind farm (see Figure 7.3).

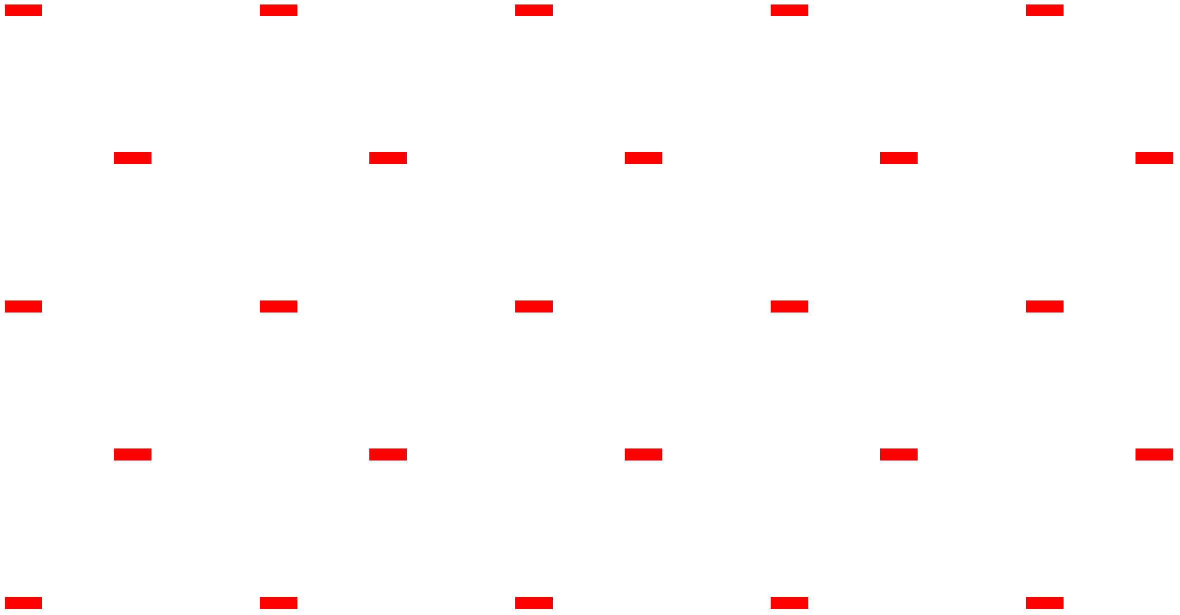

Figure 7.4 Representation of 6D/12D layout used for simulations. Source: Own elaboration

This alternative scheme of 6D/12D requires 13 057km^2 and represents 87.0% of the total area available for the wind farm (see Figure 7.4).

According to Li and Chen (2008) the penetration of wind power into the existing power system continues to increase, which implies the situation of the large wind farms is changing from being simple energy sources to having power plant status with grid support characteristics∴They declare that one major challenge in the present and coming years is the connection and optimized integration of large wind farms into electrical grids.

In $LCOE_{wso}$ methodology the *local wind turbines grid* is considered a capital expenses during the initial lifetime of a wind power project∴As it has been connected to the wind turbines sites, the *Local Wind Turbines Grid (LWTG)* of any wind farm depends on the scheme of wind turbines sitting used, for simplification of electrical grid`s types we have considered a linear configuration for *LWTG*, according to Figure 7.5.

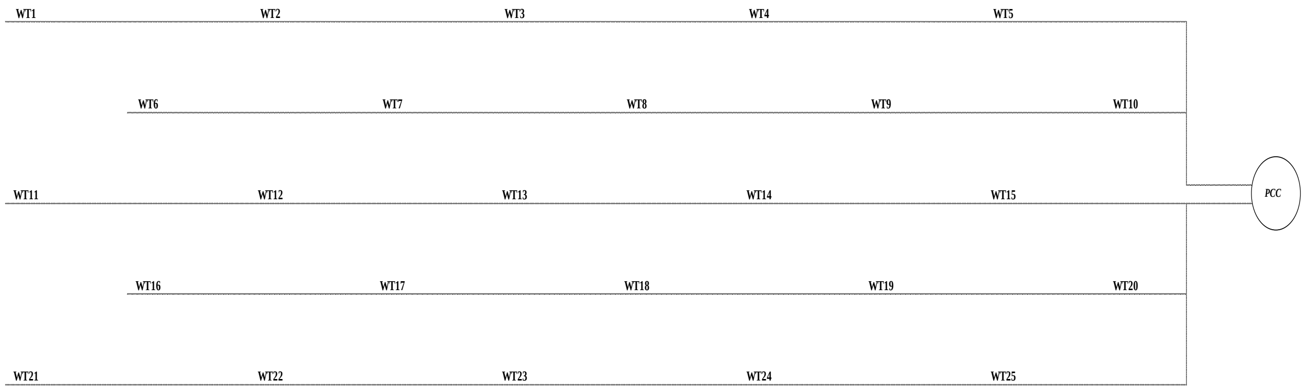

Figure 7.5 Representation of Local Wind Turbines Grid used for simulations. Source: Own elaboration

The different type of wind farm layout also impacts on land area required for implementation of the power plant, as shown in Table 7.4.

Table 7.4 Relation among layout, area and occupation

Layout type	Area (km^2)	Total area occupation (%)
5D/4D	4 374	29.2
5D/7D	6 998	46.7
5D/10D	9 623	64.2
6D/12D	13 057	87.0

Source: Own elaboration

7.2.2 CLIMATE DATA USED FOR v_W (M/S), P (KPA) AND T (°C)

7.2.2.1 WIND SPEED (v_W AND v_{WC})

Table 7.5 Wind speed series at 10m data and calculated[133] at 105m for Aracati, Corvo Island and Cape Saint James

Period	*Aracati (Brazil)*		*Corvo Island (Portugal)*		*Cape Saint James (Canada)*	
	v_w *(m/s)*	$v_{wc}^{(*)}$ *(m/s)*	v_w *(m/s)*	$v_{wc}^{(*)}$ *(m/s)*	v_w *(m/s)*	$v_{wc}^{(*)}$ *(m/s)*
January	*4.2*	*5.8*	*8.4*	*11.7*	*11.1*	*15.4*
February	*3.5*	*4.9*	*8.3*	*11.5*	*10.6*	*14.7*
March	*2.9*	*4.0*	*7.6*	*10.5*	*9.2*	*12.7*
April	*3.4*	*4.7*	*6.8*	*9.5*	*8.9*	*12.4*
May	*4.3*	*6.0*	*5.9*	*8.2*	*8.1*	*11.2*
June	*5.7*	*7.9*	*5.1*	*7.1*	*7.5*	*10.4*
July	*6.2*	*8.6*	*4.4*	*6.1*	*7.2*	*10.0*
August	*6.9*	*9.6*	*4.6*	*6.4*	*7.0*	*9.7*
September	*7.3*	*10.1*	*5.4*	*7.6*	*7.5*	*10.4*
October	*7.0*	*9.7*	*6.4*	*8.9*	*9.5*	*13.1*
November	*6.6*	*9.2*	*7.7*	*10.6*	*10.3*	*14.3*
December	*5.5*	*7.6*	*8.3*	*11.5*	*10.8*	*15.1*
Annual Average	*5.3*	*7.4*	*6.6*	*9.1*	*9.0*	*12.5*

Source: RETScreen® International Clean Energy Decision Support Centre (2009)

(*) Wind speed series for 105m calculated *(v_{wc})* by Petersen, Mortensen, Landberg, Højstrup, and Frank (1998).

Some findings about wind speed are:

1. In Aracati (Brazil) the windiest period is clearly *June, July, August, September, October, November* and *December*. During this period we can notice wind speed higher than annual average wind speed (7.4 m/s)$\therefore$When we calculate for hub height *(H=105m)*, it was found the same situation, but also an increase of 39.0% in initial wind speed *(H=10m).*

2. In Corvo Island (Portugal) the windiest period is clearly *January, February, March, April; November* and *December*. During this period we can notice wind speed higher than annual average wind speed (9.1 m/s)$\therefore$When we calculate for hub height *(H=105m)*, it was found the same situation, but also an increase of 39.0% in initial wind speed *(H=10m).*

3. In *Cape Saint James* (Canada) the windiest period is clearly *January, February, March; October, November* and *December.* During this period we can notice wind speed higher than annual average wind speed (12.5 m/s)$\therefore$When we calculate for hub height *(H=105m)*, it was found the same situation, but also an increase of 39.0% in initial wind speed *(H=10m).*

[133] *1/7th power law* scaling to calculate the hub height wind speed *(v_{wc})*: for each site (see Table 6.4) was calculated the wind speed at hub-height of 105 m used for electricity production from the hypothetical wind farm.

7.2.2.2 ATMOSPHERIC PRESSURE *(P)*

Table 7.6 Atmospheric pressure data for Aracati, Corvo Island and Cape Saint James

Period	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
	P (kPa)	*P (kPa)*	*P (kPa)*
January	*100.4*	*102.0*	*100.1*
February	*100.4*	*102.1*	*100.0*
March	*100.4*	*101.9*	*100.0*
April	*100.4*	*102.0*	*100.4*
May	*100.5*	*102.1*	*100.5*
June	*100.6*	*102.3*	*100.7*
July	*100.7*	*102.5*	*100.8*
August	*100.7*	*102.2*	*100.7*
September	*100.6*	*102.0*	*100.5*
October	*100.5*	*101.9*	*100.2*
November	*100.4*	*101.9*	*99.9*
December	*100.4*	*101.7*	*100.1*
Annual Average	*100.5*	*102.1*	*100.3*

Source: RETScreen® International Clean Energy Decision Support Centre (2009)

Some findings about atmospheric pressure are:

1. In Aracati (Brazil) the highest atmospheric pressure period is clearly *June, July, August* and *September*. During this period we can notice that atmospheric pressure is higher than annual average atmospheric pressure (100.5 kPa) $\therefore$ The atmospheric pressure data series has presented a SD[134]=0.1 kPa, 100.4 kPa and 100.7 kPa as minimum and maximum values, respectively, for the same period.

2. In Corvo Island (Portugal) the highest atmospheric pressure period is clearly *June*, *July* and *August*. During this period we can notice that atmospheric pressure is higher than annual average atmospheric pressure (102.1 kPa) $\therefore$ The atmospheric pressure data series has presented a SD=0.2 kPa, 101.7 kPa and 102.5 kPa as minimum and maximum values, respectively, for the same period.

3. In Cape Saint James (Canada) the highest atmospheric pressure period is clearly *April*, *May*, *June*, *July*, *August* and *September*. During this period we can notice that atmospheric pressure is higher than annual average atmospheric pressure (100.3 kPa) $\therefore$ The atmospheric pressure data series has presented a SD=0.3 kPa, 99.9 kPa and 100.8 kPa as minimum and maximum values, respectively, for the same period.

[134] SD = Standard Deviation.

7.2.2.3 AIR TEMPERATURE *(T)*

Table 7.7 Air temperature data for Aracati, Corvo Island and Cape Saint James

Period	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
	T (˚C)	*T (˚C)*	*T (˚C)*
January	*26.8*	*15.6*	*4.6*
February	*26.8*	*15.0*	*5.2*
March	*26.6*	*15.0*	*5.7*
April	*26.7*	*15.4*	*6.8*
May	*26.9*	*16.5*	*8.8*
June	*26.9*	*18.4*	*10.8*
July	*26.8*	*20.7*	*13.0*
August	*27.3*	*21.9*	*14.1*
September	*27.5*	*21.4*	*13.2*
October	*27.5*	*19.7*	*10.1*
November	*27.4*	*18.0*	*6.9*
December	*27.1*	*16.6*	*5.2*
Annual Average	*27.0*	*17.8*	*8.7*

Source: RETScreen® International Clean Energy Decision Support Centre (2009)

Some findings about air temperature are:

1. In Aracati (Brazil) the hottest period is clearly *August, September, October, November* and *December*. During this period we can notice that air temperature is higher than annual average air temperature (27.0˚C)∴The air temperature data series has presented a SD=0.3˚C, 26.6˚C and 27.5˚C as minimum and maximum values, respectively, for the same period.

2. In Corvo Island (Portugal) the hottest period is clearly *June, July, August, September, October*, and *November*. During this period we can notice that air temperature is higher than annual average air temperature (17.8˚C)∴The air temperature data series has presented a SD=2.5˚C, 15.0˚C and 21.9˚C as minimum and maximum values, respectively, for the same period.

3. In Cape Saint James (Canada) the hottest period is clearly *May, June, July, August, September* and *October*. During this period we can notice that air temperature is higher than annual average air temperature (8.7˚C)∴The air temperature data series has presented a SD=3.3˚C, 4.6˚C and 14.1˚C as minimum and maximum values, respectively, for the same period.

Table 7.8 Air density calculated for Aracati, Corvo Island and Cape Saint James

Period	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
	ρ (kg/m^3)	*ρ (kg/m^3)*	*ρ (kg/m^3)*
January	*1.1665*	*1.2313*	*1.2561*
February	*1.1666*	*1.2345*	*1.2522*
March	*1.1671*	*1.2329*	*1.2495*
April	*1.1667*	*1.2317*	*1.2490*
May	*1.1670*	*1.2282*	*1.2425*
June	*1.1686*	*1.2224*	*1.2351*
July	*1.1698*	*1.2154*	*1.2275*
August	*1.1677*	*1.2075*	*1.2216*
September	*1.1657*	*1.2064*	*1.2234*
October	*1.1645*	*1.2126*	*1.2327*
November	*1.1638*	*1.2194*	*1.2429*
December	*1.1651*	*1.2237*	*1.2528*
Annual Average	*1.1666*	*1.2222*	*1.2404*

Source: Own elaboration

Some findings about air density are:

1. In Aracati (Brazil) the highest air density period is clearly *March, April, May, June, July* and *August.* During this period we can notice that air density is higher than annual average air density (1.1666 kg/m^3)$\therefore$The air density calculated has presented a SD=0.0016 kg/m^3, 1.1638 kg/m^3 and 1.1698 kg/m^3 as minimum and maximum values, respectively, for the same period.

2. In Corvo Island (Portugal) the highest air density period is clearly *January, February, March, April, May, June* and *December.* During this period we can notice that air density is higher than annual average air density (1.2222 kg/m^3)$\therefore$The air density calculated has presented a SD=0.0095 kg/m^3, 1.2064 kg/m^3 and 1.2345 kg/m^3 as minimum and maximum values, respectively, for the same period.

3. In Cape Saint James (Canada) the highest air density period is clearly *January, February, March, April, May; November* and *December.* During this period we can notice that air density is higher than annual average air density (1.2404 kg/m^3)$\therefore$The air density calculated has presented a SD=0.0116 kg/m^3, 1.2216 kg/m^3 and 1.2561 kg/m^3 as minimum and maximum values, respectively, for the same period.

7.3 ECONOMIC AND FINANCIAL ASPECTS OF THE WIND PROJECT

7.3.1 ASSUMPTIONS, CONSTRAINTS, AND LIMITATIONS

For simplicity, the economic and financial issues of the wind project to be simulated the assumptions, constraints and limitations are related to *O&M costs* and *project/turbine availability* and *other losses*; *financing structure and costs*; *project lifetime*, *income taxes*, *decommissioning rates and asset depreciation*.

7.3.1.1 Assumptions

Table 7.9 Economic and financial assumptions considered for wind project

✡ Life time *(N)*	25 yrs
✡ Debt interest rate	5%/yr
✡ Debt ratio	50%[135]
✡ Debt term	14 yrs
✡ Depreciation method	Straight-line[136]
✡ Depreciation rate	4%/yr
✡ Discount rate	9%/yr
✡ Revenue taxes (R_{taxes})	30%
✡ Inflation rate *(ifr)*	2.5%/yr
✡ Period of O&M warranty	From 1 to 5 yr

Source: Own elaboration

a) The Power Purchase Agreement Rate *(PPAR)*[137] is considered different for each site, according to the energy policy by the country (Brazil, Portugal and Canada) $\therefore$ *PPAR* is defined in $/kWh;

b) We have considered the 25-year assumed project/economic life in all scenarios used in simulations;

c) The interest, inflation, debt and discount rates within debt ratio are constant during the economic lifetime of the wind project;

d) The financing structure of the wind project is constant during the economic lifetime of the wind project too;

e) O&M costs and wind farm availability are also conditioned to *Operations and Maintenance management* $(O\&M_{manag})$ proposed as described in section 7.4.2;

[135] As suggested by Wiser (1997) the LCOE is minimized at a capital structure of approximately 50% debt and 50% equity.
[136] For more explanation about depreciation methods, please, see Albadi, El-Saadany, and Albadi (2009).
[137] A *Power Purchase Agreement ("PPA")* is a long-term agreement between the seller of wind energy and the purchaser.

f) O&M costs[138] are accounted in in *Wind Farm O&M Cost Model* *($O\&M_{WFCM}$)* and information/data are also based on Table 6.8;

g) The cash flow model adopted for economic analysis by simulations is based on Welch and Venkateswaran (2009).∴We have also considered the items described in $LCOE_{wso}$ proposed in Chapter 6;

h) All monetary values used to calculate $LCOE_{wso}$ are converted[139] to 2010 US $ and updated with the inflation rate defined, in order to uniform the input-output values presented in this Ph.D. research work;

i) Initial capital costs of the wind project (yr=0) are accounted in *Wind Farm Life-Cycle Capital Cost Model* *($LCCCM_{WF}$)* and information/data are based on Table 6.7;

j) Capital costs related to major review of the wind power system are accounted in *Levelized Replacement Cost Model (LRCM)* and information/data are based on Table 6.8;

k) Decommissioning costs are included in *Wind Farm Removal Cost Model* *(RCM_{WF})* and information/data are also based on Table 6.8 and Table 6.9;

l) The policy instruments that impacts on *COE* are defined in *Renewable Energy Public Incentive Model (REPIM)* and information/data are also based on Table 6.10.

7.3.1.2 Constraints

a) We have considered *PPAR* constant during the lifetime of the wind project for all simulations, that avoid any change in energy policy during the period of instrument analyzed;

b) As we have considered only one lifetime for the wind project, we cannot analyzed the effect of lifetime flexibility in the cost of energy produced by the power plant;

c) As stated in section 7.3.1.1, item c), we cannot measure the effect of variation on macroeconomic indicators (e.g.: interest rate and inflation) for the different sites chosen for simulations;

d) The wind project is capital-intensive and the financing structure[140] can be adequate to each project; in our case we have considered a constant financing structure for the wind project simulated;

e) The energy market has changed and the competition through the economic agents raised up during the last decade, but we have considered the market and consumer able enough to buy

[138] Shipping and warehousing costs for parts are not included. Given the variability and uncertainty of parts costs, and the number of options for warehousing spares, we may reasonably assume that shipping costs are included in the parts costs.
[139] Exchange rates of 1.3252 (EUR/USD); 0.9998 (CAN/USD); 0.5986 (BRL/USD); based on rates on December 31, 2010. Available at http://www.oanda.com/currency/converter/.
[140] For a better understanding about wind project financing structures, please see at Harper, Karcher, and Bolinger (2007).

(clean) green energy for the next 25 years ∴ The renewable energy market can change and we have considered it is favorable;

f) The distribution grid of these selected sites to install a new power plant, in other words, a new wind power plant, is ready enough to receive one more producer with variable electricity generation, which cannot be so true like that!;

7.3.1.3 Limitations

a) The wind project has an only price of electricity sold, although, this price *(PPA)* has to be updated by the inflation rate adopted ∴ It can be analyzed as weakness due to the variation of the wind power plant;

b) The annualized economic variables can change during the year, but we have considered constant during the entire year, and the possible change can occurs inter-years (from one year to another), what can not reflect the real volatile nature of these variables;

c) The wind profile (distribution) at a site determines the *COE* and the revenue to a wind farm operator by determining the number of kWh sold ∴ Since WECS scales with the cube of wind velocity, the velocity of the wind is likely to be the most important single factor in determining the placement of wind farms and their profitability; we have considered these three sites in function of the highest annual mean wind speed available in RETScreen Climate Database;

d) COE can be also affect by availability of the wind farm, in our analysis we have considered only $O\&M_{manag(STD)}$; $O\&M_{manag(A)}$; $O\&M_{manag(B)}$ described in section 7.4.2, in literature is possible to find another factor (e.g.: load demanded; earthquakes or other natural disasters) ∴ In order to simplify the $LCOE_{wso}$ we have not considered catastrophic events such as hurricanes, tornados, and lightning;

e) The three different wind farms are analyzed and compare each other in order to notice the influence of technical and economic variables simulated; This analyzes can be more than comparison, but as we have stated in the objectives of this Ph.D. research work only make economic evaluation of a candidate wind project through the *LCOE* optimization;

f) According to Ngala, Alkali, and Aji (2007) researches concerning about economic evaluation of WECS have shown a lack of common economic analysis technique, and elemental cost data for validation, the $LCOE_{wso}$ calculated and named as the *"optimized cost"* cannot reflect the real minimum (optimized) cost of electricity produced by a wind farm;

g) The investment analysis done are not for exclusion reason, due to we have not considered limited funds for investment alternative, even less we know it is an important aspect to be checked in this kind of analysis.

7.3.2 REVENUE, CAPITAL, O&M, AND OTHER COSTS

Considering the variability of the wind resources, estimating the average annual revenue *(AAR_{yr_n})* of a wind farm may be challenging when the amount of information available is limited or when the idea is still in project phase∴In this Ph.D. research work, we have considered revenues from the wind farm designed to be originated by product from *AEP_{avail}* and *electricity price sold (PPAR)* and the *expected market price (EMP) (year n)*[141]. Eqn 7.1 shows the algorithm developed to calculate AAR_{yr_n} .

$$AAR_{yr_n} = \left[\left(PPAR_{yr_n} \times AEP_{avail_{yr_n}} \right) + \left(EMP_{yr_n} \times AEP_{avail_{yr_n}} \right) \right] \qquad \text{[M\$/yr]} \qquad \text{Eqn (7.1)}$$

So the Table 7.10 is shown the parameters used for calculating the average annual revenue of the hypothetical wind farm in simulations procedures.

Table 7.10 Revenue parameters considered for simulations

✡ Type of agreement	*PPA*
✡ Price of energy sold *(PPAR)*	0.08581USD/kWh[(a)], 0.16291USD/kWh[(b)] and 0.13835USD/kWh[(c)]
✡ Length of the agreement	1 to 20 yr
✡ Expected market price *(EMP_{yr})*	21 to 25 yr
✡ Economic indexation of *PPAR* and *EMP_{yr}*	Annual inflation rate (see Table 7.9)

Source: Own elaboration. Note: [(a)]*PPAR* for Brazil (Chade, Juliana, & Sauer, 2013); [(b)]*PPAR* for Portugal (ERSE, 2013) and [(c)]*PPAR* for Canada (CanWEA, 2012).

Regarding to *capital costs* (investment costs)[142] of the hypothetical wind farm, we have considered the same classification presents in Chapter 5, Table 5.1∴The referenced inputs for determining the capital costs for the simulations are based on Tables 6.7 and 6.8.

O&M costs are considered into two parts. One is the fixed O&M (see Eqn 6.2.3.1)∴This named $O\&M_{fixed_{CM}}$, based on percentage *(ϖ)* of capital cost *($LCCCM_{WF}$)* and land lease cost *(LLC)* per kWh (for cover costs such as interconnect fees and royalties including land costs)∴We have also considered the relation between *wind farm layout* and *land area* (see Table 7.4). The other part of O&M costs are considered variable *($O\&M_{variable_{CM}}$).* This variable part of O&M cost are based on

[141] *EMP_{yr}* is applicable only after finish the period of *PPA*, we have not considered both, and one does not exclude another. We have considered as a parameter for *EMP_{yr}* a ratio between *PPAR* and *EMP_{yr}* of 0.7 (70%).
[142] Capital costs are considered equal for the three different sites simulated.

warranty conditions, labor costs, revenue taxes, inflation and lifetime of the wind farm (see Eqn 6.2.3.2).

Wind farm reliability is a critical factor in the success of a wind energy project. Poor reliability directly affects both the project's revenue stream through increased O&M costs and reduced availability to power due to turbine downtime∴Many researches has confirmed that condition, although we must consider the effect of the O&M warranty contracts, such as period, frequency, items supported and other aspect which can contribute to reduce or maintain constant (compatible with the level of production).

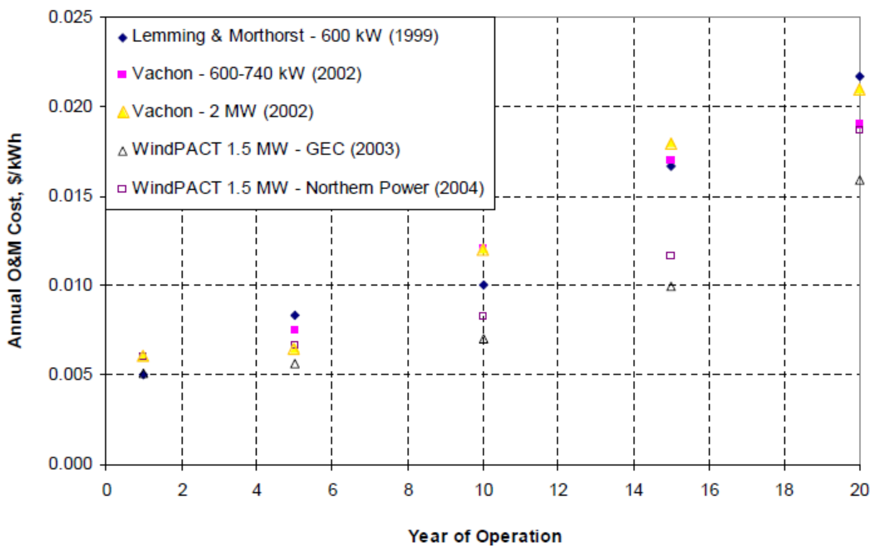

Figure 7.5 Estimated O&M cost per unit of energy production. Source: Christopher (2003)

As we can notice in Figure 7.5 higher O&M costs are accompanied by more frequent downtime of the wind turbines during the years of operation∴This will imply a lower number of production hours and a substantial negative impact on the cost per kWh∴For Blanco (2009) O&M costs make up around 10% of the expenditure, although there is substantial uncertainty around this category due to the fact that few wind turbines have reached the end of their lifetime.

The "*other costs"* of the wind power plant are difficult to be accounted analytically in a 100% included manner, and it could be an unnecessary effort due to the relative participation of *"other costs"* in the *COE*∴The institutional setting, particularly spatial planning and public permitting practices, can make a significant impact on costs of energy produced by a wind farm.

The electricity market and industry influence directly on the *COE*, when we considered the price and costs of fossil-fuel technologies, price of steel, crude, labor, and others which can increase or decrease in function of the international economic scenario∴For these variables, we consider the "*Market Cost Adjustment" (*MC_A*)* in some items of the capital cost for a wind power plant.

7.4 O&M ASSUMPTIONS FOR WIND PROJECT SIMULATIONS

7.4.1 VARIABLES AND DATA

The *Wind Farm O&M Cost Model* ($O\&M_{WFCM}$) considers the typical costs associated with ongoing operations, including scheduled maintenance, unscheduled repairs, site management, and support personnel, of a facility that comprises any number of conventional wind turbines $\therefore$ We have summarized in Table 7.11 the variables and data for $O\&M_{WFCM}$ calculations.

Table 7.11 Variables and data for running $O\&M_{WFCM}$

Variables	Data
$O\&M_{fixed_{CM}}$	calculated
$LCCCM_{WF}$	calculated
LLC	based on Table 6.8
ϖ	based on Table 6.8
if_r	based on Table 7.9
N	based on Table 7.2
$O\&M_{\text{var}iable_{CM}}$	calculated
N_{WT}	calculated
$\left(\frac{AAR}{AEP_{avail}}\right)$	calculated
n_{mlh} and n_{tlh}	based on Tables 6.11 and 7.12
MLC	based on Table 6.8
TLC	based on Table 6.8
R_{taxes}	based on Table 7.9

Source: Own elaboration

For Poore and Walford (2008) most importantly, there are no complete and consistent data for any project over the entire useful lifetime of the wind turbines $\therefore$ Without exception, the older turbines (those reaching the end of their lifetime) are smaller and simpler versions of the machines installed in the last five years.

Data for simulations have come from a variety of sources, including manufacturer publications, published case studies and scientific journals. The quality (consistency) and quantity of the available data can best be described as *demonstrative* $\therefore$ In some cases general estimates of overall maintenance costs for specific projects for periods of one or two years were available; in other cases detailed information on actual expenditures for a variety of turbines (but only for a limited period of its entire lifetime) was provided $\therefore$ As expected, the data are not in an only one consistent format ($/kW, $/wind turbine, $/hour, etc.) and are broken down into a surprising variety of categories for parts, labor, and downtime.

7.4.2 O&M PROGRAMS PROPOSED

The *Operations and Maintenance management* ($O\&M_{manag}$) proposed to the simulations are defined in $O\&M_{manag(STD)}$; $O\&M_{manag(A)}$; $O\&M_{manag(B)}$ (see Table 6.5) ∴ Data used for each O&M program are based on the information available in Table 6.11.

Table 7.12 O&M programs analyzed in simulations

Variables	$O\&M_{manag(STD)}$	$O\&M_{manag(A)}$	$O\&M_{manag(B)}$
$SC_{O\&M}$			
Number of days	5	2	3
Period[143]	Feb/Jun/Nov	Feb/Jun/Nov	Feb/Jun/Nov
$USC_{O\&M}$			
Frequency	1.5/yr	1.0/yr	1.8/yr
Repair time	3h/repair	4h/repair	2h/repair

Source: Own elaboration

Some assumptions are considered for O&M programs:

a) The $O\&M_{manag(STD)}$ *is* defined as the *base-case*. So the two more options ($O\&M_{manag(A)}$ *and* $O\&M_{manag(B)}$) are O&M programs 'variations;

b) A *work day* considered is 8 work hours, so the *hours required* in each program must be calculated as for $SC_{O\&M}$: *number of work days x period x 8 work hours/day;*

c) The *hours required* for $USC_{O\&M}$ is related to product from the *number of wind turbines*, *frequency failure rate* and *repair time* for each turbine.

d) The total hours of O&M required is the correspondent relation ($SC_{O\&M} + USC_{O\&M}$) *per year*. Each alternative is simulated for each site to be installed the hypothetical wind farm ∴ The objective is finding the best option (we must remember the less hours required better is the program proposed. It is an inverse relation);

e) For labor costs of O&M, we have considered *MLC* for $SC_{O\&M}$ and *TLC* for $USC_{O\&M}$ and the data are based on Table 6.8;

f) The *availability of the wind farm* is the relation of *hours of production* (H_{prod}) and *full load hour* (FLH_{wf}).

[143] We have considered the period with less hours available for production (see Figure 6.18).

7.5 ENERGY POLICY ASSUMPTIONS FOR WIND PROJECT SIMULATIONS

7.5.1 VARIABLES AND DATA

The *Renewable Energy Public Incentive Model (REPIM)* was developed in order to measure the effect of the public incentive on *COE* produced by RETs, in our case, WECS technology. We have focused on *investment* and *production* phase of the wind power project∴As we already said, we handle with capital-intensive and variable production energy project that is why the cost of energy produced is strongly influenced by capital costs and production∴Many studies indicate this relation (Barradale, 2010; Bolinger, 2009; Butler & Neuhoff, 2008; Ertürk, 2012; Lantz, Wiser, & Hand, 2012; Wiser & Pickle, 1998).

We have summarized in Table 7.13 the variables and data for *REPIM* calculations.

Table 7.13 Variables and data for *REPIM* calculations

Variables	Data
REI_{CM}	calculated
ψ_{total}	based on Table 6.10
n_{ψ}	based on Table 6.10
REP_{CM}	calculated
ε_0	based on Table 6.10
n_{ε}	based on Table 6.10
$OREP_{CM}$	calculated
CR_f	based on Table 6.10
$GHG.R_{CM}$	calculated
$GHG_{EF_{ff\ co_2}}$	based on Table 6.10
$GHG_{EF_{wecs\ co_2}}$	based on Table 6.10
ε_0	based on Table 6.10
ξ_n	based on Table 6.10

Source: Own elaboration

The *REPIM* variable of $LCOE_{wso}$ methodology is designed to represent a reduction of COE that is why we consider a negative sign in Eqn 6.2, in Chapter 6∴Although, we have not considered the effect on $LCOE_{wso}$ as a "*credit*" for the wind project.

We also can notice in the entire model proposed an excessive data requirement, because for each variable of the $LCOE_{wso}$ *(*$LCCCM_{WF}$*,* $LRCM$*,* $O\&M_{WFCM}$*,* RCM_{WF}*, REPIM* and $LCPM_{WF}$*)* needs several parameters for several subcomponents of the WECS and wind project, at a technical and economical point of view.

7.5.2 ENERGY POLICY INSTRUMENTS PROPOSED

All the energy policy instruments are used for simulations as we have defined in Table 6.5. Data used for each *REPIM* instrument are based on the information available in Table 6.10∴Each alternative is simulated for each site to be installed the hypothetical wind farm.

Table 7.14 *REPIM* instruments analyzed in simulations

Instrument	Base-case	Case $_1$	Case $_2$	Case $_3$
REI_{CM}				
ψ_{total}	30%	25%	20%	15%
n_{ψ}	6 yrs	5 yrs	4 yrs	3 yrs
REP_{CM}				
ε_0	88.20 €/MWh[(a)]; $75.00/MWh[(b)]; CAD $10/MWh[(c)]	decreased 10%	decreased 15%	decreased 20%
n_{ε}	10 yrs[(a)]; 15 yrs[(b)]; 10 yrs[(c)]	12 yrs[(a)]; 17 yrs[(b)]; 12 yrs[(c)]	14 yrs[(a)]; 18 yrs[(b)]; 14 yrs[(c)]	15 yrs[(a)]; 15 yrs[(b)]; 20 yrs[(c)]
$OREP_{CM}$				
CR_f	80%	60%	40%	25%
$GHG.R_{CM}$				
$GHG_{EF_{ff}\,co_2}$	410 g/kWh	690 g/kWh	890 g/kWh	1234 g/kWh
$GHG_{EF_{wecs}\,co_2}$	30 g/kWh	48 g/kWh	75 g/kWh	83 g/kWh
ε_c	35€/tCO_2[(a)]; $13.00/t$CO_2$[(b)]; $30.00/t$CO_2$[(c)]	decreased 10%	decreased 15%	decreased 20%
ξ_n	25%;25%;25%;25%	50%;25%;25%;0%	10%;50%;20%;20%	0%;0%;50%;50%

Source: Own elaboration. Note: [(a)] Brazil; [(b)] Portugal and [(c)] Canada.

Some assumptions are considered for *REPIM* cases:

a) We have considered a moderate decreasing interest of governments[144] in supporting RETs, reason why we consider decreasing trends for ε_0 in cases 1, 2 and 3;

b) The carbon credits *(* ε_c *)* also follows the same trends of governments supporting for RETs, because the carbon credit market shows in the last 5 years;

c) The *time of policy energy instrument (* n_{ε} *)* is defined due to the current legislation of each country selected for simulations.

[144] It can be probably due to the global economy recession. For more information, please see at Newell, Pizer, and Raimi (2013).

7.6 GENERAL SIMULATIONS PROCEDURES

7.6.1 STEPS USED FOR SIMULATIONS

As we have discussed in Chapter 6, section 6.4.4.3 the simulation process should follow some standard steps∴During the simulations procedures we have followed the steps as shown in Figure 7.6:

1. Problem Definition	*Explained in section 1.2 (Interest and scope of the research) and section 6.4.3.1 (Research objectives)*
2. Overall Project Plan	*Explained in section 6.4.2 (Methodological procedures)*
3. System Definition	*Explained in section 6.4.4.1 (Variables relationship and research boundary)*
4. Conceptual Model	*Explained in section 6.4.4.2 (Mathematical model structuring; Shown in Figure 6.16*
5. Experimental Design	*Explained in section 6.4.4(Research design)*
6. Model Translation	*The equations of $LCOE_{wso}$ model are written in MS Excel spreadsheet and imported to Matlab for simulations*
7. Verification & Validation	*Explained in section 6.4.4.3 (Numerical simulation and validation process)*
8. Input Data Preparation	*Explained in section 6.4.4.3 (Numerical simulation and validation process); See Tables 6.5, 6.6, 6.7, 6.8, 6.9.6,10 and 6.11*
9. Operationalization	*Explained in section 7.6 (General simulations procedures)*
10.Analysis & Interpretation	*Explained in Chapter 8 (Results and Discussion)*
11.Implementation & Documentation	*Explained in Chapter 9 (Conclusions and Implications)*

Figure 7.6 Steps of simulation of $LCOE_{wso}$ algorithm. Source: adapted from Shannon (1992) and Banks (1999)

7.6.2 OPTIMIZATION CRITERIA

We have considered some hypotheses for developing $LCOE_{wso}$ methodology as shown in Table 6.3. The optimization criteria are defined considering the relations among *variables* (v_{wc}, L_{wt}, $O\&M_{manag}$ and E_{pi}) and *hypotheses* (RH_1, RH_2, RH_4, RH_5, RH_6 and RH_7) of this Ph.D. research work∴We have summarized in Table 7.15 the variables and hypotheses considered for optimization criteria definition.

Table 7.15 Variables and hypotheses considered for optimization criteria definition

Variables	Relation with	Impact expected on $LCOE_{wso}$
1. Wind speed (v_{wc})	hypotheses RH_1, RH_2 and RH_5	down (-) and or up (+)
2. Wind turbines layout (L_{wt})	hypotheses RH_4 and RH_5	down (-) and or up (+)
3. O&M management ($O\&M_{manag}$)	hypotheses RH_5 and RH_6	down (-) and or up (+)
4. Energy policy instruments (E_{pi})	hypotheses RH_5 and RH_7	down (-) and or up (+)

Source: Own elaboration

We also try to answer two fundamentals questions through the optimization criteria:

1. *Which variables are expected to have the largest effect on $LCOE_{wso}$?*
2. *Which of these variables affect more than one component of the $LCOE_{wso}$ decomposition?*

As we have stated at section 6.4.3.4 (Research hypotheses and limitations), there is *no standard LCOE to be reference for this kind of research, it is not possible to harmonize all input/data assumptions* and the *site of the power plant becomes each wind project as unique*∴Consequently, for simulation and validating the proposed algorithm ($LCOE_{wso}$) we have considered as the main optimization criteria, when conditions can be confirmed simultaneously:

1. As *minimum as possible $LCOE_{wso}$* calculated in the simulations for each site selected for the hypothetical wind farm;
2. For the same wind farm, the *lowest $LCOE_{wso}$* calculated in the simulations, considering the whole lifetime of the hypothetical wind farm and;
3. As *maximum as possible AEP_{avail}* calculated in the simulations for each site selected for the hypothetical wind farm.

As Ozerdem, Ozer, and Tosun (2006) have discussed about cost-effective solution means the most suitable alternative, technically and economically∴The $LCOE_{wso}$ methodology may lead to safe conclusions with respect to the best performance of a wind project, in a technical and economical point of view. Power projects in the electricity supply market live for long a period that is the case of wind farms last for about 20-30 years.

7.6.3 SENSITIVITY ANALYSIS

The sensitivity analysis is a technique for finding out how the result from the reliability analysis varies, when changing the values of the input parameters∴Thus, a sensitivity analysis is appropriate to use when input data suffer from a high degree of uncertainty, just as the case for the reliability data in this Ph.D. research work.

It is important to define the central point of the proposed sensitivity analysis∴The sensitivity analysis done in the simulations is in order to *understand the influence of the governing parameters on the* $LCOE_{wso}$ and the economic efficiency of the wind power plant analyzed. These values should be representative for the techno-economic situation of the wind farm∴After extensive research data review, the following values are selected for the main parameters (data) for the wind project conditions and details (see Tables 6.5 to 6.11).

We have also considered the minimum value for each parameter (datum) used, in function of the orientation to find the *minimum* $LCOE_{wso}$[145] calculated as possible in the simulations done∴Variables, parameters/data, variations and interactions for the sensitivity analysis are presented in Table 7.16.

Table 7.16 Variables, parameters, variations and interactions of the sensitivity analysis

Variables	Variations	Interactions (*int*=900) with *N*=25yrs
1. Wind speed[146] (v_{wc})	according to Table 7.5	1 v_w *x* 3 different sites *x N* = 75 *int*
2. Wind turbines layout (L_{wt})	according to Table 7.4	4 L_{wt} *x* 3 different sites *x N* = 300 *int*
3. O&M management $(O\&M_{manag})$	according to Table 7.12	3 $O\&M_{manag}$ *x* 3 different sites *x N* = 225 *int*
4. Energy policy instruments (E_{pi})	according to Table 7.14	4 E_{pi} *x* 3 different sites *x N* = 300 *int*

Source: Own elaboration

The sensitivity analysis is organized in two parts. The first part the variables are analyzed individually (see section 8.4.1). In this part is analyzes the impact of *wind speed* (v_{wc}), *O&M management* $(O\&M_{manag})$, *wind turbines layout* (L_{wt}) and *energy policy instruments* (E_{pi}) on $LCOE_{wso}$. The second part of the sensitivity analysis a multiple variable analysis is made (see section 8.4.2)∴We have analyzed the impact of *wind speed* (v_{wc}) and *wind turbines layout* (L_{wt}) and *O&M management* $(O\&M_{manag})$ and *energy policy instruments* (E_{pi}) on $LCOE_{wso}$.

The sensitivity analysis was conducted for gaining an *insight about the impact of the variables selected to the cost of energy produced from the wind farm*∴The results are discussed and shown in graphs and tables in Chapter 8.

[145] The reference values of *LCOE/NREL* are USD 50/MWh to USD 150/MWh (see Table 6.7), considering the same conditions as explained in Lantz et al. (2012); and IEA (2005, 2010).
[146] Wind speed calculated (v_{wc}) for hub height $(H=105m)$.

7.7 SUMMARY AND CONCLUSIONS

The objective of this chapter is to implement numerical simulation and validation of the $LCOE_{wso}$ methodology proposed in Chapter 6 of this Ph.D. research work∴Model verification and validation are critical in the development of a simulation model. Unfortunately, there is no set of specific tests that can easily be applied to determine the *"correctness"* of a new model∴Furthermore, no algorithm exists to determine what techniques or procedures to use to validate it. Every simulation study represents a new and unique challenge to the author(s) of the model.

We have designed the $LCOE_{wso}$ to be applied in WECS technology which has driven us to develop a power system definition as we do in section 7.2∴Furthermore, as the goal is to find the *minimum COE* using the $LCOE_{wso}$ methodology, it is necessary to discriminate analytically the algorithm into sub-models as shown in Chapter 6, section 6.4.4.2∴To performance the numerical simulation and validation of this model so many input/data were needed, as summarized in Tables 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.7, 7.8, 7.9, 7.10, 7.11, 7.12, 7.13 and 7.14.

The calculations are done and the final results are compared with referenced values. We have considered a range for the $LCOE_{wso}$ calculated in order to be numerically validated the methodology proposed and the technical and economic aspects of the power plant (wind farm) and institutional conditions (current energy policy) and climate conditions give us a large range∴The NREL[147] has estimated the *LCOE* for onshore wind energy for US and Europe, excluding incentives, an average $LCOE_{2010}$ of *USD 71/MWh*, as we can see in Figure 7.7.

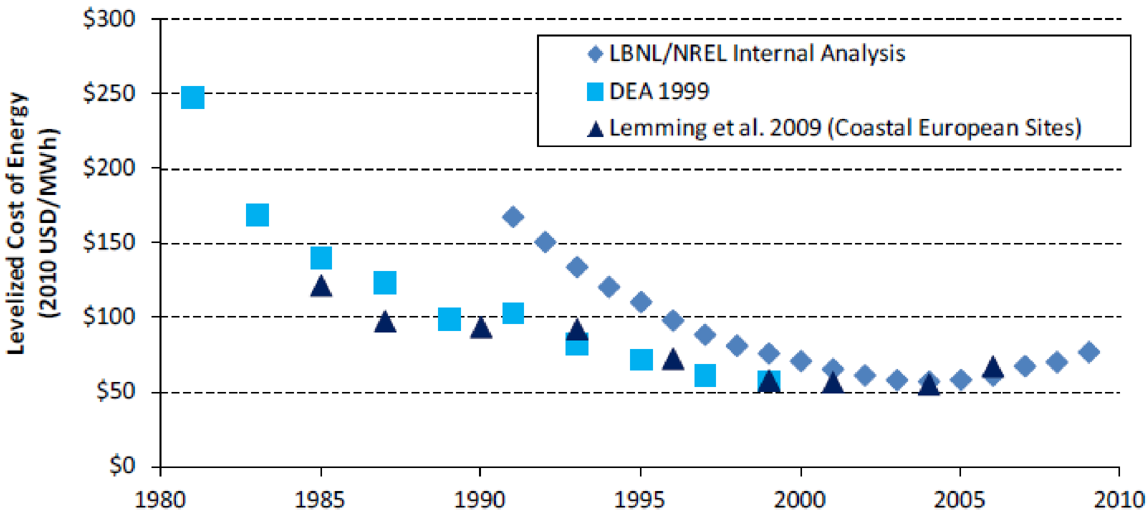

Figure 7.7 Estimated *LCOE* for wind energy between 1980 and 2009 for the United States and Europe (excluding incentives). Source: Lantz et al. (2012)

[147] The National Renewable Energy Laboratory (NREL) is the U.S. Department of Energy's primary national laboratory for renewable energy and energy efficiency research and development. For more information, please see at http://www.nrel.gov/.

An analysis of the fundamentals of $LCOE_{wso}$ methodology has resulted in a well-considered approach of cost modeling within the *LCOE/NREL* methodology that is worldwide used for cost-analysis of RETs. $LCOE_{wso}$ as a cost method analysis has been developed that can simulate the major technical and economic aspects of an *onshore wind farm* to a degree sufficient to be of use in pilot and other preliminary studies and possible other RETS (e.g. solar power, hydropower, etc.).

Costs and performance of an onshore wind farm closely relate to the $LCOE_{wso}$ variables simulated as defined in Tables 7.15 and 7.16∴Particularly the $LCOE_{wso}$ that is used to assess differences between various concepts must acknowledge this fundamental connection with the data to feed the model and its impacts on the *COE* of the wind farm analyzed∴In this Ph.D. research work is considered the operational research approach, being an engineering and economical model simultaneously. A breakdown of costs into a summation of sub-models can lead to a straightforward accumulation of inaccuracies and every level of precision can be obtained with precise input data.

$LCOE_{wso}$ has been applied for the economic analysis of the wind farm in three different sites (Brazil, Portugal and Canada). Although the simulation and validation of a model just represents a "*single concept"*, the results of this cost model are unique for each site simulated. $LCOE_{wso}$ proved a good basis to compare the effect of data (parameters) considered and to assess the effect of variations that affect both AEP_{avail} and *LCOE*∴We should consider as *"critical"* when interpreting the trend of levelized production costs in a parameter variation analysis for making a decision about the power plant (project) analyzed.

As we said in the last paragraph, the effect of the parameters/data variations impact on $LCOE_{wso}$ that is why we need to run (900 interactions) within a sensitivity analysis for numerical simulation and validation process, as detailed in section 7.6∴The sensitivity analysis was defined and undertaken as explained in sections 7.6.1, 7.6.2 and 7.6.3. Two groups of analysis are done; one for individual variable (v_{wc}, $O\&M_{manag}$, L_{wt} and E_{pi}) and other for multiple variables (v_{wc} and L_{wt}; $O\&M_{manag}$ and E_{pi}) in order to analyzed the size of impact on $LCOE_{wso}$.

This Ph.D. research work has demonstrated the importance of cost of energy produced optimization from WECS∴The results of the numerical simulations, validation and sensitivity analysis carried out in the present Ph.D. research work are presented and discussed deeply∴Also the results of the individual and multiple variable sensitivity analysis indicate that among the parameters/data tested effectively have impacts on the estimated $LCOE_{wso}$, as demonstrated in Chapter 8.

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"Then I saw that there is more gain in wisdom than in folly, as there is more gain in light than in darkness".
Ecclesiastes 2:13

CHAPTER 8

RESULTS AND DISCUSSION

This chapter demonstrates and discusses the results of the simulations carried out in the present Ph.D. research work. It is discussed the numerical treatment of wind resources *(calculation procedures and distribution of wind speed series)*, simulations analysis results *(reference case for comparison analysis, estimation of wind power production and economic evaluation results)*, sensitivity analysis results *(individual and multiple variable sensitivities and conclusions and future analysis on cost of wind energy)* and summary and conclusions are presented at the end, with the respective references.

8.1 INTRODUCTION

This chapter presents the results of the implementation of the of $LCOE_{wso}$ methodology already detailed in Chapters 6 and 7 for wind power technology (WECS) in a computer program, which allowed analyzing relational data, such as the impact of the variations in some groups of variables on the cost of energy produced and the estimate of annual production∴Sensitivity analyses were made to the variables selected *(v_{wc}, $O\&M_{manag}$, L_{wt} and E_{pi})*∴In addition, a comparison was made between the estimates of the annual energy production at three different sites, using the $LCPM_{WF}$ methodology described in section 6.4.4.2.

The results and discussions about the $LCOE_{wso}$ methodology go from the most general to the most detailed issues, taking into consideration the key assumptions and data∴It started with *numerical treatment of wind resources* (section 8.2) where is explained the *calculation procedures* (section 8.2.1) and *distribution wind speed series* (section 8.2.2) for *Aracati* (section 8.2.2.1), *Corvo Island* (section 8.2.2.2) and *Cape Saint James* (section 8.2.2.3).

The *simulations analysis results* (section 8.3) are organized in *reference case for comparison analysis* (section 8.3.1) based on *initial results summary of* $LCOE_{wso}$ as *referenced values* (section 8.3.1.1) and the *breakdown structure of* $LCOE_{wso}$ (section 8.3.1.2)∴In the section 8.3.2 is presented the *estimation of wind power production* for each site chosen (see sections 8.3.2.1, 8.3.2.2 and 8.3.2.3). Section 8.3.3 is related about *economic evaluation results* also for each site (see sections 8.3.3.1, 8.3.3.2 and 8.3.3.3).

The *sensitivity analysis results* (section 8.4) was carried out based on Table 7.16 and the results were separated into two groups∴The *individual variable sensitivities* (section 8.4.1), where we made some variations considering the impact on $LCOE_{wso}$ of wind speed *(v_{wc})* (section 8.4.1.1), operations and maintenance management (section 8.4.1.2), wind turbines layout (section 8.4.1.3) and energy policy instruments (section 8.4.1.4)∴The *multiple variable sensitivities* (section 8.4.2) was also made, but we tested the impact on $LCOE_{wso}$ of wind speed and wind turbine layout (section 8.4.2.1) and O&M management and energy policy instruments (section 8.4.2.2). Some *conclusions and future analysis on cost of wind energy* are presented in section 8.4.3. Finally, *the summary and conclusions* of this chapter are summarized in section 8.5 and all *references* (section 8.6) used are shown at the end of this chapter.

8.2 NUMERICAL TREATMENT OF WIND SPEED SERIES

8.2.1 CALCULATION PROCEDURES

The wind measurements are usually made at a height different than the hub height of the wind turbine. The wind speed is extrapolated to the hub height by using the well-known "1/7th wind power law"∴The wind speeds for simulations procedures at hub-height of 105 m was also done considering the 1/7th wind power law, as described by Petersen, Mortensen, Landberg, Højstrup, and Frank (1998). We have considered some procedures for calculation of the numerical treatment of wind speed series, as follows:

1. Determine the calculated wind speed *(v_{wc})* per month based on wind speed *(v_w)* at 10 m high for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada);

2. We consider the Eqn. 8.1 as $U(z) = U_r\left(\frac{z}{z_r}\right)^a$, where, where *($U_r$)* is the wind speed at a reference height (typically 10 m), and *(U(z))* is the wind speed at height *(z)* above ground, is commonly used in the wind energy community to estimate the wind speed and *(a)* is the *terrain rugosity factor*;

3. Calculate the *annual wind speed* at hub-high (105 m) for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) (see Table 7.5 and Figures 8.1, 8.2 and 8.3).

Some assumptions were considered for wind speed series calculations:

1. Wind speeds for all calculations are considered in *m/s* in order we have the same metric for comparison purpose;

2. The *wind speed calculated (v_{wc})* is based on Table 7.5 for all simulations done for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada);

3. The *terrain rugosity factor (a)* for the three sites simulated is considered *constant* within the same value *($a = \frac{1}{7}$; a=0.14);* In order to simplify the simulations with AEP_{avail} and $LCOE_{wso}$ *model calculations* we simulated the hypothetical wind farm at a macro site point of view for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) as well;

4. We have considered for wind speed calculated the same scale for the three sites chosen. The values range from *2 m/s (minimum) to 25 m/s (maximum).* In order to differentiate the wind trends profile, for each site we use a type of line (see Figure 8.4);

5. Temperature, humidity, and atmospheric pressure data were are also based on Tables 7.6, 7.7 and 7.8 All these data were used in the calculations of *air density (ρ)* in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada).

8.2.2 DISTRIBUTION OF WIND SPEED SERIES

8.2.2.1 IN ARACATI (BRAZIL)

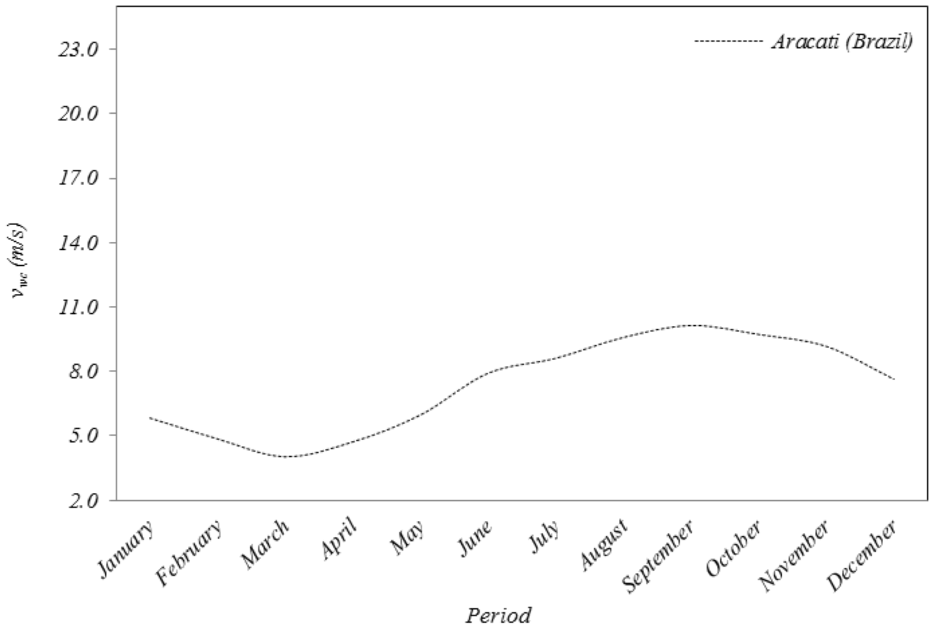

Figure 8.1 Calculated wind speed distribution for Aracati (Brazil). Source: based on RETScreen® International Clean Energy Decision Support Centre (2009)

Figure 8.1 shows the wind speed behavior in Aracati (Brazil) for one year and some considerations we can take from it:

1. In the beginning of the year the monthly *wind speed calculated for 105 m hub-high* is possible lower than in the rest of this same year $\therefore$ This initial wind profile is changed in fourth month in the year *(April)* and keep it up until the end of the year;

2. As we already said in section 7.2.2.1 the windiest period is clearly *June*, *July*, *August*, *September*, *October*, *November* and *December* $\therefore$ The highest wind speed is in *September* (10.1 m/s) and in the same period *(from June to December)* the monthly wind speed is higher than annual average wind speed (7.4 m/s);

3. Statistically, during one year the wind speed series in Aracati (Brazil) has presented a SD=2.1 m/s, 4.0 m/s and 10.1 m/s as minimum and maximum wind speeds, respectively, for the same period.

8.2.2.2 IN CORVO ISLAND (PORTUGAL)

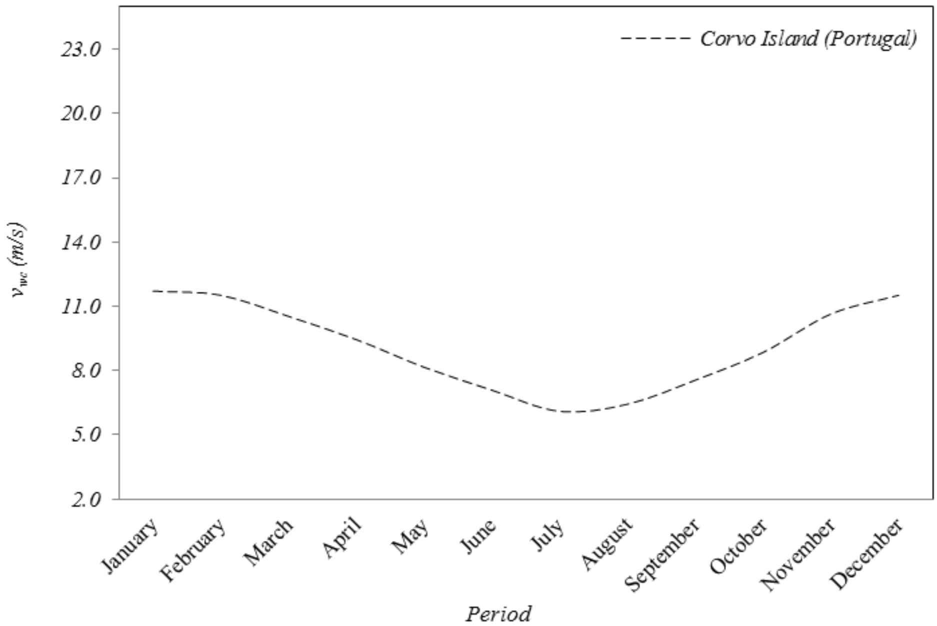

Figure 8.2 Calculated wind speed distribution for Corvo Island (Portugal). Source: based on RETScreen® International Clean Energy Decision Support Centre (2009)

Figure 8.2 shows the wind speed behavior in Corvo Island (Portugal) for one year and some considerations we can take from it:

1. Differently from Aracati (Brazil), as shown in Figure 8.2, in the beginning of the year the monthly *wind speed calculated for 105 m hub-high* is possible highest than in the rest of this same year *(11.7 m/s in January)* at Corvo Island (Portugal)$\therefore$This initial wind profile is changed in third month in the year *(March)* and there is an increasing trend since from *July* until the end of the year with a *monthly wind speed calculated* in *December* of 11.5 m/s;

2. As we already said in section 7.2.2.1 the windiest period are clearly *January, February, March, April; November* and *December*$\therefore$The lowest wind speed is in *July* (6.1 m/s), where this initial wind profile changes to an increasing trend until the rest of the year;

3. Statistically, during one year the wind speed series in Corvo Island (Portugal) has presented a SD=2.0 m/s, 6.1 m/s and 11.7 m/s as minimum and maximum wind speeds, respectively, for the same period.

8.2.2.3 IN CAPE SAINT JAMES (CANADA)

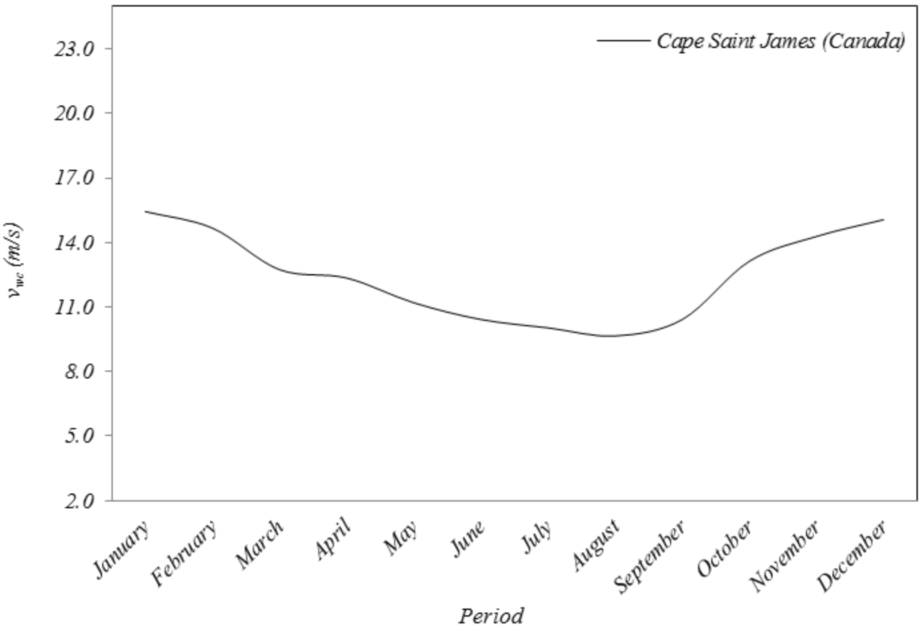

Figure 8.3 Calculated wind speed distribution for Cape Saint James (Canada). Source: based on RETScreen® International Clean Energy Decision Support Centre (2009)

Figure 8.3 shows the wind speed behavior in Cape Saint James (Canada) for one year and some considerations we can take from it:

1. Likely Corvo Island (Portugal), as shown in Figure 8.3, in the beginning of the year the monthly *wind speed calculated for 105 m hub-high* is possible highest than in the rest of this same year *(15.4 m/s in January)*∴This initial wind profile is changed in eighth month in the year *(August)* and there is an increasing trend since September until the end of the year with a *monthly wind speed calculated* in *December* of 15.1 m/s;

2. As we already said in section 7.2.2.1 the windiest period is clearly *January*, *February*, *March; October*, *November* and *December*. The highest wind speed is in *January* (15.4 m/s) and in the same period *(January, February, March; October, November* and *December)* the monthly wind speed is higher than annual average wind speed (12,7 m/s);

3. Statistically, during one year the wind speed series in Cape Saint James (Canada) has presented a SD=2.0 m/s, 9.7 m/s and 15.4 m/s as minimum and maximum wind speeds, respectively, for the same period.

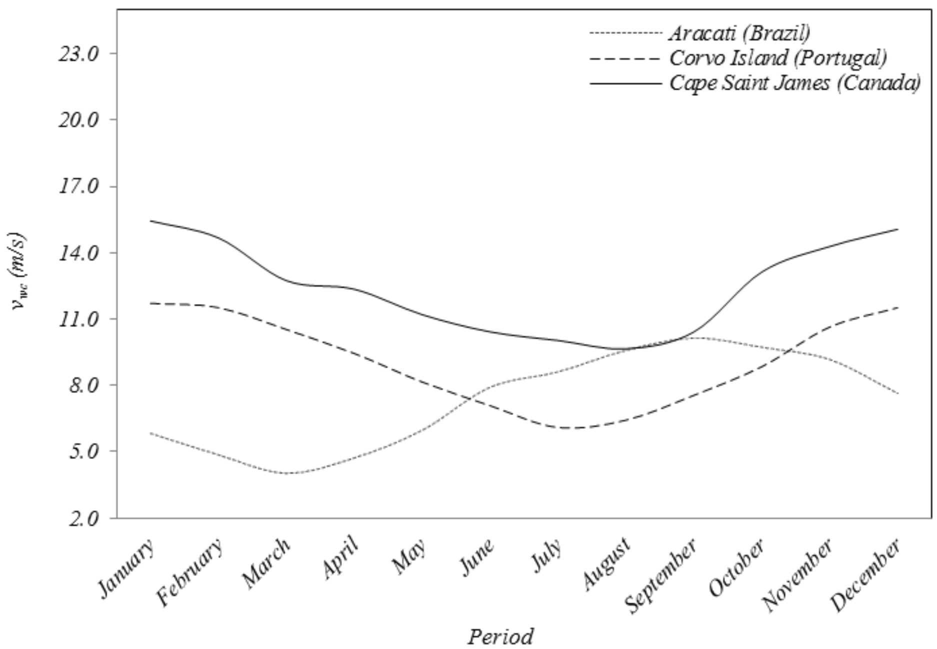

Figure 8.4 Comparison among the calculated wind speed behavior of the three sites selected. Source: Own elaboration

When we made the comparison of the wind profile during one year, according to the data shown in Figure 6.11, 6.12, 6.13 and Table 7.5, some evidences must be taken in relation the wind speed behavior in an a yearly basis∴Figure 8.3 shows the annual wind speed behavior in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) and we highlight the following aspects:

1. Both Corvo Island (Portugal) and Cape Saint James (Canada) present a similar wind speed behavior during the year analyzed;

2. Wind speed series of Aracati (Brazil) and Cape Saint James (Canada) make interception in *August* and *September*∴The wind speeds are 9.6 m/s and 9.7 m/s in *August* for Aracati (Brazil) and Cape Saint James (Canada), respectively∴The same situation happens in *September* the wind speed of 10.1 m/s and 10.4 m/s for Aracati (Brazil) and Cape Saint James (Canada), respectively;

3. The behavior of wind speed in Aracati (Brazil) and Corvo Island (Portugal) present similarities∴In *June* and *October* we can notice a monthly wind speed of 7.9 m/s and 7.1 m/s and 9.7 m/s and 8.9 m/s, respectively.

8.3 SIMULATION ANALYSIS RESULTS

8.3.1 REFERENCE CASES FOR COMPARISON ANALYSIS

Wind Project Information		***Notes***
Project Name	*Firestar Wind Farm*	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines *(N_{WT})*	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity *(WF_{cap})*	50 000	[kW]
Rotor Diamenter *(D)*	90.0	[m]
Swept Area per Turbine *(A)*	6 361.7	[m^2]
Hub height *(H)*	105.0	[m]
Wind speed measured at *(H_0)*	10.0	[m]
Terrain rugosity factor *(a)*	0.14	[–]
Betz Limit`s coefficient *(C_{PBetz})*	0.5926	[–]
Lifetime of Wind Farm *(N)*	25	[yr]
Production Efficiency *(WF_{PE})*	11.2%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Project Information		***Notes***
Project Name	*Firestar Wind Farm*	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines *(N_{WT})*	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity *(WF_{cap})*	50 000	[kW]
Rotor Diamenter *(D)*	90.0	[m]
Swept Area per Turbine *(A)*	6 361.7	[m^2]
Hub height *(H)*	105.0	[m]
Wind speed measured at *(H_0)*	10.0	[m]
Terrain rugosity factor *(a)*	0.14	[–]
Betz Limit`s coefficient *(C_{PBetz})*	0.5926	[–]
Lifetime of Wind Farm *(N)*	25	[yr]
Production Efficiency *(WF_{PE})*	20.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Project Information		***Notes***
Project Name	*Firestar Wind Farm*	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines *(N_{WT})*	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity *(WF_{cap})*	50 000	[kW]
Rotor Diamenter *(D)*	90.0	[m]
Swept Area per Turbine *(A)*	6 361.7	[m^2]
Hub height *(H)*	105.0	[m]
Wind speed measured at *(H_0)*	10.0	[m]
Terrain rugosity factor *(a)*	0.14	[–]
Betz Limit`s coefficient *(C_{PBetz})*	0.5926	[–]
Lifetime of Wind Farm *(N)*	25	[yr]
Production Efficiency *(WF_{PE})*	48.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Figure 8.5 Wind project information for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration. Note: numbers in gray represent results from $LCOE_{wso}$ methodology calculations

8.3.1.1 INITIAL RESULTS SUMMARY OF $LCOE_{WSO}$

Initial Results Summary of $LCOE_{wso}$			Notes
67.6603	yr_1	70.7762	yr_{15}
67.8118	yr_2	69.8077	yr_{15}
68.0210	yr_3	69.9988	yr_{16}
68.1822	yr_4	70.1987	yr_{17}
68.4349	yr_5	70.3955	yr_{18}
68.6241	yr_6	70.7564	yr_{19}
68.8710	yr_7	70.3686	yr_{20}
69.0863	yr_8	70.5514	yr_{21}
69.2587	yr_9	70.8222	yr_{22}
69.4873	yr_{10}	71.1051	yr_{23}
69.7236	yr_{11}	71.3664	yr_{25}
70.0026	yr_{12}	69.6792	*Mean*
70.2282	yr_{13}	1.0823	*SD*
70.4423	yr_{14}	-0.4514	*Υ (skewness)*
$LCOE_{wso}$	**69.6792**	**US $/MWh**	*valid !*
	0.069679	**US $/kWh**	

Initial Results Summary of $LCOE_{wso}$			Notes
73.0793	yr_1	78.4116	yr_{15}
73.4776	yr_2	77.5903	yr_{15}
73.7436	yr_3	78.1098	yr_{16}
74.0885	yr_4	78.5637	yr_{17}
74.4286	yr_5	79.0704	yr_{18}
74.8887	yr_6	79.5598	yr_{19}
75.1794	yr_7	77.6767	yr_{20}
75.4693	yr_8	78.1898	yr_{21}
75.9694	yr_9	78.6500	yr_{22}
76.3656	yr_{10}	78.9953	yr_{23}
76.6792	yr_{11}	79.3896	yr_{25}
77.1795	yr_{12}	76.8138	*Mean*
77.5814	yr_{13}	2.0085	*SD*
78.0080	yr_{14}	-0.4651	*Υ (skewness)*
$LCOE_{wso}$	**76.8138**	**US$/MWh**	*valid !*
	0.076814	**US$/kWh**	

Initial Results Summary of $LCOE_{wso}$			Notes
84.2996	yr_1	94.3718	yr_{15}
84.9743	yr_2	94.0482	yr_{15}
85.6626	yr_3	94.8532	yr_{16}
86.1247	yr_4	95.7496	yr_{17}
86.8183	yr_5	96.6483	yr_{18}
87.5429	yr_6	97.4272	yr_{19}
88.1156	yr_7	93.9167	yr_{20}
88.8127	yr_8	94.6168	yr_{21}
89.7238	yr_9	95.6632	yr_{22}
90.3120	yr_{10}	96.4289	yr_{23}
91.1318	yr_{11}	97.4427	yr_{25}
91.8409	yr_{12}	91.7081	*Mean*
92.5685	yr_{13}	4.1890	*SD*
93.6087	yr_{14}	-0.3343	*Υ (skewness)*
$LCOE_{wso}$	**91.7081**	**US $/MWh**	*valid !*
	0.091708	**US $/kWh**	

Figure 8.6 Initial results of $LCOE_{wso}$ for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration. Note: numbers in gray represent results from $LCOE_{wso}$ methodology calculations

8.3.1.2 BREAKDOWN STRUCTURE OF $LCOE_{WSO}$

$\boldsymbol{LCOE_{wso}}$[148] = 67,6603 US$/MWh ($yr_1$); 69,6792 US$/MWh (Mean); SD=1.0823 US$/MWh; Υ=-0,4514 (skewness)		
$\boldsymbol{LCCCM_{WF}}$ = 1 204.5180 $/kW		
WT_{CM} 553.7256 $/kW	T_{CM} 484.3859 $/kW	$LWTG_{CM}$ 39.1957 $/m/kW
CP_{CM} 30.9069 $/kW	TS_{CM} 11.4566 $/kW_e$	SI_{CM} 42.7345 $/m^2/kW
PO_{CM} 35.9374 $/kW	F_{CM} 3.7712 $/kW	CCC_{CM} 2.4042 $/kW

$\boldsymbol{LCPM_{WF}}$ 48 856 319 kW_eh/yr		$\boldsymbol{O\&M_{WFCM}}$ 0.124133 $/kWh/yr
WF_{CM} 50.000 kW_e/yr	WT_{LM} 5D4D	$O\&M_{fixed_{CM}}$ 0.098275 $/kWh
PC_{PM} 97.9% (availability)	$P\&D_{LM_{factor}}$ 0.839325	$O\&M_{variable_{CM}}$ 0.025858 $/kWh

$\boldsymbol{LRCM}$ = 16.8443 $/kW	
AR_{CM} 16.8442 $/kW	TO_{CM} 0.000033 $/kW
$\boldsymbol{RCM_{WF}}$ = 1 278.8970 $/kW	
DCM_{WF} 1 339.9154 $/kW	RVM_{WF} 61.0184 $/kW
$\boldsymbol{REPIM}$[149] = 420.0830 $/proj	
REI_{CM} 70.8203 $/kW_e$	REP_{CM} 0.00002627 $/kW_eh$
$OREP_{CM}$ 13.0797 $/kW_e$	$GHG.R_{CM}$ 1 596.4321 $/t$CO_2$

Figure 8.7 Breakdown structure of $LCOE_{wso}$ for Aracati (Brazil). Source: Own elaboration

[148] All the values calculated of $LCOE_{wso}$ for Aracati (Brazil) is based on the situation of year one (yr=1)
[149] *REPIM*`s values are calculated by the proportional to 25% for each energy policy instrument, according to Table 7.14.

$LCOE_{wso}$[150] *= 73.0793 US$/MWh ($yr_1$); 76.8138 US$/MWh (Mean); SD= 2.0085 US$/MWh; ϒ=-0,4651 (skewness)*

$LCCCM_{WF}$ *= 1 204.5180 $/kW*

WT_{CM} 553.7256 $/kW	*T_{CM}* 484.3859 $/kW	*$LWTG_{CM}$* 39.1957 $/m/kW
CP_{CM} 30.9069 $/kW	*TS_{CM}* 11.4566 $/kW$_e$	*SI_{CM}* 42.7345 $/m^2/kW
PO_{CM} 35.9374 $/kW	*F_{CM}* 3.7712 $/kW	*CCC_{CM}* 2.4042 $/kW

$LCPM_{WF}$ *89 657 257 kW$_e$h/yr*

$O\&M_{WFCM}$ *0.147210 $/kWh/yr*

WF_{CM} 50.000 kW$_e$/yr	*WT_{LM}* 5D4D	*$O\&M_{fixed_{CM}}$* 0.098275 $/kWh
PC_{PM} 97.9% (availability)	*$P\&D_{LM_{factor}}$* 0.839325	*$O\&M_{variable_{CM}}$* 0.048935$/kWh

LRCM *= 16.8443 $/kW*

AR_{CM} 16.8442 $/kW	*TO_{CM}* 0.000033 $/kW

RCM_{WF} *= 1 278.8970 $/kW*

DCM_{WF} 1 339.9154 $/kW	*RVM_{WF}* 61.0184 $/kW

REPIM[151] *= 228.2900 $/proj*

REI_{CM} 70.8203 $/kW$_e$	*REP_{CM}* 0.00001039 $/kW$_e$h
$OREP_{CM}$ 21.2151 $/kW$_e$	*$GHG.R_{CM}$* 821.1245 $/t$CO_2$

Figure 8.8 Breakdown structure of *$LCOE_{wso}$* for Corvo Island (Portugal). Source: Own elaboration

[150] All the values calculated of *$LCOE_{wso}$* for Corvo Island (Portugal) is based on the situation of year one (yr=1)
[151] *REPIM*`s values are calculated by the proportional to 25% for each energy policy instrument, according to Table 7.14.

$LCOE_{wso}$[152] *= 84.2996 US$/MWh ($yr_1$); 91.7091 US$/MWh (Mean); SD=4.1890 US$/MWh; ϒ=-0,3343 (skewness)*

$LCCCM_{WF}$ *= 1 204.5180 $/kW*

WT_{CM} 553.7256 $/kW	T_{CM} 484.3859 $/kW	$LWTG_{CM}$ 39.1957$/m/kW
CP_{CM} 30.9069 $/kW	TS_{CM} 11.4566 $/kW$_e$	SI_{CM} 42.7345 $/m^2/kW
PO_{CM} 35.9374 $/kW	F_{CM} 3.7712 $/kW	CCC_{CM} 2.4042 $/kW

$LCPM_{WF}$ *212 467 325 kW$_e$h/yr*

$O\&M_{WFCM}$ *0.139806 $/kWh/yr*

WF_{CM} 50.000 kW$_e$/yr	WT_{LM} 5D4D	$O\&M_{fixed_{CM}}$ 0.098275 $/kWh
PC_{PM} 97.9% (availability)	$P\&D_{LM_{factor}}$ 0.814145	$O\&M_{variable_{CM}}$ 0.041531 $/kWh

LRCM *= 16.8443 $/kW*

AR_{CM} 16.8442 $/kW	TO_{CM} 0.000033 $/kW

RCM_{WF} *= 1 278.8970 $/kW*

DCM_{WF} 1 339.9154 $/kW	RVM_{WF} 61.0184 $/kW

REPIM[153] *= 1 154.5477 $/proj*

REI_{CM} 70.8203 $/kW$_e$	REP_{CM} 0.00000052 $/kW$_e$h
$OREP_{CM}$ 56.8814 $/kW$_e$	$GHG.R_{CM}$ 4 490.4890 $/tCO_2$

Figure 8.9 Breakdown structure of $LCOE_{wso}$ for Cape Saint James (Canada). Source: Own elaboration

[152] All the values calculated of $LCOE_{wso}$ for Cape Saint James (Canada) is based on the situation of year one (yr=1)
[153] *REPIM*`s values are calculated by the proportional to 25% for each energy policy instrument, according to Table 7.14.

8.3.2 ESTIMATION OF WIND POWER PRODUCTION

8.3.2.1 FOR ARACATI (BRAZIL)

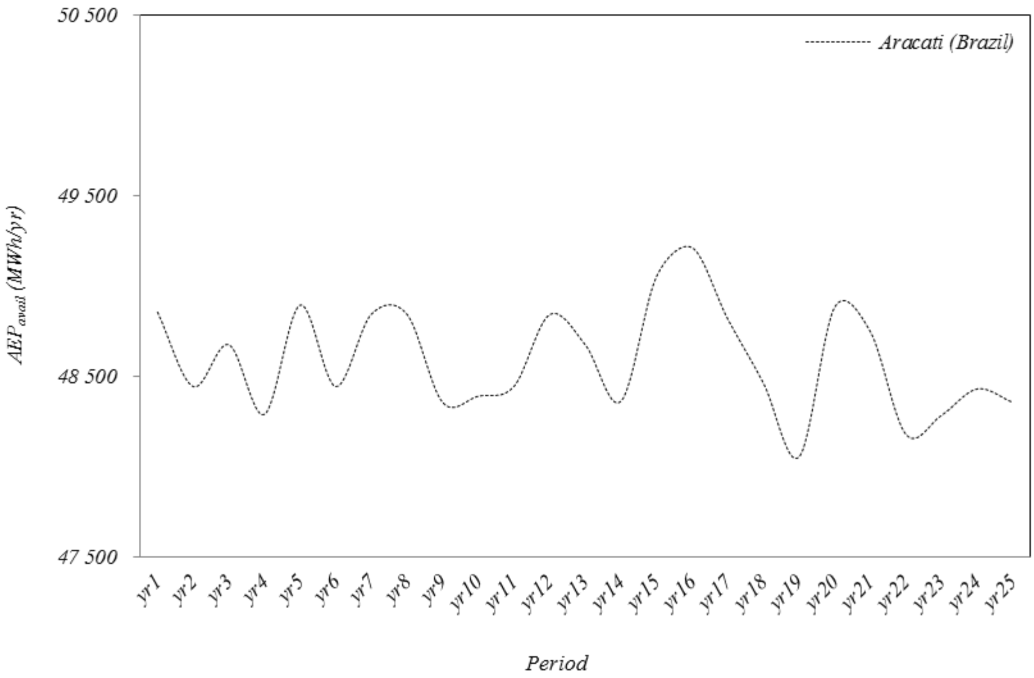

Figure 8.10 *AEP_{avail}* for 25 years of the wind farm for Aracati (Brazil) in standard operation. Source: Own elaboration

As we can see in Figure 8.10, the *AEP_{avail}* of the wind farm in Aracati (Brazil) varies from *48 055 MWh/yr* to *49 213 MWh/yr* with *SD=288 MWh, 48 594 MWh (Mean)* and *48 444 MWh (Mode).* The *AEP_{avail}* has shown a *positive moderate asymmetric*[154] distribution *(ϒ=0.2056)* during the wind farm lifetime *(N=25yrs)*.

In the years *16 (yr_{16})* and *19 (yr_{19})*, we can notice the highest and lowest level of production, respectively∴This wind power plant expects to produce as *AEP_{avail}* about *1 214 852 MWh (1 215 GWh)* during the operational phase (see Figure 8.13).

[154] The *skewness* can be classified into *symmetric (if ϒ<0.15), moderate asymmetry (if 0.15 ≤|ϒ|≤ 1.0), strong asymmetry (if ϒ ≥1.0).* For more explanations, please, see at Groeneveld and Meeden (1984).

8.3.2.2 FOR CORVO ISLAND (PORTUGAL)

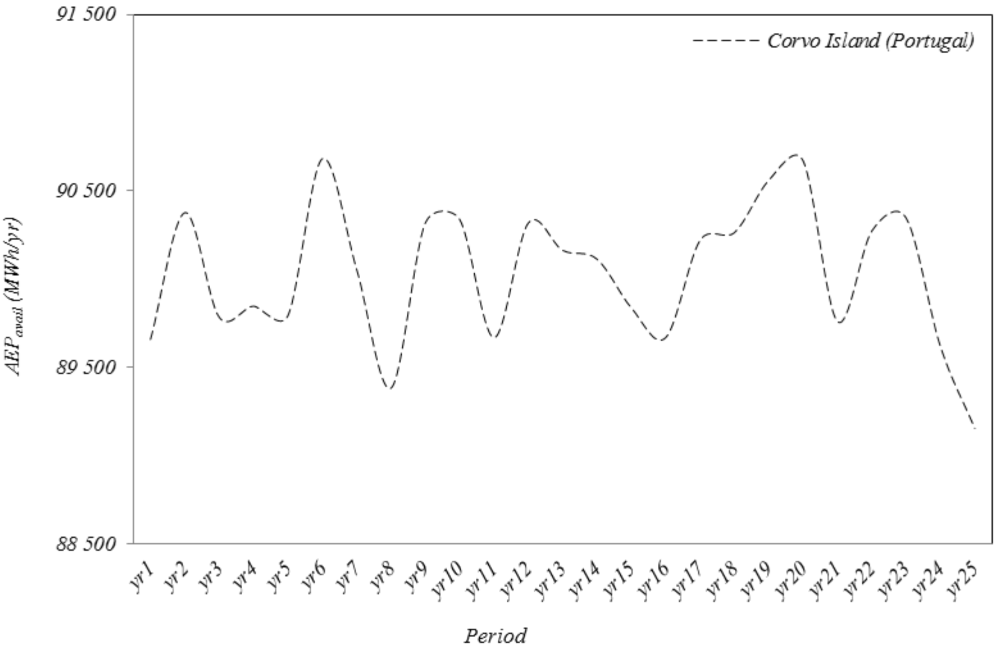

Figure 8.11 AEP_{avail} for 25 years of the wind farm in Corvo Island (Portugal) in standard operation. Source: Own elaboration

As we can see in Figure 8.11, the AEP_{avail} of the wind farm in Corvo Island (Portugal) also varies from *89 154 MWh/yr* to *90 682 MWh/yr* with *SD=390 MWh, 90 035 MWh (Mean)* and *90 318 MWh (Mode)*$\therefore$The AEP_{avail} has shown a *negative moderate asymmetric* distribution *(ϒ=-0.2882)* during the wind farm lifetime *(N=25yrs)*.

In the years *6 (yr_6)* and *25 (yr_{25})*, we can notice the highest and lowest level of production, respectively$\therefore$This wind power plant expects to produce as AEP_{avail} about *2 250 871 MWh (2 251 GWh)* during the operational phase (see Figure 8.13).

8.3.2.3 FOR CAPE SAINT JAMES (CANADA)

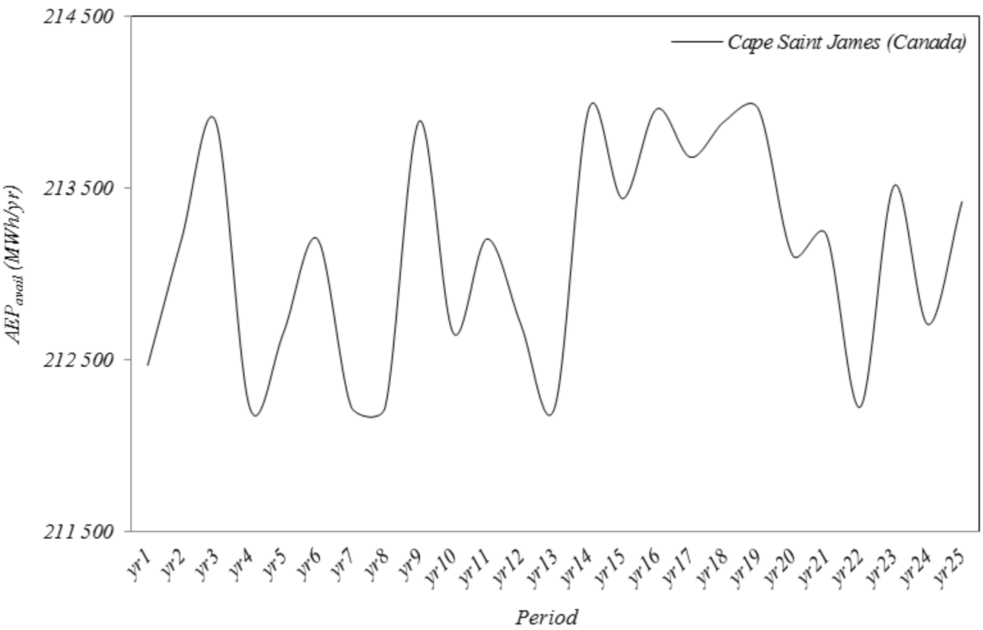

Figure 8.12 *AEP_{avail}* for 25 years of the wind farm in Cape Saint James (Canada) in standard operation. Source: Own elaboration

As we can see in Figure 8.12, the *AEP_{avail}* of the wind farm in Cape Saint James (Canada) also varies from *212 224 MWh/yr* to *213 959 MWh/yr* with *SD=626 MWh*, *213 114 MWh (Mean)* and *212 224 MWh (Mode)* ∴ The *AEP_{avail}* has shown a *negative symmetric* distribution *(Υ=-0.1060)* during the wind farm lifetime *(N=25yrs)*.

In the years *7 (yr_7)* and *16 (yr_{16})*, we can notice the highest and lowest level of production, respectively ∴ This wind power plant expects to produce as *AEP_{avail}* about *5 327 844 MWh (5 328 GWh)* during the operational phase (see Figure 8.13).

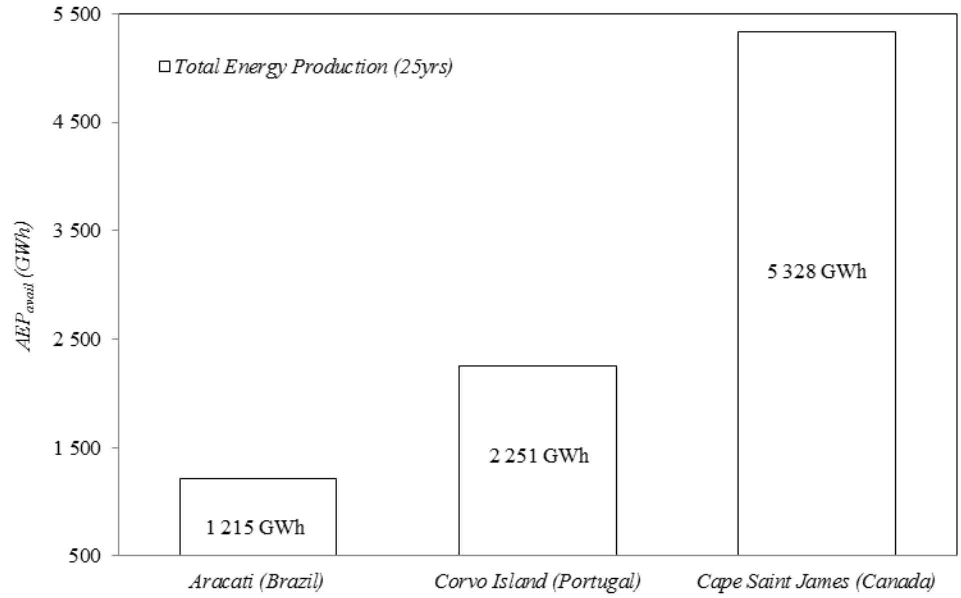

Figure 8.13 Total AEP_{avail} during the lifetime of 50MW$_e$ wind farm in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration

The AEP_{avail} and *wind speed* (v_{wc}) have a direct as specific relation – *the power output is the cube of wind speed* – and in those three different wind speeds (wind resources) impacts on wind farm production as well as the wind speed increases∴We can see this *strong relation* when we have done the correlation analysis between AEP_{avail} and *wind speed* (v_{wc}) for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada), as shown in Table 8.1:

Table 8.1 Correlation analysis between AEP_{avail} and *wind speed* (v_{wc})

Items	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
AEP_{avail} *(GWh)*	*1 215*	*2 251*	*5 328*
v_{wc} *(m/s)*	*7.4*	*9.1*	*12.5*
Correlation Coeff. 0.994			

Source: Own elaboration

8.3.3 ECONOMIC EVALUATION RESULTS

The economic evaluation results organized considering the same structure of the projected cash flow analysis (Appendix G)∴For Aracati (Brazil) (section 8.3.3.1), Corvo Island (Portugal) (section 8.3.3.2) and Cape Saint James (Canada) (section 8.3.3.3) the results have started with $LCCCM_{WF}$, *AAR*, $O\&M_{WFCM}$, *LRCM*, RCM_{WF} and *REPIM*.

8.3.3.1 FOR ARACATI (BRAZIL)

The $LCOE_{wso}$ methodology organizes the investment costs without any kind of public incentive effect *(REPIM)* in $LCCCM_{WF}$. For the standard (base-case) situation the $LCCCM_{WF}$ has shown the following structure, as represented by Table 8.2:

Table 8.2 $LCCCM_{WF}$ breakdown structure for Aracati (Brazil)

Investment cost	*US$*	*%*
WT_{CM}	*27 686 278*	*46.0%*
T_{CM}	*24 219 295*	*40.2%*
$LWTG_{CM}$	*1 959 783*	*3.3%*
CP_{CM}	*1 545 346*	*2.6%*
TS_{CM}	*572 832*	*1.0%*
SI_{CM}	*2 136 726*	*3.5%*
PO_{CM}	*1 796 870*	*3.0%*
F_{CM}	*188 559*	*0.3%*
CCC_{CM}	*120 211*	*0.1%*
$LCCCM_{WF}$	*60 225 901*	*100.0%*

Source: Own elaboration

The capital cost per kW installed is about *1 204.52 US$/kW* and the most part is centralized in *wind turbines (46.0% for WT_{CM})* and *towers (40.2% for T_{CM})*∴It is also important to highlight the *local wind turbines grid ($LWTG_{CM}$), collecting point (CP_{CM})* and *transmission system (TS_{CM})* that represents about *7.0%* of the *total capital costs (6.9%).*

When we consider the effect of public incentive *(REPIM)* on initial investments in multi-megawatts wind farm (50 MW_e) we notice a *reduction around 0.64%*[155] and the $LCCCM_{WF}$ can reach the cost per kW about *1 196.82 US$/kW.*

[155] In $LCOE_{wso}$ methodology, the *REPIM* instruments applied to Aracati (Brazil) are calculated considering the base-case defined in Tables 7.13 and 7.14.

The *AAR* of the hypothetical wind farm is shown in Figure 8.14 within its particularities and behavior∴We have calculated the *AAR per year* according to Eqn. 7.1 with the conditions defined in Table 7.10.

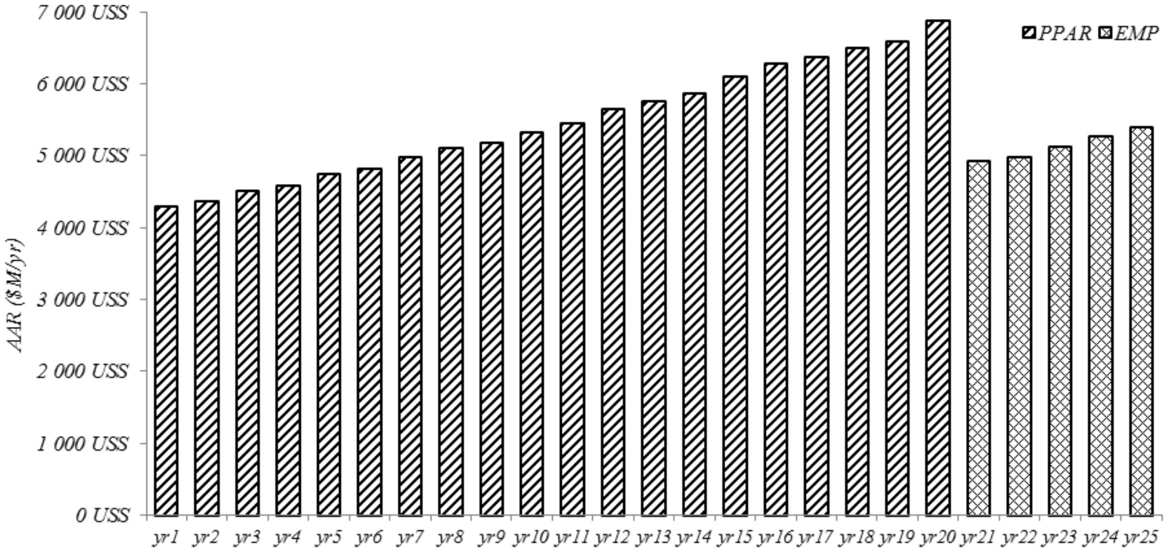

Figure 8.14 *AAR (US$M/yr)* during the lifetime of the 50MW$_e$ wind farm in Aracati (Brazil). Source: Own elaboration

According to Figure 8.14, the *AAR* of the wind farm in Aracati (Brazil) varies from *4 297 170 US$M/yr* to *6 873 465 US$M/yr* with *SD=713 406 US$M and 5 398 391 US$M/yr (Mean)*∴The *AAR* has shown a *positive moderate asymmetry* distribution *(ϒ=0.4437)* during the wind farm lifetime *(N=25yrs)*.

In the years *1 (yr$_1$)* and *20 (yr$_{20}$)*, we can notice the lowest and highest level of revenue, respectively∴This wind power plant expects to receive as total *AAR* about *134 959 772 US$M* during the operational phase. The relation between the total *AAR* and *LCPM$_{WF}$* is *0.111092 US$* per kWh produced. We have to remember the effect of the inflation rate *(2.5% per year)* on revenues.

For Gross, Blyth, and Heptonstall (2010) the returns of a wind power project depends on revenues as well as cost, so the price of electricity becomes an important risk factor in the investment decision.

The $O\&M_{WFCM}$ of the hypothetical wind farm is shown in Figure 8.15 within its particularities and behavior∴We have calculated the $O\&M_{WFCM}$ *per year* according to Eqns 6.2.3, 6.2.3.1 and 6.2.3.2 with the conditions defined in Tables 7.11 and 7.12.

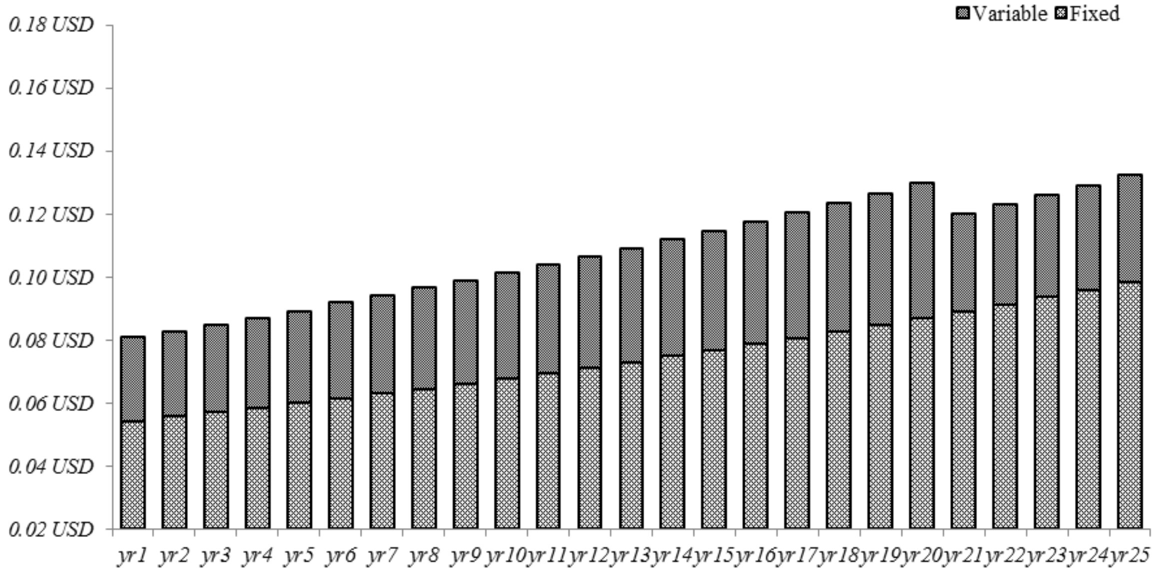

Figure 8.15 $O\&M_{WFCM}$ splited into *fixed* $(O\&M_{fixed_{CM}})$ and *variable* $(O\&M_{variable_{CM}})$ during the lifetime of the 50MW$_e$ wind farm in Aracati (Brazil). Source: Own elaboration

As we can see in Figure 8.15, the $O\&M_{WFCM}$ of the wind farm in Aracati (Brazil) varies from *0.0808 US$ kWh/yr* to *0.1323 US$ kWh/yr* with *SD=0.0161 US$ kWh* and *0.1081 US$ kWh/yr (Mean)*∴The $O\&M_{WFCM}$ has shown a *negative moderate asymmetry* distribution *(ϒ=-0.1745)* during the wind farm lifetime *(N=25yrs)*.

In the years *1* (yr_1) and *25* (yr_{25}), we can notice the lowest and highest level of $O\&M_{WFCM}$, respectively∴This wind power plant expects to spend as total $O\&M_{WFCM}$ about *131 300 872 US$M* during the operational phase. The relation between the total $O\&M_{WFCM}$ and $LCPM_{WF}$ is *0.108080 US$* per kWh produced∴ We also have to remember the effect of the inflation rate *(2.5% per year)* on O&M costs.

As have discussed Poore and Walford (2008) the facility costs are linked to the size of the facility and are assumed to remain constant over the life of the project∴This implies that the infrastructure is maintained in good condition for the project's life and that no improvements or expansions are made∴For this reason we have also considered in $LCOE_{wso}$ methodology the *LRCM* and RCM_{WF} for capital costs during the lifetime of the wind project *(applied to specific cost for revisions or substitution of parts of WECS, such as, nacelles, wind turbines, rotor, blades, generators and* *other) that usually can occur during the lifetime of the power project)* and when at the *end of lifetime of the wind project (removing or repowering situation)*.

The *LRCM* of the hypothetical wind farm is shown in Figure 8.16 within its particularities and behavior∴We have calculated the *LRCM per year* according to Eqns 6.2.2, 6.2.2.1, 6.2.2.1.1, 6.2.2.1.2, 6.2.2.2, and 6.2.2.2.1 with the conditions defined in Table 6.8.

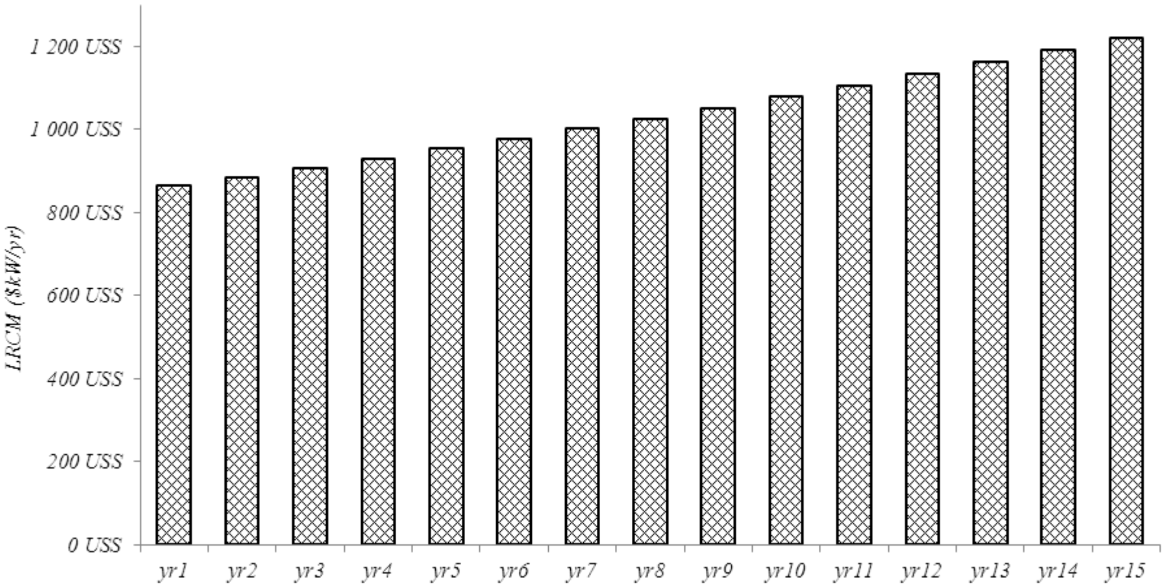

Figure 8.16 *LRCM* during the 15 years of the 50MW$_e$ wind farm in Aracati (Brazil). Source: Own elaboration

As shown in Figure 8.16, the *LRCM* of the wind farm in Aracati (Brazil) varies from *863 268 US$ kW/yr* to *1 219 776 US$ kW/yr* with *SD=109 970 US$ kW and 1 032 004 US$ kW/yr (Mean).* The *LRCM* has shown a *positive symmetric* distribution *(Υ=0.1407)* during the wind farm lifetime *(N=25yrs)*.

In the years *1 (yr_1)* and *15 (yr_{15})*, we can notice the lowest and highest level of *LRCM savings*, respectively. This wind power plant expects to save as total *LRCM* about *15 480 065 US$* during 15 years of the operational phase∴The relation between the total *LRCM* and *kW produced* in 15 years is *182.0645 US$* per kW produced. We also have to remember the effect of the inflation rate *(2.5% per year)* on *LRCM*.

As have stated Oliveira and Fernandes (2012) the aim of *LRCM* (equivalent to *LRC*) is to make funds available when needed to repair or total replacement of occurrence∴The exercise involves calculating the net present value or even to allocate costs for review and replacement on an annualized basis consistent with other cost elements∴That is why we have also considered the *costs for removing the wind farm at the end of its lifetime*, if the investor desires to stop operations or repower it for a new phase. This mechanism works as a *saving acc*ount, an *"economic reserve"*. It has been calculated year by year and named RCM_{WF}.

The RCM_{WF} of the hypothetical wind farm is shown in Figure 8.17 within its particularities and behavior∴We have calculated the RCM_{WF} *per year* according to Eqns 6.2.4, 6.2.4.1, 6.2.4.1.1, 6.2.4.1.2, 6.2.4.1.3, 6.2.4.2, 6.2.4.2.1, 6.2.4.2.2 and 6.2.4.3 with the conditions defined in Tables 6.8 and 6.9.

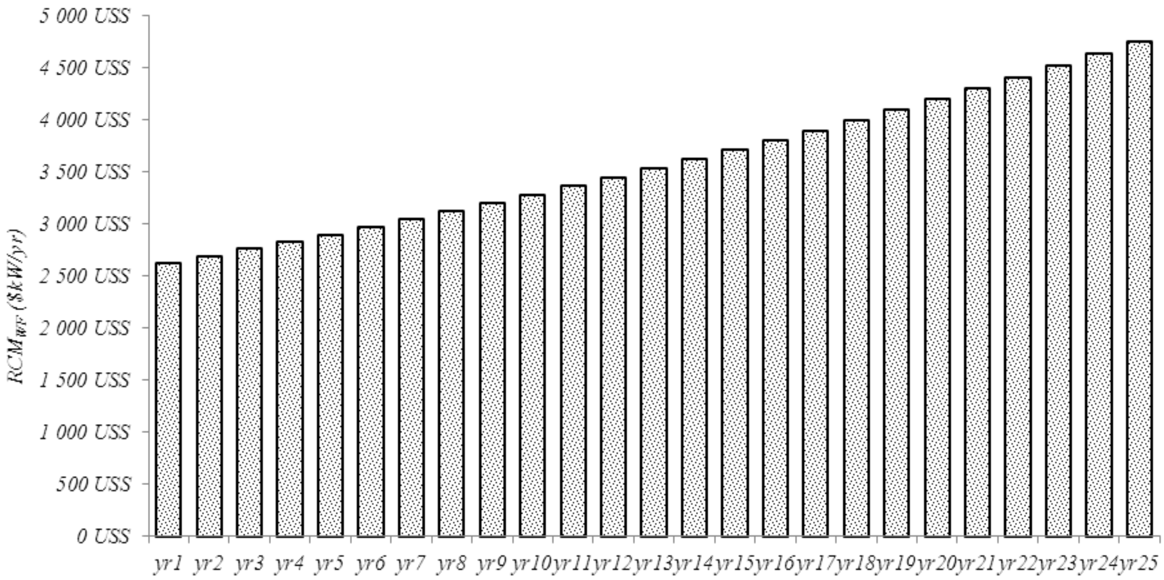

Figure 8.17 RCM_{WF} during the lifetime of the 50MW$_e$ wind farm in Aracati (Brazil). Source: Own elaboration

According to Figure 8.17, the RCM_{WF} of the wind farm in Aracati (Brazil) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW and 3 582 109 US$ kW/yr (Mean).*

The RCM_{WF} has shown a *positive moderate asymmetry* distribution *(ϒ=0.2259)* during the wind farm lifetime *(N=25yrs)*.

In the years *1 (yr$_1$)* and *25 (yr$_{25}$)*, we can notice the lowest and highest level of RCM_{WF} *savings*, respectively∴This wind power plant expects to save as total RCM_{WF} about *89 552 736 US$* during the operational phase. The relation between the total RCM_{WF} and *kW produced* in 25 years is *1 053 US$* per kW produced. We also have to remember the effect of the inflation rate *(2.5% per year)* on RCM_{WF}.

The RCM_{WF} was developed in order to cover the costs of removing the wind farm and *"rebuild"* the local environment conditions, so when we get a *value equal or equivalent* amount of funds for cover the costs of decommissioning the wind farm, which is the purpose of this indicator! In the case of the hypothetical wind farm in Aracati (Brazil) if we have consider the total $LCCCM_{WF}$

(60 225 901 US$) added to *LRCM (15 480 065 US$)*, the RCM_{WF} about *89 552 736 US$* really covers it *(75 705 966 US$ < 89 552 736 US$).*

The *REPIM or Renewable Energy Public Incentive Model* is a part of our proposed $LCOE_{wso}$ methodology that measures the impact of some and *most common kinds of energy policy instruments applied to RETs*∴We have proposed four different types of instruments: two of them are related to investment incentive *(*REI_{CM} and $OREP_{CM}$*)* and the others are related to energy production *(*REP_{CM} and $GHG.R_{CM}$*)*.

The REI_{CM} of the hypothetical wind farm is shown in Figure 8.18 within its particularities and behavior∴We have calculated the REI_{CM} *for initial year of the wind project (yr=0)* according to Eqns 6.2.5.1with the conditions defined in Tables 6.10 and 7.14.

REI_{CM}	70.8203	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_{ψ}	6	[yr]

Figure 8.18 REI_{CM} for 50MW$_e$ wind farm in Aracati (Brazil). Source: Own elaboration

The total REI_{CM} received by the hypothetical wind farm was calculated with the following Eqn 8.2:

$$Total_{REI_{CM}} = REI_{CM}\ WF_{cap}\xi_{REI_{CM}} \qquad [\$/kW_e] \qquad \text{Eqn (8.2)}$$

When we made the calculations according to data shown in Figure 8.18 and Tables 6.10 and 7.14, the expected value received from the government is *221 313 US$*∴An analogous situation occurs to $OREP_{CM}$ although according to Eqn 6.2.5.3.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

$OREP_{CM}$	13.0797	[$/kW$_e$]
$LCCCM_{WF_{OREG_{CM}}}$	2.7664	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	10	[yr]
CR_f	80.0%	[%]

Figure 8.19 $OREP_{CM}$ for 50MW$_e$ wind farm in Aracati (Brazil). Source: Own elaboration

The total $OREP_{CM}$ received by the hypothetical wind farm was calculated with the Eqn 8.3:

$$Total_{OREP_{CM}} = OREP_{CM}\ WF_{cap}\xi_{OREP_{CM}} \qquad [\$/kW_e] \qquad \text{Eqn (8.3)}$$

When we made the calculations according to data shown in Figure 8.19, the expected value received from the government is *163 497 US$.*

We have also considered the side of production, in other words, the AEP_{avail} from the wind project analyzed$\therefore$The REP_{CM} was developed according to Eqns 6.2.5.3 and 6.2.5.3.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

REP_{CM}	0.00002627	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5 695	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1496	[$/kW$_e$h]
ε_0	0.116883	[$/kW$_e$h]
n_{ε}	10	[yr]

Figure 8.20 REP_{CM} for 50MW$_e$ wind farm in Aracati (Brazil). Source: Own elaboration

According to Table G.8, the REP_{CM} of the wind farm in Aracati (Brazil) varies from *1 447 US$ kW$_e$h/yr* to *1 825 US$ kW$_e$h/yr* with *SD=117 US$ kW$_e$h* and *1 629 US$ kW$_e$h/yr (Mean)*$\therefore$The REP_{CM} has shown a *positive symmetry* distribution *(Υ=0.0838)* during the period of energy policy instrument.

In the years *10 (yr_{10})* and *1 (yr_1)*, we can notice the lowest and highest level of REP_{CM}, respectively. When we made the calculations according to data shown in Figure 8.20, the expected value received from the government during the period of the energy policy instrument is *16 285 US$.* We also have to remember the effect of the inflation rate *(2.5% per year)* on REP_{CM}.

The total REP_{CM} received by the hypothetical wind farm was calculated with the Eqn 8.4:

$$Total_{REP_{CM}} = \sum REP_{CM/yr}\ \xi_{REP_{CM}} \qquad [\$/kW_eh] \qquad \text{Eqn (8.4)}$$

Finally we development among the energy policy instruments analyzed, one regard to CO_2 *non-emissions,* defined as $GHG.R_{CM}$ $\therefore$ According to Eqns 6.2.5.4 and 6.2.5.4.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

$GHG.R_{CM}$	1 596.4321	[$/tCO$_2$]
$LCER_{CO_2}$	18.6	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail\ yr_1+...+yr_n}$	48 856	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0.00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ co_2}}$	0.00003	[tCO$_2$/MW$_e$h]
ε_c	46.3820	[$/tCO$_2$]

Figure 8.21 $GHG.R_{CM}$ for 50MW$_e$ wind farm in Aracati (Brazil). Source: Own elaboration

According to Table G.8, the $GHG.R_{CM}$ of the wind farm in Aracati (Brazil) varies from *221 US$/tCO$_2$ to 395 US$/tCO$_2$* with *SD=53 US$/tCO$_2$ and 300 US$/tCO$_2$ (Mean)* $\therefore$ The $GHG.R_{CM}$ has shown a *positive moderate asymmetry* distribution *(Υ=0.1961)* during the period of energy policy instrument.

In the years *1 (yr_1)* and *25 (yr_{25})*, we can notice the lowest and highest level of $GHG.R_{CM}$, respectively $\therefore$ When we made the calculations according to data shown in Figure 8.21, the expected value received from the government during the period of the energy policy instrument is *7 495 US$.* We also have to remember the effect of the inflation rate *(2.5% per year)* on $GHG.R_{CM}$.

The total $GHG.R_{CM}$ received by the hypothetical wind farm was calculated the following Eqn 8.5:

$$Total_{GHG.R_{CM}} = \sum GHG.R_{CM/yr}\ \xi_{GHG.R_{CM}} \qquad [US\$/tCO_2] \qquad \text{Eqn (8.5)}$$

8.3.3.2 FOR CORVO ISLAND (PORTUGAL)

The $LCOE_{wso}$ methodology organizes the investment costs without any kind of public incentive effect *(REPIM)* in $LCCCM_{WF}$ ∴ For the standard (base-case) situation the $LCCCM_{WF}$ has shown the following structure, as represented by Table 8.3:

Table 8.3 $LCCCM_{WF}$ breakdown structure for Corvo Island (Portugal)

Investment cost	*US$*	*%*
WT_{CM}	*27 686 278*	*46.0%*
T_{CM}	*24 219 295*	*40.2%*
$LWTG_{CM}$	*1 959 783*	*3.3%*
CP_{CM}	*1 545 346*	*2.6%*
TS_{CM}	*572 832*	*1.0%*
SI_{CM}	*2 136 726*	*3.5%*
PO_{CM}	*1 796 870*	*3.0%*
F_{CM}	*188 559*	*0.3%*
CCC_{CM}	*120 211*	*0.1%*
$LCCCM_{WF}$	*60 225 901*	*100.0%*

Source: Own elaboration

The capital cost per kW installed is about *1 204.52 US$/kW* and the most part is centralized in *wind turbines (46.0% for* WT_{CM}*)* and *towers (40.2% for* T_{CM}*)* ∴ It is also important to highlight the *local wind turbines grid (*$LWTG_{CM}$*), collecting point (*CP_{CM}*)* and *transmission system (*TS_{CM}*)* that represents about *7.0%* of the *total capital costs (6.9%).*

When we consider the effect of public incentive *(REPIM)* on initial investments in multi-megawatts wind farm (50 MW_e) we notice a *reduction around 0.81%*[156] and the $LCCCM_{WF}$ can reach the cost per kW about *1 194.79 US$/kW.*

When we make the comparison between Corvo Island (Portugal) and Aracati (Brazil) considering the different periods of $OREP_{CM}$ *(Brazil=10 yrs and Portugal=15 yrs)* the impact on $LCCCM_{WF}$ (initial investment) reduce in a few more ∴ An increasing of 26.4% is noticed on initial investment *(from 0.64% to 0.81%)* ∴ The reduction on $LCCCM_{WF}$ changes from *7.6962 US$/kW* to *9.7300 US$/kW.* We can probably confirm that the period on the energy policy instrument makes a sensible difference on the results of competitiveness of RETs.

[156] In $LCOE_{wso}$ methodology, the *REPIM* instruments applied to Corvo Island (Portugal) are calculated considering the base-case defined in Tables 7.13 and 7.14.

The *AAR* of the hypothetical wind farm is shown in Figure 8.22 within its particularities and behavior∴We have calculated the *AAR per year* according to Eqn. 7.1 with the conditions defined in Table 7.10.

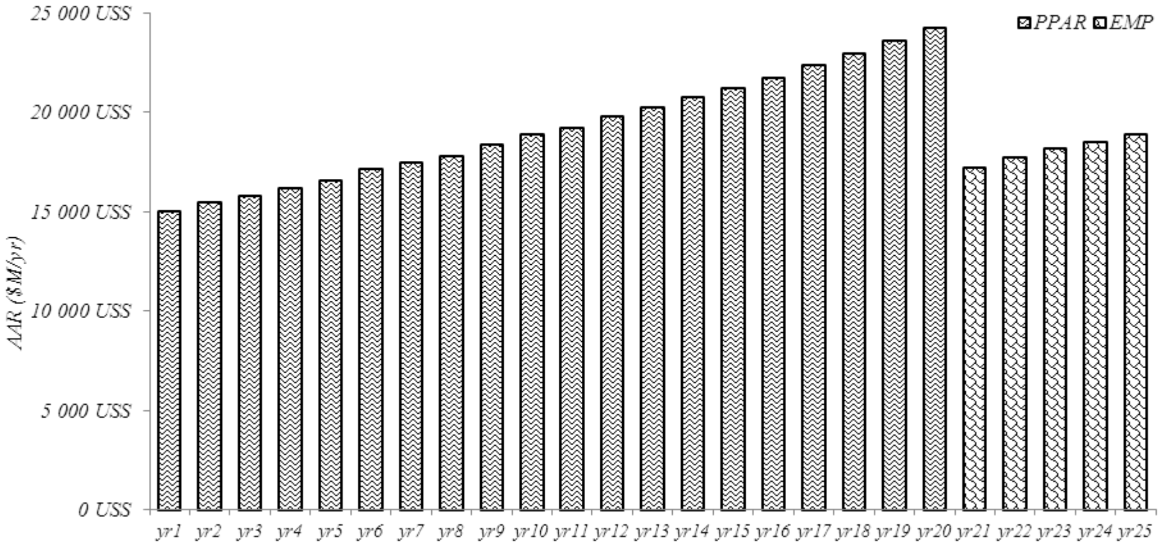

Figure 8.22 *AAR (US$M/yr)* during the lifetime of the 50MW$_e$ wind farm in Corvo Island (Portugal). Source: Own elaboration

According to Figure 8.22, the *AAR* of the wind farm in Corvo Island (Portugal) varies from *14 970 925 US$M/yr* to *24 203 932 US$M/yr* with *SD=2 524 373 US$M and 18 990 481 US$M/yr (Mean)*∴The *AAR* has shown a *positive moderate asymmetry* distribution *(ϒ=0.4655)* during the wind farm lifetime *(N=25yrs)*.

In the *years 1 (yr$_1$)* and *20 (yr$_{20}$)*, we can notice the lowest and highest level of revenue, respectively∴This wind power plant expects to receive as total *AAR* about *474 762 014 US$M* during the operational phase∴The relation between the total *AAR* and *LCPM$_{WF}$* is *0.210924 US$* per kWh produced∴We have to remember the effect of the inflation rate *(2.5% per year)* on revenues.

When we compare *AAR* of Corvo Island (Portugal) and Aracati (Brazil) considering the different annual wind speed *(Brazil=7.4 m/s and Portugal=9.1 m/s)* (see Table 8.1) and *PPAR*s *(Brazil=0.08581 US$/kWh and Portugal=0.16291 US$/kWh)* (see Table 7.10) the impact on *AAR* is tremendous∴An increasing is noticed on *total AAR (from 134 959 772 US$M to 474 762 014 US$M)*∴The increasing of *23%* and *89.8% in wind speed* and *PPAR, respectively,* reflects in an *increasing* of *251.8%* on *total AAR*.

The *$O\&M_{WFCM}$* of the hypothetical wind farm is shown in Figure 8.23 within its particularities and behavior∴We have calculated the *$O\&M_{WFCM}$ per year* according to Eqns 6.2.3, 6.2.3.1 and 6.2.3.2 with the conditions defined in Tables 7.11 and 7.12.

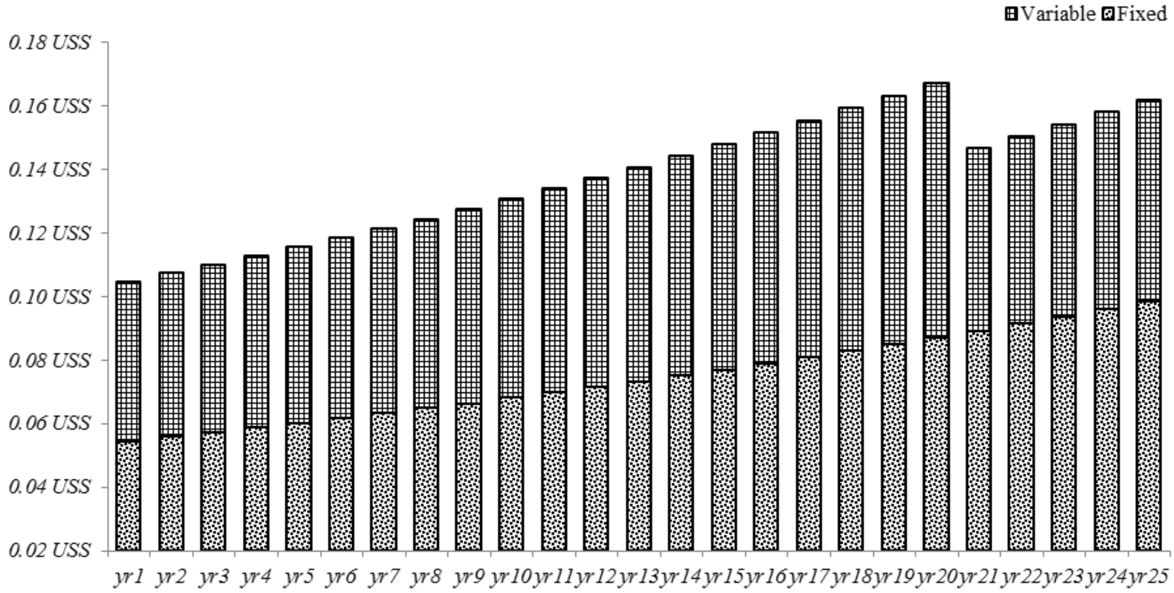

Figure 8.23 *$O\&M_{WFCM}$* splited into *fixed ($O\&M_{fixed_{CM}}$)* and *variable ($O\&M_{variable_{CM}}$)* during the lifetime of the $50MW_e$ wind farm in Corvo Island (Portugal). Source: Own elaboration

As we can see in Figure 8.23, the *$O\&M_{WFCM}$* of the wind farm in Corvo Island (Portugal) varies from *0.0969 US$ kWh/yr* to *0.1549 US$ kWh/yr* with *SD=0.0180 US$ kWh* and *0.1280 US$ kWh/yr (Mean)*∴The *$O\&M_{WFCM}$* has shown a *negative moderate asymmetry* distribution *(Υ=-0.2251)* during the wind farm lifetime *(N=25yrs)*.

In the years *1 (yr_1)* and *20 (yr_{20})*, we can notice the lowest and highest level of *$O\&M_{WFCM}$*, respectively∴This wind power plant expects to spend as total *$O\&M_{WFCM}$* about *309 664 717 US$M* during the operational phase∴The relation between the total *$O\&M_{WFCM}$* and *$LCPM_{WF}$* is *0.137576 US$* per kWh produced. We also have to remember the effect of the inflation rate *(2.5% per year)* on O&M costs.

The *$O\&M_{WFCM}$* in Corvo Island (Portugal) and Aracati (Brazil) shows some particularities∴The cost per kWh produced as not high as the increasing of *$LCPM_{WF}$* (see Figure 8.13 and Table 8.1). Within the level of total energy production *(1 215 GWh for Aracati and 2 251 for Portugal) and the average of $O\&M_{WFCM}$ (0.108080 US$/kWh for Aracati and 0.137576 US$/kWh)*, which represents an increasing of *27.3%* on *$O\&M_{WFCM}$*.

The *LRCM* of the hypothetical wind farm is shown in Figure 8.24 within its particularities and behavior∴We have calculated the *LRCM per year* according to Eqns 6.2.2, 6.2.2.1, 6.2.2.1.1, 6.2.2.1.2, 6.2.2.2, and 6.2.2.2.1 with the conditions defined in Table 6.8.

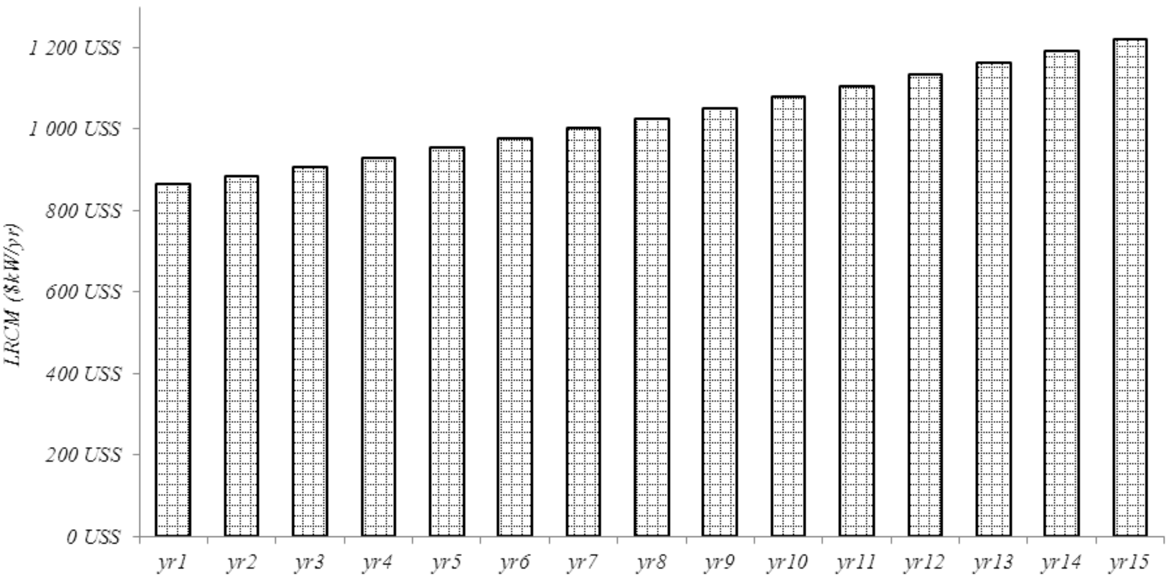

Figure 8.24 *LRCM* during the 15 years of the $50MW_e$ wind farm in Corvo Island (Portugal). Source: Own elaboration

As shown in Figure 8.24, the *LRCM* of the wind farm in Corvo Island (Portugal) varies from *863 268 US$ kW/yr* to *1 219 776 US$ kW/yr* with *SD=109 970 US$ kW and 1 032 004 US$ kW/yr (Mean)*∴The *LRCM* has shown a *positive symmetric* distribution *(ϒ=0.1407)* during the wind farm lifetime *(N=25yrs)*.

In the years *1 (yr_1)* and *15 (yr_{15})*, we can notice the lowest and highest level of *LRCM savings*, respectively∴This wind power plant expects to save as total *LRCM* about *15 480 065 US$* during 15 years of the operational phase∴The relation between the total *LRCM* and *kW produced* in 15 years is *182.0645 US$* per kW produced∴We also have to remember the effect of the inflation rate *(2.5% per year)* on *LRCM*.

We have notice the same figure for *LRCM* both to Aracati (Brazil) and Corvo Island (Portugal) which seems to be the way this sub model was developed∴We can find the *same value per kW installed (16.8443 US$/kW)* and some initial aspects of this part of $LCOE_{wso}$ methodology:

1. The *LRCM* can work as an *economic reserve*, independent of *AAR* and $LCPM_{WF}$;
2. The *LRCM* is not driven by the *price of electricity sold (PPAR)* – the wind farm developer or manager can create the *"best cost strategy"* independent of the *price and the level of production of the wind farm*.

The RCM_{WF} of the hypothetical wind farm is shown in Figure 8.25 within its particularities and behavior∴We have calculated the *RCM_{WF} per year* according to Eqns 6.2.4, 6.2.4.1, 6.2.4.1.1, 6.2.4.1.2, 6.2.4.1.3, 6.2.4.2, 6.2.4.2.1, 6.2.4.2.2 and 6.2.4.3 with the conditions defined in Tables 6.8 and 6.9.

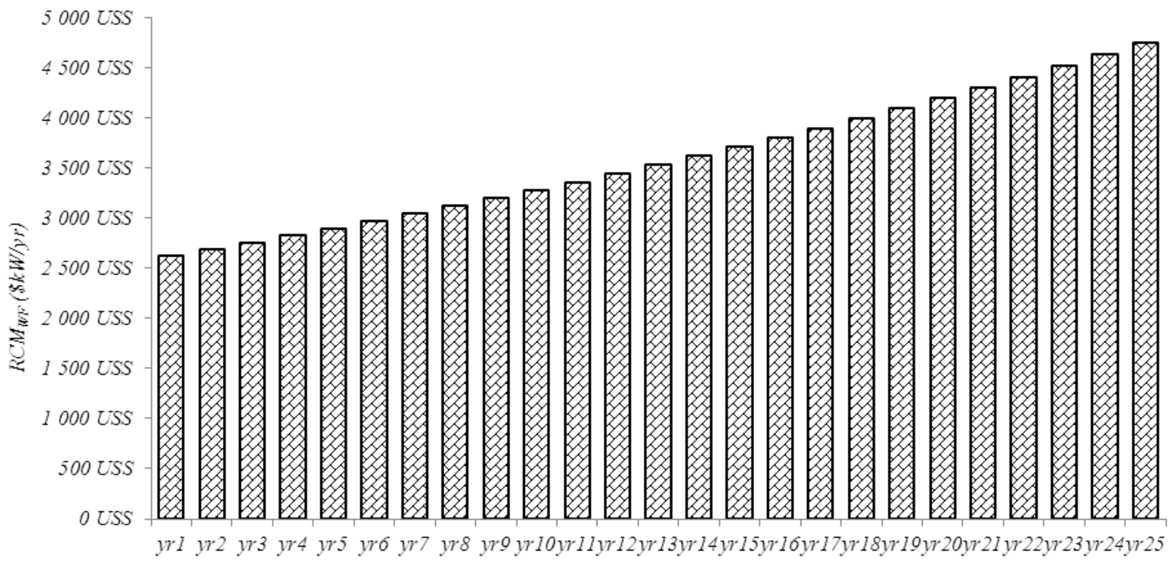

Figure 8.25 RCM_{WF} during the lifetime of the $50MW_e$ wind farm in Corvo Island (Portugal). Source: Own elaboration

According to Figure 8.25, the RCM_{WF} of the wind farm in Corvo Island (Portugal) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW and 3 582 109 US$ kW/yr (Mean)*∴The RCM_{WF} has shown a *positive moderate asymmetry* distribution *(ϒ=0.2259)* during the wind farm lifetime *(N=25yrs)*.

In the years *1 (yr_1)* and *25 (yr_{25})*, we can notice the lowest and highest level of *RCM_{WF} savings*, respectively∴his wind power plant expects to save as total RCM_{WF} about *89 552 736 US$* during the operational phase∴he relation between the total RCM_{WF} and *kW produced* in 25 years is *1 053 US$* per kW produced∴We also have to remember the effect of the inflation rate *(2.5% per year)* on RCM_{WF}.

The RCM_{WF} was developed in order to cover the costs of removing the wind farm and *"rebuild"* the local environment conditions, so when we get a *value equal or equivalent* amount of funds for cover the costs of decommissioning the wind farm, which is the purpose of this indicator! In the case of the hypothetical wind farm in Corvo Island (Portugal) if we have consider the total *$LCCCM_{WF}$ (60 225 901 US$)* added to *LRCM (15 480 065 US$)*, the RCM_{WF} about *89 552 736 US$* really covers it *(75 705 966 US$ < 89 552 736 US$)*.

For RCM_{WF} we have noticed the same conditions and conclusions of *LRCM* that is why we do not comment again (see page 329 of this Chapter).

As we have already said the *REPIM or Renewable Energy Public Incentive Model* is a part of the proposed $LCOE_{wso}$ methodology that measures the impact of some and *most common kinds of energy policy instruments applied to RETs*∴We have proposed four different types of instruments: two of them are related to investment incentive *(REI_{CM} and $OREP_{CM}$)* and the others are related to energy production *(REP_{CM} and $GHG.R_{CM}$).*

The REI_{CM} of the hypothetical wind farm is shown in Figure 8.26 within its particularities and behavior∴We have calculated the REI_{CM} *for initial year of the wind project (yr=0)* according to Eqns 6.2.5.1with the conditions defined in Tables 6.10 and 7.14.

REI_{CM}	70.8203	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_{ψ}	6	[yr]

Figure 8.26 REI_{CM} for 50MW$_e$ wind farm in Corvo Island (Portugal). Source: Own elaboration

The total REI_{CM} received by the hypothetical wind farm was also calculated with the Eqn 8.2. When we made the calculations according to data shown in Figure 8.26 and Tables 6.10 and 7.14, the expected value received from the government is *221 313 US$*∴An analogous situation occurs to $OREP_{CM}$ although according to Eqn 6.2.5.3.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

$OREP_{CM}$	21.2151	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	2.4451	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	15	[yr]
CR_f	80.0%	[%]

Figure 8.27 $OREP_{CM}$ for 50MW$_e$ wind farm in Corvo Island (Portugal). Source: Own elaboration

The total $OREP_{CM}$ received by the hypothetical wind farm was also calculated with the Eqn 8.3. When we made the calculations according to data shown in Figure 8.27, the expected value received from the government is *265 188 US$.*

As we already said the side of production is considered, in other words, the AEP_{avail} from the wind project analyzed $\therefore$ The REP_{CM} was developed according to Eqns 6.2.5.3 and 6.2.5.3.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

REP_{CM}	0.00002627	[\$/kW$_e$h]
AEP_{avail}/H_{prod}	5 695	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1496	[\$/kW$_e$h]
ε_0	0.116883	[\$/kW$_e$h]
n_ε	10	[yr]

Figure 8.28 REP_{CM} for 50MW$_e$ wind farm in Corvo Island (Portugal). Source: Own elaboration

According to Table G.9, the REP_{CM} of the wind farm in Corvo Island (Portugal) varies from *939 US\$ kW$_e$h/yr* to *1 325 US\$ kW$_e$h/yr* with *SD=119 US\$ kW$_e$h* and *1 125 US\$ kW$_e$h/yr (Mean)* $\therefore$ The REP_{CM} has shown a *positive symmetry* distribution *(Υ=0.1260)* during the period of energy policy instrument.

In the years *15 (yr_{15})* and *1 (yr_1)*, we can notice the lowest and highest level of REP_{CM}, respectively $\therefore$ When we made the calculations according to data shown in Figure 8.28, the total expected value received from the government during the period of the energy policy instrument is *16 879 US\$* (calculated with Eqn 8.4) $\therefore$ We also have to remember the effect of the inflation rate *(2.5% per year)* on REP_{CM}.

Finally we also development among the energy policy instruments analyzed, one regard to *CO_2 non-emissions*, defined as $GHG.R_{CM}$. According to Eqns 6.2.5.4 and 6.2.5.4.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

$GHG.R_{CM}$	821.1245	[\$/tCO$_2$]
$LCER_{CO_2}$	34.1	[tCO$_2$/MW$_e$h
$\sum AEP_{avail\ yr_1+...+yr_n}$	89 657	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0.00041	[tCO$_2$/MW$_e$h
$GHG_{EM_{wecs\ CO_2}}$	0.00003	[tCO$_2$/MW$_e$h
ε_c	13.0000	[\$/tCO$_2$]

Figure 8.29 $GHG.R_{CM}$ for 50MW$_e$ wind farm in Corvo Island (Portugal). Source: Own elaboration

According to Table G.9, the $GHG.R_{CM}$ of the wind farm in Corvo Island (Portugal) varies from *113 US\$/tCO₂ to 204 US\$/tCO₂* with *SD=28 US\$/tCO₂* and *156 US\$/tCO₂ (Mean)*∴The $GHG.R_{CM}$ has shown a *positive moderate asymmetry* distribution *(Ƴ=0.1985)* during the period of energy policy instrument.

In the years *1 (yr_1)* and *25 (yr_{25})*, we can notice the lowest and highest level of $GHG.R_{CM}$, respectively∴When we made the calculations according to data shown in Figure 8.29, the total expected value received from the government during the period of the energy policy instrument is *3 893 US\$* (calculated with Eqn 8.5)∴We also have to remember the effect of the inflation rate *(2.5% per year)* on $GHG.R_{CM}$.

In order to compare the *REPIM* results between Aracati (Brazil) and Corvo Island (Portugal) we have resumed in Table 8.4.

Table 8.4 Comparison of *REPIM* in relation to Aracati (Brazil) and Corvo Island (Portugal)

Instrument	*Unit*	*Aracati (Brazil)*	*Corvo Island (Portugal)*
REI_{CM}	US\$/kW_e	221 313	221 313
REP_{CM}	US\$/kW_eh	16 285	16 879
$OREP_{CM}$	US\$/kW_e	163 497	265 188
$GHG.R_{CM}$	US\$/tCO_2	7 495	3 893

Source: Own elaboration

A brief analysis can be taken from the results shown in Table 8.4:

1. Some of most interesting is the $GHG.R_{CM}$ that is *strongly* influenced by the *price of* tCO_2 paid by government per kWh produced in the wind farm∴For example the *price in US\$* for Aracati (Brazil) considered was *46.3820 US\$/*tCO_2 and Corvo Island (Portugal) was *13 US\$/*tCO_2∴The difference of *33.3820 US\$/*tCO_2 was big enough to overcome the higher level of energy production and better local wind resources (see Table 8.1);

2. In the case of $OREP_{CM}$ another important aspect must be explained, the period considering for the energy policy instrument applied to the energy project *(Aracati-Brazil=10 yrs and Corvo Island-Portugal=15 yrs);*

3. Energy policy maker have to take into consideration the *price of* CO_2, *the periodicity of the instrument analyzed* and *the wind resources*, geographically defined in the legislation proposed to the renewable energy producers.

8.3.3.3 FOR CAPE SAINT JAMES (CANADA)

As we have said yet the $LCOE_{wso}$ methodology organizes the investment costs without any kind of public incentive effect *(REPIM)* in $LCCCM_{WF}$ ∴ For the standard (base-case) situation the $LCCCM_{WF}$ has shown the following structure, as represented by Table 8.5:

Table 8.5 $LCCCM_{WF}$ breakdown structure for Cape Saint James (Canada)

Investment cost	*US$*	*%*
WT_{CM}	*27 686 278*	*46.0%*
T_{CM}	*24 219 295*	*40.2%*
$LWTG_{CM}$	*1 959 783*	*3.3%*
CP_{CM}	*1 545 346*	*2.6%*
TS_{CM}	*572 832*	*1.0%*
SI_{CM}	*2 136 726*	*3.5%*
PO_{CM}	*1 796 870*	*3.0%*
F_{CM}	*188 559*	*0.3%*
CCC_{CM}	*120 211*	*0.1%*
$LCCCM_{WF}$	*60 225 901*	*100.0%*

Source: Own elaboration

In the same conditions of investment as Aracati (Brazil), Corvo Island (Portugal) the capital cost per kW installed for Cape Saint James (Canada) is about *1 204.52 US$/kW* and the most part is centralized in *wind turbines (46.0% for* WT_{CM}*)* and *towers (40.2% for* T_{CM}*)*. It is also important to highlight the *local wind turbines grid (*$LWTG_{CM}$*)*, *collecting point (*CP_{CM}*)* and *transmission system (*TS_{CM}*)* that represents about *7.0%* of the *total capital costs (6.9%).*

Analogous to the two other sites when we consider the effect of public incentive *(REPIM)* on initial investments in multi-megawatts wind farm (50 MW_e) we notice a *reduction around 1.55%*[157] and the $LCCCM_{WF}$ can reach the cost per kW about *1 185.87 US$/kW.*

In comparison to Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) and the different periods of $OREP_{CM}$ *(Brazil and Canada=10 yrs; Portugal=15 yrs)* the impact on $LCCCM_{WF}$ (initial investment) for the wind farm in Cape Saint James (Canada) reduce more than the other two cited ∴ In relation to Corvo Island (Portugal) there is an increasing of *91.6%* and *142.3%* to Aracati (Brazil), respecfully ∴ The reduction on $LCCCM_{WF}$ changes from *7.6962 US$/kW* to *18.6466 US$/kW.*

[157] In $LCOE_{wso}$ methodology, the *REPIM* instruments applied to Cape Saint James (Canada) are calculated considering the base-case defined in Tables 7.13 and 7.14.

The *AAR* of the hypothetical wind farm is shown in Figure 8.30 within its particularities and behavior∴We have calculated the *AAR per year* according to Eqn. 7.1 with the conditions defined in Table 7.10.

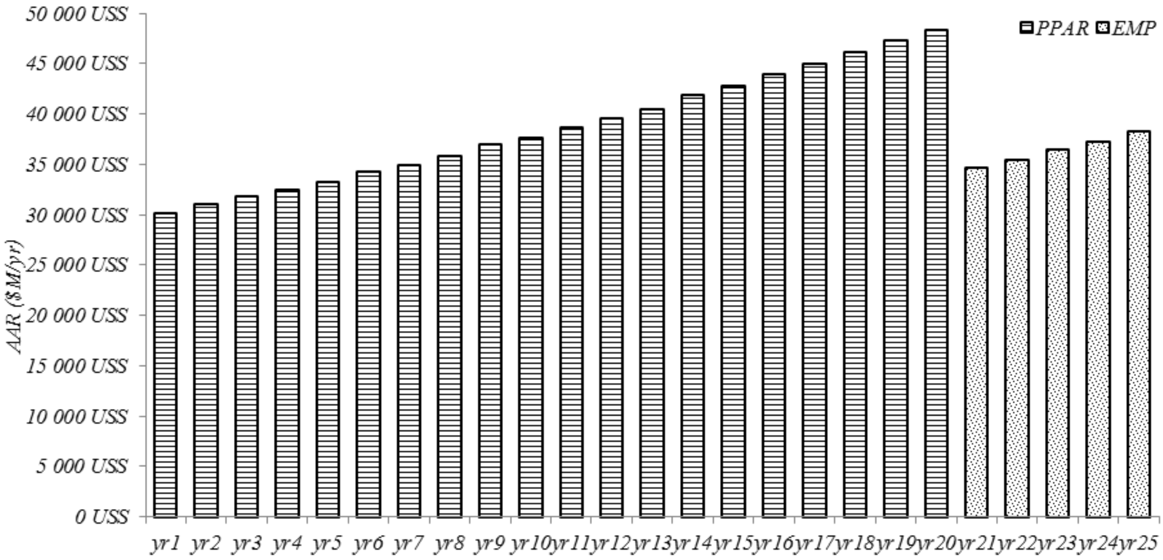

Figure 8.30 *AAR (US\$M/yr)* during the lifetime of the 50MW$_e$ wind farm in Cape Saint James (Canada). Source: Own elaboration

According to Figure 8.30, the *AAR* of the wind farm in Cape Saint James (Canada) varies from *30 129 143 US\$M/yr* to *48 311 614 US\$M/yr* with *SD=5 069 795 US\$M* and *38 174 169 US\$M/yr (Mean).* The *AAR* has shown a *positive moderate asymmetry* distribution *(ϒ=0.4408)* during the wind farm lifetime *(N=25yrs).*

In the *years 1* (yr_1) and *20* (yr_{20}), we can notice the lowest and highest level of revenue, respectively. This wind power plant expects to receive as total *AAR* about *954 354 217 US\$M* during the operational phase. The relation between the total *AAR* and $LCPM_{WF}$ is *0.179126 US\$* per kWh produced. We have to remember the effect of the inflation rate *(2.5% per year)* on revenues.

When we compare *AAR* of Cape Saint James (Canada) with Corvo Island (Portugal) and Aracati (Brazil) considering the different annual wind speed *(Brazil=7.4 m/s, Portugal=9.1 m/s* and *Canada=12.5 m/s)* (see Table 8.1) and *PPAR*s *(Brazil=0.08581 US\$/kWh, Portugal=0.16291 US\$/kWh and Canada=0.13835 US\$/kWh)* (see Table 7.10) the impact on *AAR* is tremendous. An increasing is noticed on *total AAR (from 134 959 772 US\$M to 954 354 217 US\$M).* The increasing of *69.3%* and *61.2% in wind speed* and *PPAR, respectively,* reflects in an *increasing* of *607.1%* on *total AAR.*

The $O\&M_{WFCM}$ of the hypothetical wind farm is shown in Figure 8.31 within its particularities and behavior∴We have calculated the $O\&M_{WFCM}$ *per year* according to Eqns 6.2.3, 6.2.3.1 and 6.2.3.2 with the conditions defined in Tables 7.11 and 7.12.

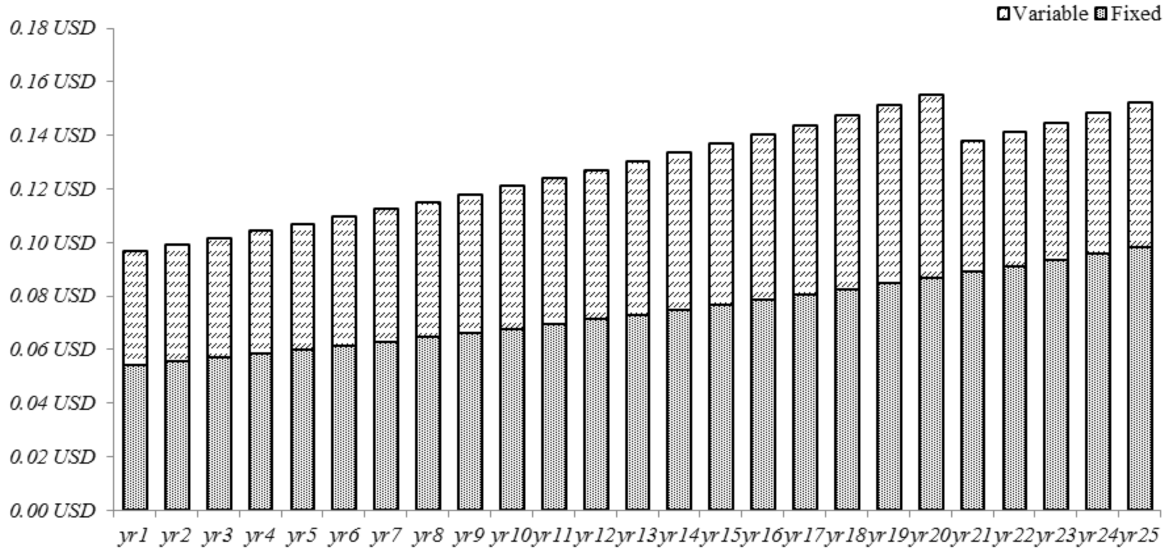

Figure 8.31 $O\&M_{WFCM}$ splited into *fixed* ($O\&M_{fixed_{CM}}$) and *variable* ($O\&M_{variable_{CM}}$) during the lifetime of the 50MW$_e$ wind farm in Cape Saint James (Canada). Source: Own elaboration

As we can see in Figure 8.31, the $O\&M_{WFCM}$ of the wind farm in Cape Saint James (Canada) varies from *0.0969 US$ kWh/yr* to *0.1549 US$ kWh/yr* with *SD=0.0180 US$ kWh* and *0.1280 US$ kWh/yr (Mean)*∴The $O\&M_{WFCM}$ has shown a *negative symmetric* distribution *(ϒ=0.1280)* during the wind farm lifetime *(N=25yrs)*.

In the years *1* (yr_1) and *20* (yr_{20}), we can notice the lowest and highest level of $O\&M_{WFCM}$, respectively∴This wind power plant expects to spend as total $O\&M_{WFCM}$ about *682 022 915 US$M* during the operational phase∴The relation between the total $O\&M_{WFCM}$ and $LCPM_{WF}$ is *0.128011 US$* per kWh produced. We also have to remember the effect of the inflation rate *(2.5% per year)* on O&M costs.

The $O\&M_{WFCM}$ in Cape Saint James (Canada), Corvo Island (Portugal) and Aracati (Brazil) shows some particularities∴The cost per kWh produced as not high as the increasing of $LCPM_{WF}$ (see Figure 8.13 and Table 8.1). *Within the level of total energy production (1 215 GWh for Aracati, 2 251 for Portugal and 5 328 GWh for Canada) and the average of* $O\&M_{WFCM}$ *(0.108080 US$/kWh for Aracati, 0.137576 US$/kWh for Portugal and 0.128011 US$/kWh for Canada),* which represents an increasing of *18.4%* on $O\&M_{WFCM}$ (in relation to Aracati-Brazil).

The *LRCM* of the hypothetical wind farm is shown in Figure 8.32 within its particularities and behavior∴We have calculated the *LRCM per year* according to Eqns 6.2.2, 6.2.2.1, 6.2.2.1.1, 6.2.2.1.2, 6.2.2.2, and 6.2.2.2.1 with the conditions defined in Table 6.8.

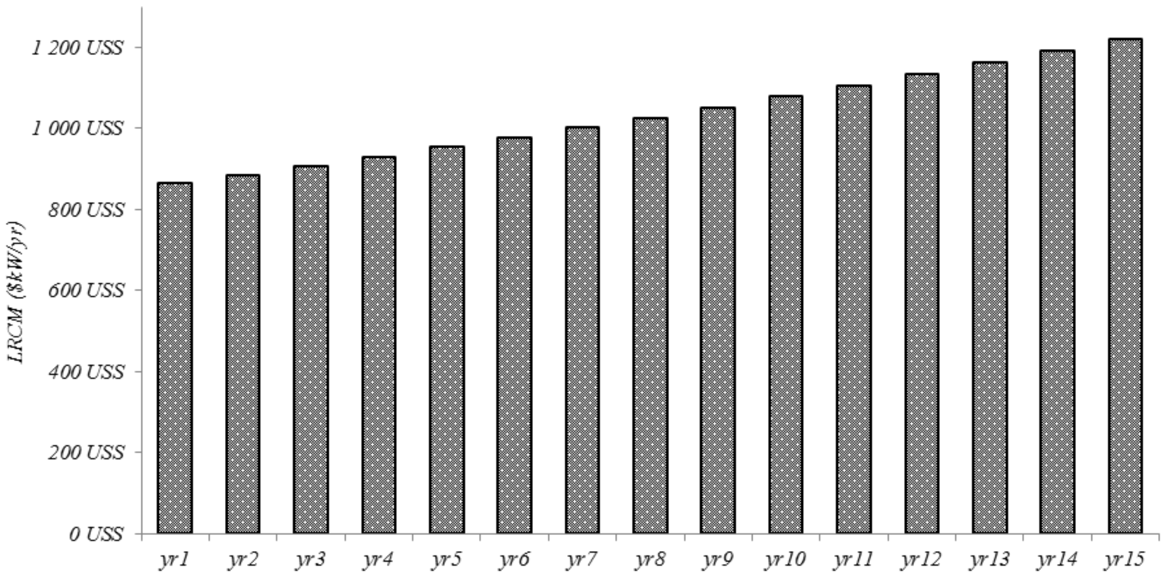

Figure 8.32 *LRCM* during the 15 years of the 50MW$_e$ wind farm in Cape Saint James (Canada). Source: Own elaboration

As shown in Figure 8.32, the *LRCM* of the wind farm in Cape Saint James (Canada) varies from *863 268 US$ kW/yr* to *1 219 776 US$ kW/yr* with *SD=109 970 US$ kW and 1 032 004 US$ kW/yr (Mean)*∴The *LRCM* has shown a *positive symmetric* distribution *(ϒ=0.1407)* during the wind farm lifetime *(N=25yrs)*.

In the years *1 (yr$_1$)* and *15 (yr$_{15}$)*, we can notice the lowest and highest level of *LRCM savings*, respectively∴This wind power plant expects to save as total *LRCM* about *15 480 065 US$* during 15 years of the operational phase. The relation between the total *LRCM* and *kW produced* in 15 years is *182.0645 US$* per kW produced∴We also have to remember the effect of the inflation rate *(2.5% per year)* on *LRCM*.

We have notice the same figure for *LRCM* in Cape Saint James (Canada), Aracati (Brazil) and Corvo Island (Portugal) which seems to be the way this sub model was developed∴We can find the *same value per kW installed (16.8443 US$/kW)* which can be understood as an *economic reserve*, independent of *AAR* and *LCPM$_{WF}$* and it is not driven by the *price of electricity sold (PPAR), so* wind farm developer or manager can create the *"best cost strategy"* independent of the *price and the level of production of the wind farm,* as we have already said before.

The RCM_{WF} of the hypothetical wind farm is shown in Figure 8.33 within its particularities and behavior∴We have calculated the RCM_{WF} *per year* according to Eqns 6.2.4, 6.2.4.1, 6.2.4.1.1, 6.2.4.1.2, 6.2.4.1.3, 6.2.4.2, 6.2.4.2.1, 6.2.4.2.2 and 6.2.4.3 with the conditions defined in Tables 6.8 and 6.9.

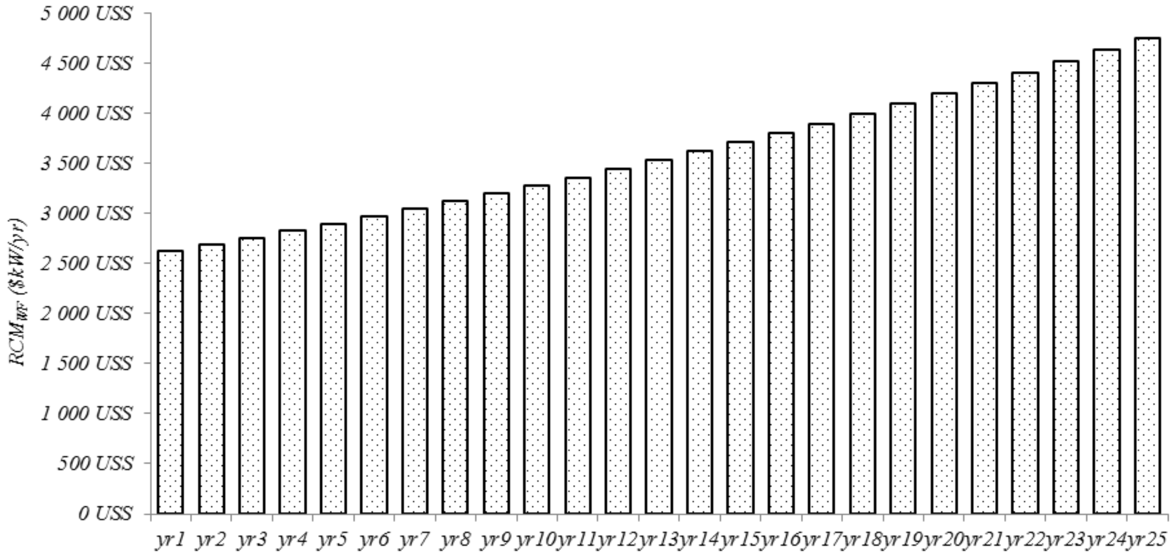

Figure 8.33 RCM_{WF} during the lifetime of the $50MW_e$ wind farm in Cape Saint James (Canada). Source: Own elaboration

According to Figure 8.33, the RCM_{WF} of the wind farm in Cape Saint James (Canada) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW and 3 582 109 US$ kW/yr (Mean)*∴The RCM_{WF} has shown a *positive moderate asymmetry* distribution *(ϒ=0.2259)* during the wind farm lifetime *(N=25yrs)*.

In the years *1 (yr_1)* and *25 (yr_{25})*, we can notice the lowest and highest level of RCM_{WF} *savings*, respectively∴This wind power plant expects to save as total RCM_{WF} about *89 552 736 US$* during the operational phase∴The relation between the total RCM_{WF} and *kW produced* in 25 years is *1 053 US$* per kW produced. We also have to remember the effect of the inflation rate *(2.5% per year)* on RCM_{WF}.

As we have discussed yet the RCM_{WF} was developed in order to cover the costs of removing the wind farm and *"rebuild"* the local environment conditions, so when we get a *value equal or equivalent* amount of funds for cover the costs of decommissioning the wind farm, which is the purpose of this indicator! In the case of the hypothetical wind farm in Cape Saint James (Canada) if we have consider the total $LCCCM_{WF}$ *(60 225 901 US$)* added to *LRCM (15 480 065 US$)*, the RCM_{WF} about *89 552 736 US$* really covers it *(75 705 966 US$ < 89 552 736 US$)*.

For RCM_{WF} in Cape Saint James (Canada) we have noticed the same conditions and conclusions of *LRCM* that is why we do not comment again (see page 329 of this Chapter).

For *REPIM model w*e have also applied four different types of instruments to the wind farm in Cape Saint James (Canada): two of them are related to investment incentive *(REI_{CM} and $OREP_{CM}$)* and the others are related to energy production *(REP_{CM} and $GHG.R_{CM}$).*

The REI_{CM} of the hypothetical wind farm is shown in Figure 8.34 within its particularities and behavior $\therefore$ We have calculated the REI_{CM} *for initial year of the wind project (yr=0)* according to Eqns 6.2.5.1with the conditions defined in Tables 6.10 and 7.14.

REI_{CM}	70.8203	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_{ψ}	6	[yr]

Figure 8.34 REI_{CM} for 50MW$_e$ wind farm in Cape Saint James (Canada). Source: Own elaboration

The total REI_{CM} received by the hypothetical wind farm was also calculated with the Eqn 8.2. When we made the calculations according to data shown in Figure 8.34 and Tables 6.10 and 7.14, the expected value received from the government is *221 313 US$* $\therefore$ An analogous situation occurs to $OREP_{CM}$ although according to Eqn 6.2.5.3.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

$OREP_{CM}$	56.8814	[$/kW$_e$]
$LCCCM_{WF_{OREG_{CM}}}$	2.7664	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	10	[yr]
CR_f	80.0%	[%]

Figure 8.35 $OREP_{CM}$ for 50MW$_e$ wind farm in Cape Saint James (Canada). Source: Own elaboration

The total $OREP_{CM}$ received by the hypothetical wind farm was also calculated with the Eqn 8.3. When we made the calculations according to data shown in Figure 8.35, the expected value received from the government is *711 018 US$.*

As we already said the side of production is considered, in other words, the AEP_{avail} from the wind project analyzed∴The REP_{CM} was developed according to Eqns 6.2.5.3 and 6.2.5.3.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

REP_{CM}	0.00000052	[$/kW$_e$h]
AEP_{avail}/H_{prod}	24 766	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0128	[$/kW$_e$h]
ε_0	0.009998	[$/kW$_e$h]
n_ε	10	[yr]

Figure 8.36 REP_{CM} for 50MW$_e$ wind farm in Cape Saint James (Canada). Source: Own elaboration

According to Table G.10, the REP_{CM} of the wind farm in Cape Saint James (Canada) varies from *125 US$ kW$_e$h/yr* to *156 US$ kW$_e$h/yr* with *SD=10 US$ kW$_e$h* and *140 US$ kW$_e$h/yr (Mean)*∴The REP_{CM} has shown a *positive symmetry* distribution *(Υ=0.1048)* during the period of energy policy instrument.

In the years *10 (yr_{10})* and *1 (yr_1)*, we can notice the lowest and highest level of REP_{CM}, respectively∴When we made the calculations according to data shown in Figure 8.36, the total expected value received from the government during the period of the energy policy instrument is *1 403 US$* (calculated with Eqn 8.4)∴We also have to remember the effect of the inflation rate *(2.5% per year)* on REP_{CM}.

Finally we also development among the energy policy instruments analyzed, one regard to *CO_2 non-emissions,* defined as $GHG.R_{CM}$∴According to Eqns 6.2.5.4 and 6.2.5.4.1 with the conditions defined in Tables 6.10, 7.13 and 7.14.

$GHG.R_{CM}$	4 490.4890	[$/t$CO_2$]
$LCER_{CO_2}$	80.7	[tCO_2/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	212 467	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0.00041	[tCO_2/MW$_e$h]
$GHG_{EM_{wecs\ co_2}}$	0.00003	[tCO_2/MW$_e$h]
ε_c	30.0000	[$/t$CO_2$]

Figure 8.37 $GHG.R_{CM}$ for 50MW$_e$ wind farm in Cape Saint James (Canada). Source: Own elaboration

According to Table G.10, the *GHG.R*$_{CM}$ of the wind farm in Cape Saint James (Canada) varies from *621 US\$/tCO*$_2$ *to 1 128 US\$/tCO*$_2$ with *SD=152 US\$/tCO*$_2$ and *851 US\$/tCO*$_2$ *(Mean).* The *GHG.R*$_{CM}$ has shown a *positive moderate asymmetry* distribution *(ϒ=0.2159)* during the period of energy policy instrument.

In the years *1 (yr*$_1$*)* and *25 (yr*$_{25}$*)*, we can notice the lowest and highest level of *GHG.R*$_{CM}$, respectively. When we made the calculations according to data shown in Figure 8.37, the total expected value received from the government during the period of the energy policy instrument is *21 268 US\$* (calculated with Eqn 8.5)$\therefore$We also have to remember the effect of the inflation rate *(2.5% per year)* on *GHG.R*$_{CM}$.

In order to better comprehension about *REPIM* mode through the results among Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) we have resumed the main values in the Table 8.6.

Table 8.6 Comparison of *REPIM* in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada)

Instrument	*Unit*	*Aracati (Brazil)*	*Corvo Island (Portugal)*	Cape Saint James (Canada)
REI$_{CM}$	*US\$/kW*$_e$	*221 313*	*221 313*	*221 313*
REP$_{CM}$	*US\$/kW*$_e$*h*	*16 285*	*16 879*	*1 403*
OREP$_{CM}$	*US\$/kW*$_e$	*163 497*	*265 188*	*711 018*
GHG.R$_{CM}$	*US\$/tCO*$_2$	*7 495*	*3 893*	*21 268*

Source: Own elaboration

A conclusive analysis can be taken from the results shown in Table 8.6:

1. The *REI*$_{CM}$ is not dependent of the *level of production (LCPM*$_{WF}$*)*, *local wind speed* at a *constant percentage (*ψ_{total}*)* and *period of the energy policy instrument (* n_Ψ *)*;

2. On *REP*$_{CM}$ the impact is *more effective* in function of the *value paid by government (* ε_0 *)* *than the time of policy energy instrument (* n_ε *)*$\therefore$Although the wind farm in Cape Saint James (Canada) presents much more potential production *(LCPM*$_{WF}$*)* (see Figure 8.13 and Table 8.1) but the value paid is the lowest (see Table 7.14);

3. The *OREP*$_{CM}$ is driven by the *period of the energy policy instrument (n*$_\psi$*)* and *AEP*$_{avail}$ what can be justified the highest *value paid* to the wind far in Cape Saint James (Canada), even this government adopts the lowest *value paid*;

4. For *GHG.R*$_{CM}$ we can see analogous situation, but the *lowest value* paid is in Corvo Island (Portugal).

8.4 SENSITIVITY ANALYSIS RESULTS

8.4.1 INDIVIDUAL VARIABLE SENSITIVITIES

8.4.1.1 IMPACT ON $LCOE_{WSO}$ OF WIND SPEED (V_{WC})

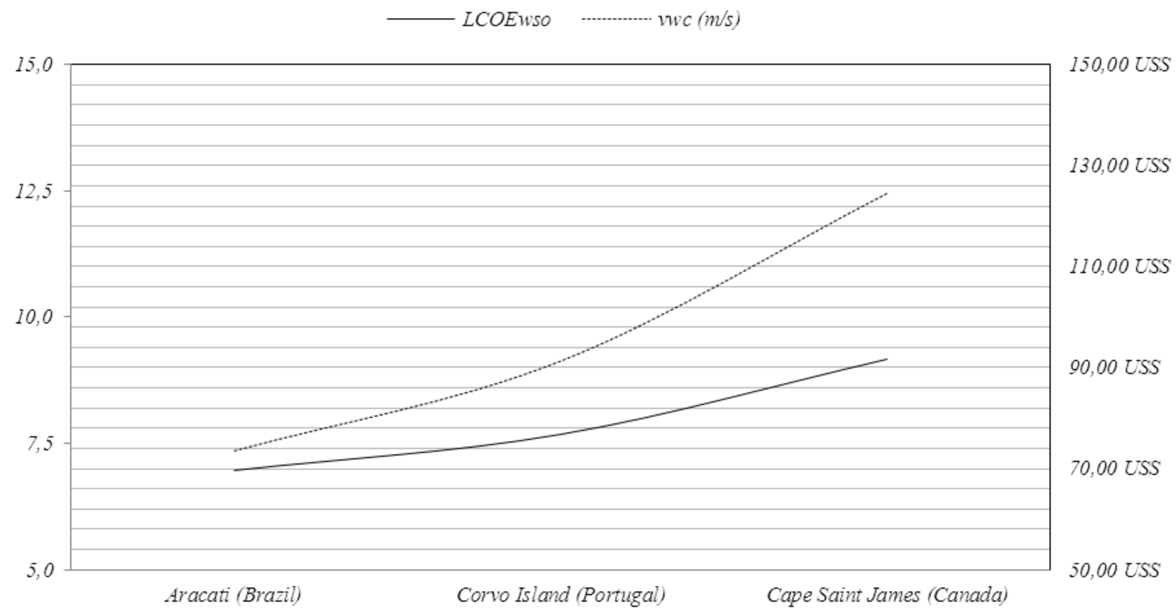

Figure 8.38 Impact on $LCOE_{wso}$ of wind speed (v_{wc}). Source: Own elaboration

The relation between $LCOE_{wso}$ and *wind speed* (v_{wc}) as *we can understand* from the Figure 8.38 *seems to present* a *partial inverse relation* ∴ We can state that it works like the same principle of *economy of scale.* As has said Rosa (2009) the *AEP* from WECS is the cube of wind speed, that is why the local wind resources where the wind farm will be installed is a *fundamental question* for this type of RETs.

For these three different sites, we have noticed that when *wind speed* (v_{wc}) *increases in 23.0%,* we get *10.2%* of increasing on $LCOE_{wso}$ (from Aracati-Brazil to Corvo Island-Portugal) ∴ The same situation occurs in relation to Corvo Island (Portugal) and Cape Saint James (Canada) when the *wind speed increases 37.4%* reflects and *increases 19.4% on* $LCOE_{wso}$ (see Table 8.7).

Table 8.7 Sensitivity analysis between $LCOE_{wso}$ and v_{wc}

Items	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
$LCOE_{wso}$	*69.6792*	*76.8138*	*91.7081*
v_{wc} *(m/s)*	*7.4*	*9.1*	*12.5*

Source: Own elaboration. Note: according to Tables 6.5 and 7.5.

8.4.1.2 IMPACT ON $LCOE_{WSO}$ OF OPERATIONS AND MAINTENANCE MANAGEMENT *($O\&M_{MANAG}$)*

According to Obdam, Braam, Rademakers, and Eecen (2007) O&M costs of wind farms contribute significantly to the energy production costs∴Reliable estimates of these costs are required during planning and operation of the wind farm at several stages. Such estimates however have a large spread and are uncertain.

These O&M costs and strategies can oscillate during the lifetime of the wind farm and the impact on LCOE assumes a similar behavior∴In our methodology the $O\&M_{MANAG}$ has also impact on $LCOE_{wso}$ and wind farm availability∴Figure 8.39 shows the results of $LCOE_{wso}$ due to the strategy simulated in the sensibility analysis done according to Table 7.12.

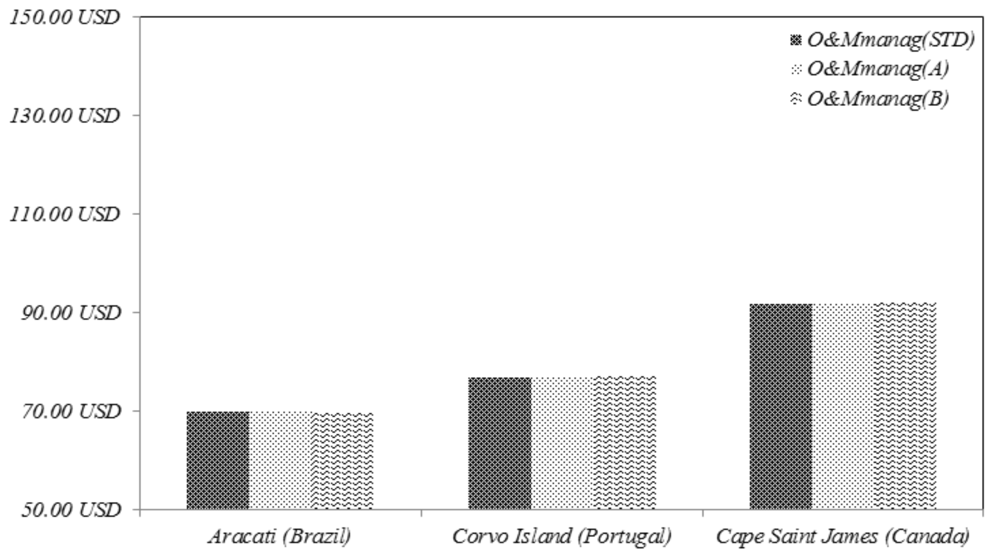

Figure 8.39 Resume of sensitivity analysis of $LCOE_{wso}$ and $O\&M_{manag}$ for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration

We focused our Ph.D. research work on $LCOE_{wso}$ impact when is considered different strategies for *O&M management* in the wind farms analyzed∴As we have defined in Chapter 7, section 7.6.2 *(optimization criteria)*, the optimization moment is related finding (calculating) the *lowest* $LCOE_{wso}$ as possible.

Table 8.8 shows the results and effects on $LCOE_{wso}$ due to the $O\&M_{manag}$ programs (strategies) tested by the sensitivity analysis done∴We also highlight the *"best option"* to choose about O&M strategy to follow.

The *wind farm availability* increases in *0.44% for* $O\&M_{manag(A)}$ and *0.24% for* $O\&M_{manag(B)}$ in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Figure 8.40 shows the availability for each site and strategy considered.

Table 8.8 Sensitivity analysis between $LCOE_{wso}$ and $O\&M_{manag}$

	Strategies	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
$LCOE_{wso}$	$O\&M_{manag(STD)}$	*69.6873 US$/MWh*	*76.8138 US$/MWh*	*91.7081 US$/MWh*
	$O\&M_{manag(A)}$	*69.6991 US$/MWh*	*76.8666 US$/MWh*	*91.8264 US$/MWh*
	$O\&M_{manag(B)}$	*69.6873 US$/MWh*	*76.8666 US$/MWh*	*91.7691 US$/MWh*

Source: Own elaboration

When we analyze the effect of $O\&M_{manag}$ on $LCOE_{wso}$ for each site, we get some interesting aspects to be understood∴Fisrt of all, we have considered as base for comparison the $O\&M_{manag(STD)}$∴We possible conclude about $O\&M_{manag}$ such considerations:

1. In the case of Aracati (Brazil) the option $O\&M_{manag(B)}$ can be adopted, because there is no effect on the $LCOE_{wso}$, but if we get the $O\&M_{manag(A)}$ the cost of electricity produced increases in *0.02%*;
2. For Corvo Island (Portugal) both $O\&M_{manag(A)}$ and $O\&M_{manag(B)}$ increase the $LCOE_{wso}$ in *0.07%.* The $O\&M_{manag(STD)}$ is the optimized strategy for O&M costs;
3. In Cape Saint James (Canada) occurs the same situation of Corvo Island (Portugal), but we get an increasing of *0.13% for* $O\&M_{manag(A)}$ and *0.07% for* $O\&M_{manag(B)}$. Also the $O\&M_{manag(STD)}$ is the optimized strategy for O&M costs.

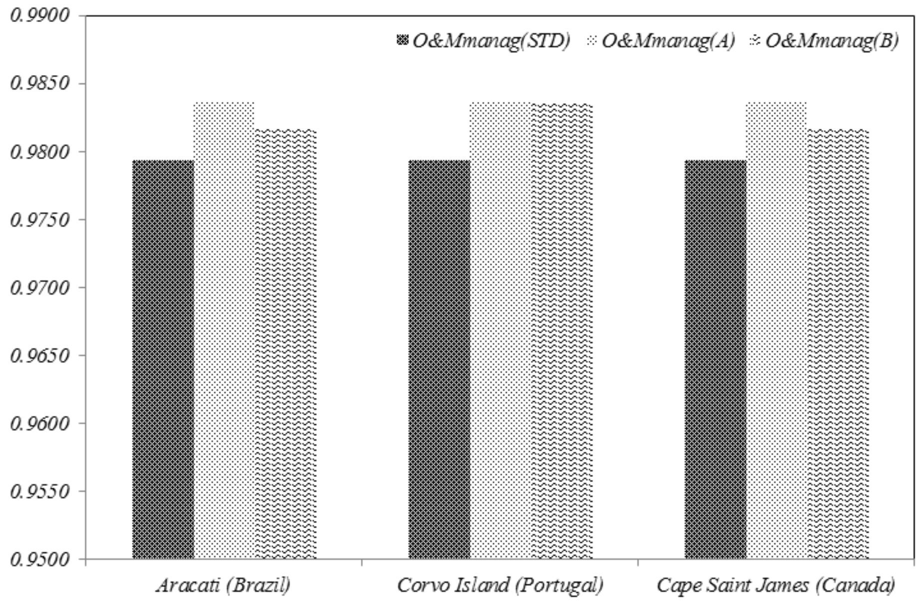

Figure 8.40 Resume of sensitivity analysis of $O\&M_{manag}$ and *wind farm availability* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration

8.4.1.3 IMPACT ON $LCOE_{WSO}$ OF WIND TURBINES LAYOUT *(L_{WT})*

As has discussed by Eriksson (2008) is important to look at different wind farm layouts and compare the reliability and the investment between the alternatives, since it is hard to interpret the result from a reliability calculation for a single layout without comparing it to alternatives.

In $LCOE_{wso}$ methodology the L_{wt} has also impact on the costs of the wind farm as a whole. Figure 8.41 shows the results of $LCOE_{wso}$ due to the alternative wind farm layouts *(5D4D, 5D7D, 5D10D and 6D12D)* simulated in the sensibility analysis done according to Table 6.5.

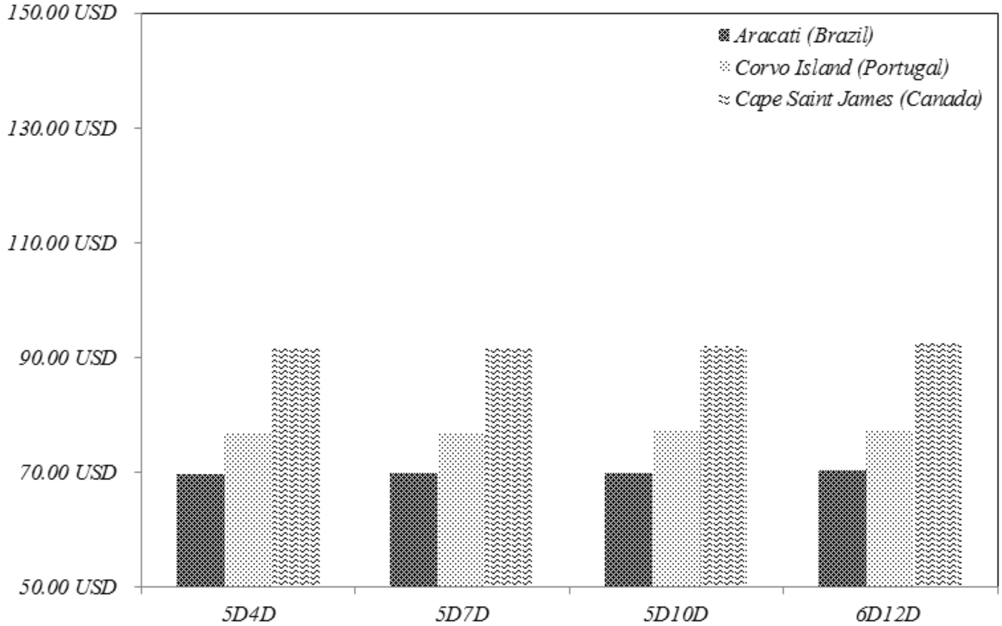

Figure 8.41 Resume of sensitivity analysis of $LCOE_{wso}$ and L_{wt} for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration

We focused our Ph.D. research work on $LCOE_{wso}$ impact when is considered alternative layouts for L_{wt} variable in the wind farms analyzed$\therefore$As we have defined in Chapter 7, section 7.6.2 (optimization criteria), the optimization moment is related finding (calculating) the *lowest $LCOE_{wso}$* as possible$\therefore$Table 8.9 shows the results and effects on $LCOE_{wso}$ due to L_{wt} alternatives tested by the sensitivity analysis done$\therefore$We also highlight the *"best option"* to choose of L_{wt} to be implemented.

As we can see at Figure 8.42 the wind turbines layout impacts on $LCCCM_{WF}$ because the *distances between the wind turbines, dimension of local wind turbines grid (LWTG)* and correlated capital costs influenced by L_{wt} for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada)$\therefore$The *5D7D, 5D10D and 6D12D layouts* can increase the $LCCCM_{WF}$ in *0.25%, 0.51% and 1.10%*, respectively.

Table 8.9 Sensitivity analysis between $LCOE_{wso}$ and L_{wt}

	Layouts	Aracati (Brazil)	Corvo Island (Portugal)	Cape Saint James (Canada)
$LCOE_{wso}$	*5D4D*	*69.6792 US$/MWh*	*76.8138 US$/MWh*	*91.7081 US$/MWh*
	5D7D	*69.8318 US$/MWh*	*76.9663 US$/MWh*	*91.8606 US$/MWh*
	5D10D	*69.9843 US$/MWh*	*77.1188 US$/MWh*	*92.0131 US$/MWh*
	6D12D	*70.3401 US$/MWh*	*77.4747 US$/MWh*	*92.3690 US$/MWh*

Source: Own elaboration

When we analyze the effect of L_{wt} on $LCOE_{wso}$ for each site, we get some interesting aspects to be understood∴Fisrt of all, we have considered as base for comparison the layout *5D4D*∴We possible conclude about L_{wt} such considerations:

1. In the case of Aracati (Brazil) the option *5D4D* can be adopted, because it is cheapest alternative *(effect on $LCOE_{wso}$)*, but if we get the *5D7D, 5D10D or 6D12D* the cost of electricity produced increases in *0.22%,0.44% and 0.95%*, respectively;
2. For Corvo Island (Portugal) both we can see a similar situation with Aracati (Brazil) with the cost of electricity produced increases in *0.20%,0.40% and 0.86%*, respectively;
3. In Cape Saint James (Canada) occurs the same situation of Corvo Island (Portugal) and Aracati (Brazil) with the cost of electricity produced increases in *0.17%,0.33% and 0.72%*, respectively;
4. We can confirm, *mutatis mutandis*, among the layouts alternatives analyzed that *5D4D* is the *optimized solution* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada)∴This layout is pointed by many researchers (Dicorato, Forte, Pisani, & Trovato, 2011; Lundberg, 2003, 2006a, 2006b) as one possible optimized onshore wind turbines.

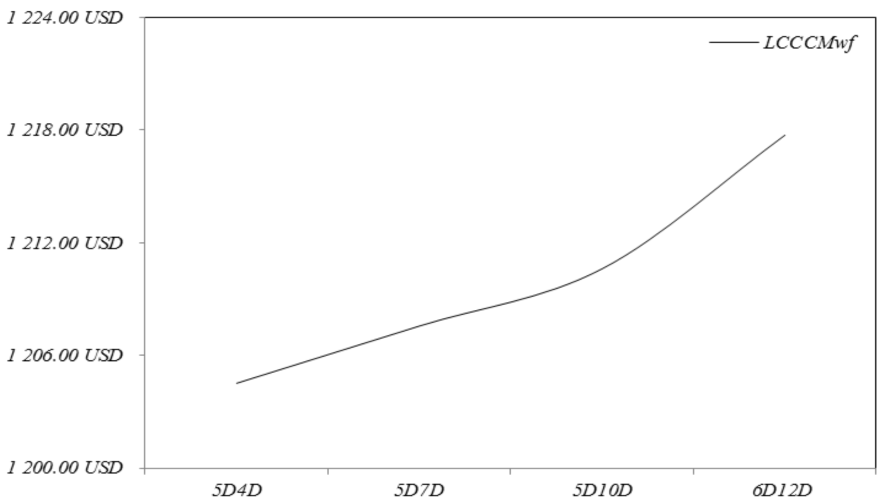

Figure 8.42 Impact on $LCCCM_{WF}$ due to *alternative layouts (L_{wt})*. Source: Own elaboration

8.4.1.4 IMPACT ON $LCOE_{WSO}$ OF ENERGY POLICY INSTRUMENTS *(E_{PI})*

Globally, governments tend to appreciate the advantages of renewable energy production more than conventional energy production. Therefore, to support the expansion of production capacity of renewable energy in many ways that basically aims to reduce the disadvantages of most technologies for renewable energy production: *the cost and the lack of controllability*.

The cost (investment and/or production) can reduce with the RETs project receive some support from government for construction or investment incentives such as accelerated depreciation, tax advantages or subsidies may lead to the construction of a significant number of new renewable power plants (Enzensberger, Wietschel, & Rentz, 2002)∴The *energy policy instruments* are represented in $LCOE_{wso}$ methodology by *REPIM* model within its sub-models REI_{CM}, REP_{CM}, $OREP_{CM}$ and $GHG.R_{CM}$ (see Chapter 6, pp. 238-241).

The sensitivity analysis in *REPIM* was done according to Table 7.14 and optimization criteria defined in section 7.6.2.

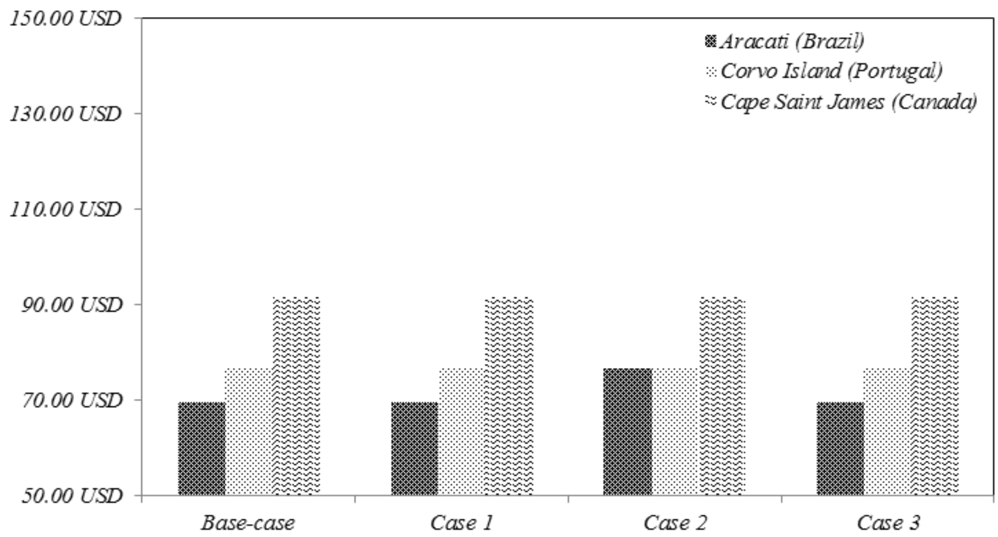

Figure 8.43 Resume of sensitivity analysis of $LCOE_{wso}$ and E_{pi} for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration

We focused our Ph.D. research work on $LCOE_{wso}$ impact of alternative public incentives for E_{pi} variable in the wind farms analyzed∴As we have defined in Chapter 7, section 7.6.2 *(optimization criteria)*, the optimization moment is related finding (calculating) the *lowest* $LCOE_{wso}$ as possible∴ Table 8.10 shows the results and effects on $LCOE_{wso}$ due to E_{pi} alternatives tested by the sensitivity analysis done∴We also highlight the *"best option"* to choose of case for E_{pi} to be implemented.

In $LCOE_{wso}$ methodology the E_{pi} has also impact on $LCCCM_{WF}$. Figure 8.44 shows the results of $LCCCM_{WF}$ due to the alternative E_{pi} *(Base-case, Case $_1$, Case $_2$ and Case $_3$)* simulated in the sensibility analysis done according to Table 6.5.

Table 8.10 Sensitivity analysis between $LCOE_{wso}$ and E_{pi}

	Situations	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
$LCOE_{wso}$	*Base-case*	*69.6792 US$/MWh*	*76.8138 US$/MWh*	*91.7081 US$/MWh*
	Case $_1$	*69.6792 US$/MWh*	*76.8138 US$/MWh*	*91.7081 US$/MWh*
	Case $_2$	*76.8138 US$/MWh*	*76.8138 US$/MWh*	*91.7081 US$/MWh*
	Case $_3$	*69.6792 US$/MWh*	*76.8138 US$/MWh*	*91.7081 US$/MWh*

Source: Own elaboration

According to Table 8.10 it is possible to take some conclusions about the effect of E_{pi} on $LCOE_{wso}$:

1. In the case of Aracati (Brazil) only the *Case $_2$* makes the *cost of electricity produced increases* in *10.24%*;

2. For Corvo Island (Portugal) and Cape Saint James (Canada) the *cost of electricity produced remains* in the same level as the base-case;

3. We also can say that *base-case situation* is the *optimized solution* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada).

Figure 8.44 shows the impacts of E_{pi} on $LCCCM_{WF}$ for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Both *Case $_1$* and *Case $_3$* decrease the $LCCCM_{WF}$ in *1.23%, 1.34%* and *1.79%*, respectively. *In Case $_3$* there is *an increasing of 0.19% and 0.10%* for Aracati (Brazil), and Corvo Island (Portugal) and *decreases 0.22%* for Cape Saint James (Canada) (see Table V.5).

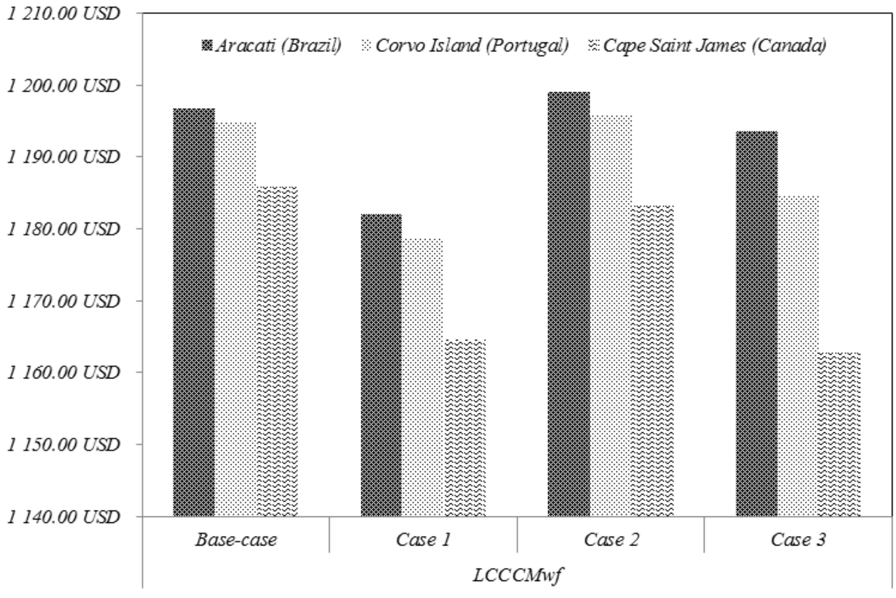

Figure 8.44 Impact on $LCCCM_{WF}$ due to *alternative energy policy (E_{pi})*. Source: Own elaboration

8.4.2 MULTIPLE VARIABLE SENSITIVITIES

8.4.2.1 IMPACT ON $LCOE_{WSO}$ OF WIND SPEED (V_{WC}) AND WIND TURBINE LAYOUT (L_{WT})

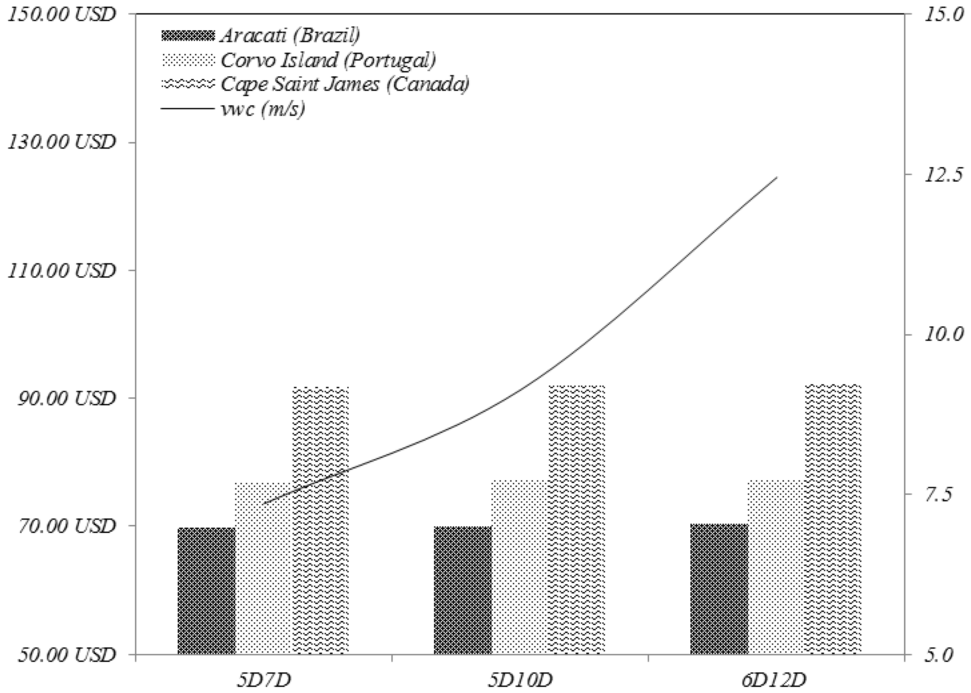

Figure 8.45 Resume of sensitivity analysis of the impact on $LCOE_{wso}$ of *wind speed (v_{wc})* and *wind turbine layout (L_{wt})* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration

When we analyzed the sensibility studies considering multiple variables, case of this section, when it is crossed $LCOE_{wso}$, v_{wc} and L_{wt} a wider conclusion can be made. First of all, we also confirm the same ideas from individual analysis of these variables, such as, (a) the lowest $LCOE_{wso}$ is *5D7D* layout for L_{wt}, (b) $LCOE_{wso}$ as higher as the v_{wc} is, but not in the same proportion and (c) the v_{wc} has stronger impact on $LCOE_{wso}$ than L_{wt} (see Figure 8.45).

As we considered the *5D4D* as the reference layout and optimized one, due to find the lowest $LCOE_{wso}$ among Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). The mean calculated of them is *79.4004 US$/MWh.* For the other layouts simulated in sensitivity analysis we found *79.5529 US$/MWh, 79.7054 US$/MWh* and *80.0613 US$/MWh* for *5D7D, 5D10D and 6D12D*, respectively.

According to Table V.4 the $LCOE_{wso}$ *increases 0.19%, 0.38% and 0.83%* considering the *5D4D layout* as reference, as we already said before, for *5D7D, 5D10D and 6D12D*, respectively.

8.4.2.2 IMPACT ON $LCOE_{WSO}$ OF O&M MANAGEMENT ($O\&M_{MANAG}$) AND ENERGY POLICY INSTRUMENTS (E_{PI})

The $O\&M_{manag}$ and E_{pi} as supposed to have different impacts on $LCOE_{wso}$. In the case of the possible combinations of $O\&M_{manag(A)}$, $O\&M_{manag(B)}$ and E_{pi} (*Case* $_1$, *Case* $_2$ and *Case* $_3$) we found some interesting situations (see Tables 8.11, 8.12 and 8.13).

Table 8.11 Resume of sensitivity analysis of the impact on $LCOE_{wso}$ of $O\&M_{manag(A)}$ and E_{pi} for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada)

	Item	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
			$O\&M_{manag(A)}$	
$LCOE_{wso}$	*Reference*	*69.6792*	*76.8138*	*91.7081*
	Case $_1$	*69.6991*	*76.8666*	*91.8264*
	Case $_2$	*69.6991*	*76.8666*	*91.8264*
	Case $_3$	*69.6991*	*76.8666*	*91.8264*

Source: Own elaboration

$O\&M_{manag(A)}$ and E_{pi} *(Case 1, 2 and 3)* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) we found an increasing of *0.03%*, *0.07%* and *0.13%*, respectively, in relation to reference situation.

Table 8.12 Resume of sensitivity analysis of the impact on $LCOE_{wso}$ of $O\&M_{manag(B)}$ and E_{pi} for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada)

	Item	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
			$O\&M_{manag(B)}$	
$LCOE_{wso}$	*Reference*	*69.6792*	*76.8138*	*91.7081*
	Case $_1$	*69.6873*	*76.8666*	*91.7691*
	Case $_2$	*69.6873*	*76.8666*	*91.7691*
	Case $_3$	*69.6873*	*76.8666*	*91.7691*

Source: Own elaboration

$O\&M_{manag(B)}$ and E_{pi} *(Case 1, 2* and *3)* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) we found an increasing of *0.01%*, *0.07%* and *0.07%*, respectively, in relation to reference situation.

In Table 8.13 shows the difference of *O&M programs* and E_{pi} simulated in the sensitivity analysis done for understanding the optimized option for *O&M proposed programs*.

Table 8.13 Resume of sensitivity analysis of the impact on $LCOE_{wso}$ of $O\&M_{manag(A\text{-}B)}$ and E_{pi} for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada)

	Item	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
		$O\&M_{manag(A)} - O\&M_{manag(B)}$		
$LCOE_{wso}$	*Reference*	*69.6792*	*76.8138*	*91.7081*
	Case $_1$	*0.0117*	*nihill*	*0.0574*
	Case $_2$	*0.0117*	*nihill*	*0.0574*
	Case $_3$	*0.0117*	*nihill*	*0.0574*

Source: Own elaboration

Some conclusions can be taken by the results obtained for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada):

1. The optimized situation is the *reference* one. As we have already discussed the mean of $LCOE_{wso}$ is *79.4004 US$/MWh;*

2. The relation between the $LCOE_{wso}$ for each site and the mean of $LCOE_{wso}$ is *-14.0%, 10.2%* and *31.6%* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada), respectively;

3. For *O&M programs* ($O\&M_{manag(A)}$ *and* $O\&M_{manag(B)}$) and E_{pi} *(Cases* $_1$, $_2$ and $_3$*)*, in Aracati (Brazil) and Cape Saint James (Canada) increase *0.0117 US$/MWh* and *0.0574 US$/MWh*, respectively;

4. In Corvo Island (Portugal) shows no variation between $O\&M_{manag(A)}$ and $O\&M_{manag(B)}$, but as we already said, increases *0.0528 US$/MWh* in relation to reference situation;

5. We can possible conclude that *O&M management* ($O\&M_{manag}$) and *energy policy instruments* (E_{pi}) combined have a positive impact on $LCOE_{wso}$. We have to remember that the *optimized solution* for these variables analyzes is the *reference situation*.

As have stated Barradale (2010) about energy policy when discuss that alongside cost-effectiveness and other dimensions that are usually considered in the choice of policy incentives, therefore, stability should be added to the list of criteria to be explicitly considered. This *stability* refers to the macroeconomic situation of the government that subsidizes the renewable energy technologies from the supporting programs practice.

8.4.3 CONCLUSIONS AND FUTURE ANALYSIS ON COST OF WIND ENERGY

The *cost of the electricity produced* depends on, apart from the *initial capital investment costs*, on the general *wind conditions at the site* (v_{wc}), *O&M expenses* and on the *financing mechanism* adopted for the wind power project.

The results of simulations done according to Table 7.15 within the variables selected (v_{wc}, L_{wt}, $O\&M_{manag}$ and E_{pi}) for validation the $LCOE_{wso}$ methodology confirm the impact expected on the *cost of energy produced* by the hypothetical wind farms at Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). As expected, changes in *wind speed* (v_{wc}) have such a significant impact on the $LCOE_{wso}$ in function of the AEP_{avail}. Table 8.14 shows the main results from the simulations, but the *strong correlation* confirm the *expected impact* of this variable.

Table 8.14 Relation among $LCOE_{wso}$, AEP_{avail} and v_{wc} for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada)

Item	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
$LCOE_{wso}$ *(US$/MWh)*	*69.6792*	*76.8138*	*91.7081*
AEP_{avail} *(GWh)*	*1 215*	*2 251*	*5 328*
v_{wc} *(m/s)*	*7.4*	*9.1*	*12.5*
Correlation Coeff. 0.9969			

Source: Own elaboration

In relation to the *energy production cost*, there is a *strong evidence of direct dependence* of the *average wind speed* (v_{wc}). As an example, the *energy production cost* at an average wind speed of *7.4m/s* was increased in *10.2%* as the cost for an average wind speed of *9.1m/s*. It was also found that the *energy production cost decreases* when the power of the wind farm increases.

The *layout effect* (L_{wt}) was analyzed and some aspects can be highlighted. In the hand of *investment costs* ($LCCCM_{WF}$) *there is a direct relation* as we can see at Figure 8.42. As *more as spaced* as the wind turbines layout, *more is the investment needed* to be done. Afterword, this increasing of $LCCCM_{WF}$ impacts on $LCOE_{wso}$. We also remember that Table 7.4 shows the relation of *layout*, *area* (km^2) and *occupation rate (%)*. It could be an interesting analysis takes into consideration two options for land costs: *one the land area is rented* and the other is part of *initial investment* ($LCCCM_{WF}$). In our $LCOE_{wso}$ methodology we considered only the *rent option,* so it was included into $O\&M_{\mathrm{variable}_{CM}}$ (see Eqn. 6.2.3.1).

Another aspect analyzed was the $O\&M_{MANAG}$.The $O\&M_{MANAG}$ impacts on AEP_{avail} ($LCPM_{WF}$) because is connected directly to *period of electricity production* (H_{prod}) by the wind farm. This effect sensible reflects on others aspects of the $LCOE_{wso}$ methodology, such as *O&M costs*, *total AAR*, *wind farm availability*. For illustration, Figure 8.46 shows the impact on H_{prod} and *availability of the wind farm* in Aracati (Brazil).

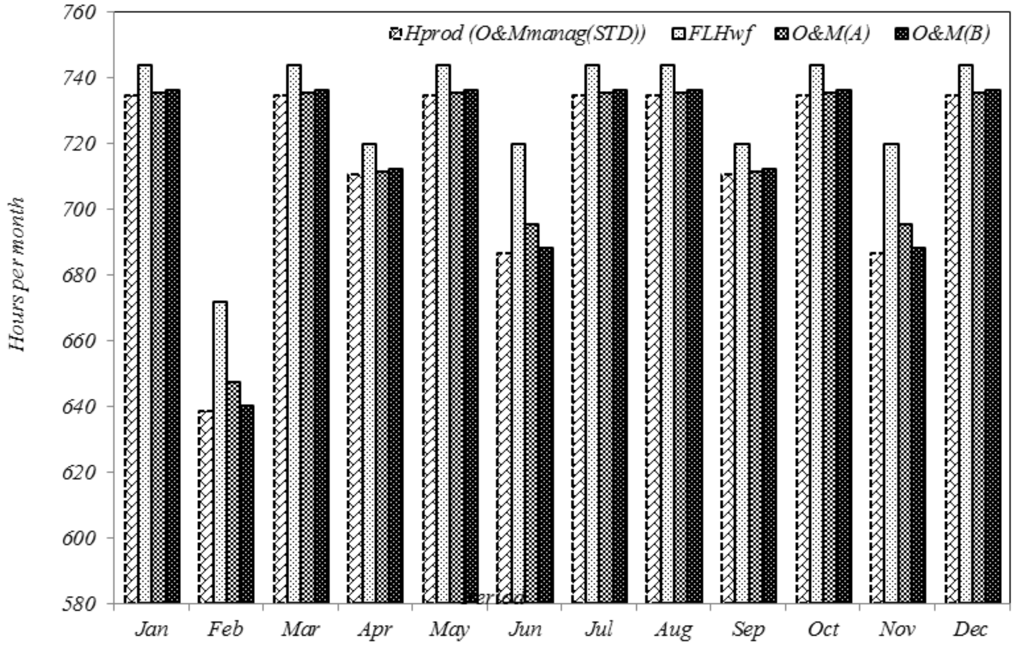

Figure 8.46 Impact of $O\&M_{MANAG}$ on *hours of production* (H_{prod}) and *wind farm availability* for Aracati (Brazil). Source: Own elaboration

The *total AAR* of wind farms for 25 years is affected by v_{wc}, $O\&M_{manag}$, and $O\&M_{manag}$ combined with E_{pi}. The L_{wt} has not impacted on *total AAR* due to the objective of the alternatives layouts simulated *(constant* WF_{cap} *and cost impacts driven to* $LCCCM_{WF}$*)*, otherwise the different layouts impacts direct on *total AAR*. Table 8.15 summarize the variables simulated and the impact on *total AAR (US$M)* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada).

In the simple variable analysis the $O\&M_{manag}$ impacted on *total AAR* differently for each wind farm and program analyzed. In the case of $O\&M_{manag(A)}$ increases the *total AAR* in *0.45%, 0.43%* and *0.44%*, respectively for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). $O\&M_{manag(B)}$ also increases the *total AAR* in *0.24%, 0.43%* and *0.23%*, respectively for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada).

In the multiples variables analyzes when we consider the combination of $O\&M_{manag(A)}$, $O\&M_{manag(B)}$, E_{pi} *(Cases* $_1$, $_2$ and $_3$*)*. For the first group of variables *(*$O\&M_{manag(A)}$*+ Case* $_{1,2,3}$*)* we can notice an increasing on *total AAR* of *0.45%, 0.43%* and *0.44%*, respectively for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Although in second group of variables *(*$O\&M_{manag(B)}$*+ Case* $_{1,2,3}$*)* we also have an increasing on *total AAR* of *0.24%, 0.43%* and *0.23%*, respectively, for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) (see Table 8.15).

Table 8.15 Variables simulated and the impact on *total AAR (US$M)* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada)

Variables	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
Simple variable	*7.4 m/s*	*9.1m/s*	*12.5m/s*
v_{wc}	*134 959 772*	*474 762 014*	*954 354 217*
L_{wt}			
5D7D	*134 959 772*	*474 762 014*	*954 354 217*
5D10D	*134 959 772*	*474 762 014*	*954 354 217*
6D12D	*134 959 772*	*474 762 014*	*954 354 217*
$O\&M_{manag}$			
$O\&M_{manag(STD)}$	*134 959 772*	*474 762 014*	*954 354 217*
$O\&M_{manag(A)}$	*135 567 821*	*476 812 536*	*958 516 231*
$O\&M_{manag(B)}$	*135 279 734*	*476 812 536*	*956 513 783*
Epi			
$Case_{1}$	*134 959 772*	*474 762 014*	*954 354 217*
$Case_{2}$	*134 959 772*	*474 762 014*	*954 354 217*
$Case_{3}$	*134 959 772*	*474 762 014*	*954 354 217*
Multiples variables			
$O\&M_{manag(A)}+Case_{1}$	*135 567 821*	*476 812 536*	*958 516 231*
$O\&M_{manag(A)}+Case_{2}$	*135 567 821*	*476 812 536*	*958 516.231*
$O\&M_{manag(A)}+Case_{3}$	*135 567 821*	*476 812 536*	*958 516 231*
$O\&M_{manag(B)}+Case_{1}$	*135 279 734*	*476 812 536*	*956 513 783*
$O\&M_{manag(B)}+Case_{2}$	*135 279 734*	*476 812 536*	*956 513 783*
$O\&M_{manag(B)}+Case_{3}$	*135 279 734*	*476 812 536*	*956 513 783*

Source: Own elaboration

For future analyzes we recommend explaining some more relations and behavior for $LCOE_{wso}$ methodology proposed, such as:

- $LCOE_{wso}/AAR$: develop correlations with cost of energy produced and the revenues of the wind farm in order to measure the elasticity between them. It is important to define the level of *AAR* for certain $LCOE_{wso}$ desired or constrained by the energy policy instrument, for example.

- $LCOE_{wso}/DPB$: define the influence of the cost of electricity produced and the payback period of the wind project. As we have not the objective to analyze it, but we know it is important the payback for the investor/financer of the project.

- $LCOE_{wso}/ifr$: what size of the influence of inflation on $LCOE_{wso}$ because this kind of analysis is applied for long term *(N=25 yrs)*. The inflation effect on the values must be carefully analyzed, if can change the type of decision made (during the Ph.D. research work, all analyzes done the inflation rate was constant).

- ✡ *$LCOE_{wso}$/$LCPM_{WF}$:* in $LCOE_{wso}$ methodology the production of the wind farm is determined by the $LCPM_{WF}$. It could be a great indicator some variable that make the correlation and influence of production on $LCOE_{wso}$. The wind farm output (production) can be analyzed by the $P\&D_{LM\ factor}$, but we do not make any analysis with this variable and $LCOE_{wso}$.

- ✡ *$LCOE_{wso}$/O&M warranty conditions:* as we have defined the O&M contracts influence on the O&M costs, so, try to develop some algorithm for calculating these variations would be important for O&M effect on $LCOE_{wso}$ at all.

- ✡ *$LCOE_{wso}$/PPAR-EMP:* define the correlation and sensibility between the cost of energy produced and the price of electricity sold. For this Ph.D. research work we have considered the *PPAR/EMP* constant for all simulations done. Meanwhile we recognize price is a *key-parameter* for the success of a wind project (Blanco, 2009; Chapman, 1974; Gross et al., 2010; Ibenholt, 2002; Lee, Chen, & Kang, 2009; Levitt, Kempton, Smith, Musial, & Firestone, 2011; Milborrow, 1995; Robert S, 1993; Strbac, Jenkins, & Allan, 1997).

So we suggest many *"roads"* to follow in future analysis on *cost of wind energy* both *onshore* and *offshore*, the challenge of wind energy Ph.D. research lies in developing alternative methodologies that make the optimization with respect to both cost and production. One of the prerequisite to overcome this challenge for the cost-effective analysis is the availability of a systematic group of equations that generates accurate and reliable results according the official data published in the scientific renewable energy community.

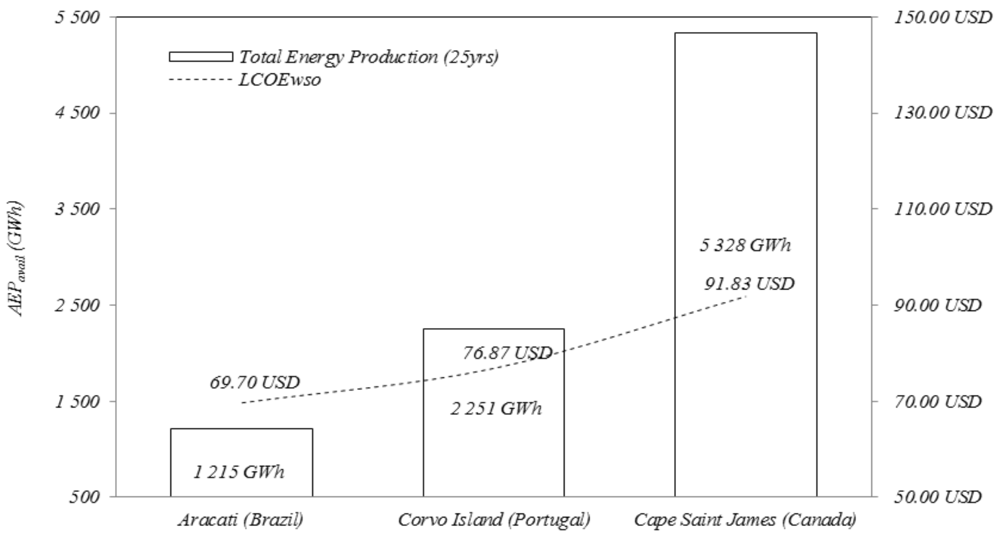

Figure 8.47 Relation of *total AEP_{avail}* and $LCOE_{wso}$ during the lifetime of $50MW_e$ wind farm in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration. Source: Own elaboration

As we can notice in Figure 8.47 the simulations and sensitivity analysis show that increasing AEP_{avail} leads to increasing $LCOE_{wso}$. AEP_{avail} and related variables must be considered together, and they have a *strong influence* on $LCOE_{wso}$.

8.5 SUMMARY AND CONCLUSIONS

This chapter shows the results from the simulations and sensitivity analysis in $v_{wc,}$, L_{wt}, $O\&M_{manag}$ and E_{pi} to a 50 MW_e onshore wind farm located at Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada), operating for 25 years. We start by simulation a *standard situation (reference simulation)* and developed 900 interactions for $LCOE_{wso}$ calculations according to Table 7.16.

We show the results expected to $LCCCM_{WF}$, *AAR*, $O\&M_{WFCM}$, *LRCM*, RCM_{WF} and *REPIM* (see section 8.3.3) for each site analyzed. The *investment costs* (measured by $LCCCM_{WF}$) calculated about *1 205 USD/kW* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada), but in the sensitivity analysis the $LCCCM_{WF}$ oscillates as shown in Figure 8.42 in function of the *alternatives wind farm layouts* (L_{wt}).

The *total AAR* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) varies from *134 959 772 US$M* to *958 516 231 US$M*. We can resume the main results of *AAR* for each site analyzed, as:

1. In Aracati (Brazil) varies from *4 297 170 US$M/yr* to *6 873 465 US$M/yr* with *SD=713 406 US$M and 5 398 391 US$M/yr (Mean);*
2. In Corvo Island (Portugal) varies from *14 970 925 US$M/yr* to *24 203 932 US$M/yr* with *SD=2 524 373 US$M* and *18 990 481 US$M/yr (Mean);*
3. In Cape Saint James (Canada) varies from *30 129 143 US$M/yr* to *48 311 614 US$M/yr* with *SD=5 069 795 US$M* and *38 174 169 US$M/yr (Mean).*

The operation costs of the wind farm also have shown a peculiar behavior. $O\&M_{WFCM}$ in the $LCOE_{wso}$ methodology analyzed the operational costs and we get the final results:

1. In Aracati (Brazil) varies from *0.0808 US$ kWh/yr* to *0.1323 US$ kWh/yr* with *SD=0.0161 US$ kWh* and *0.1081 US$ kWh/yr (Mean);*
2. In Corvo Island (Portugal) varies from *0.0969 US$ kWh/yr* to *0.1549 US$ kWh/yr* with *SD=0.0180 US$ kWh* and *0.1280 US$ kWh/yr (Mean);*
3. In Cape Saint James (Canada) varies from *0.0969 US$ kWh/yr* to *0.1549 US$ kWh/yr* with *SD=0.0180 US$ kWh* and *0.1280 US$ kWh/yr (Mean).*

In the case of the *techno-economic reserves*, case of *LRCM* and RCM_{WF}. These models shown different results. For *LRCM* we obtain some interesting values, as detailed:

1. In Aracati (Brazil) varies from *863 268 US$ kW/yr* to *1 219 776 US$ kW/yr* with *SD=109 970 US$ kW* and *1 032 004 US$ kW/yr (Mean);*
2. In Corvo Island (Portugal) varies from *863 268 US$ kW/yr* to *1 219 776 US$ kW/yr* with *SD=109 970 US$ kW* and *1 032 004 US$ kW/yr (Mean);*
3. In Cape Saint James (Canada) varies from *863 268 US$ kW/yr* to *1 219 776 US$ kW/yr* with *SD=109 970 US$ kW* and *1 032 004 US$ kW/yr (Mean).*

For RCM_{WF}, the main results are:

1. In Aracati (Brazil) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW* and *3 582 109 US$ kW/yr (Mean);*

2. In Corvo Island (Portugal) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW* and *3 582 109 US$ kW/yr (Mean);*

3. In Cape Saint James (Canada) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW* and *3 582 109 US$ kW/yr (Mean).*

The government support to RETs in the $LCOE_{wso}$ methodology is represented by *REPIM* model. According to Table 8.6 the sub-models of *REPIM* have the main results:

1. For Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) the REI_{CM} is about *221 313 US$/kW*$_e$;

2. REP_{CM} is about *16 285 US$/kW*$_e$*h* (for Aracati (Brazil)), *16 879 US$/kW*$_e$*h* (for Corvo Island (Portugal)) and *1 403 US$/kW*$_e$*h* (Cape Saint James (Canada));

3. $OREP_{CM}$ is about *163 497 US$/kW*$_e$ (for Aracati (Brazil)), *265 188 US$/kW*$_e$ (for Corvo Island (Portugal)) and *711 018 US$/kW*$_e$ (Cape Saint James (Canada));

4. $GHG.R_{CM}$ is about *7 495 US$/tCO*$_2$ (for Aracati (Brazil)), *3 893 US$/tCO*$_2$ (for Corvo Island (Portugal)) and *21 268 US$/tCO*$_2$ (Cape Saint James (Canada)).

Figure 8.48 shows the final $LCOE_{wso}$ results for the sites selected for the hypothetical 50 MW_e onshore wind farm.

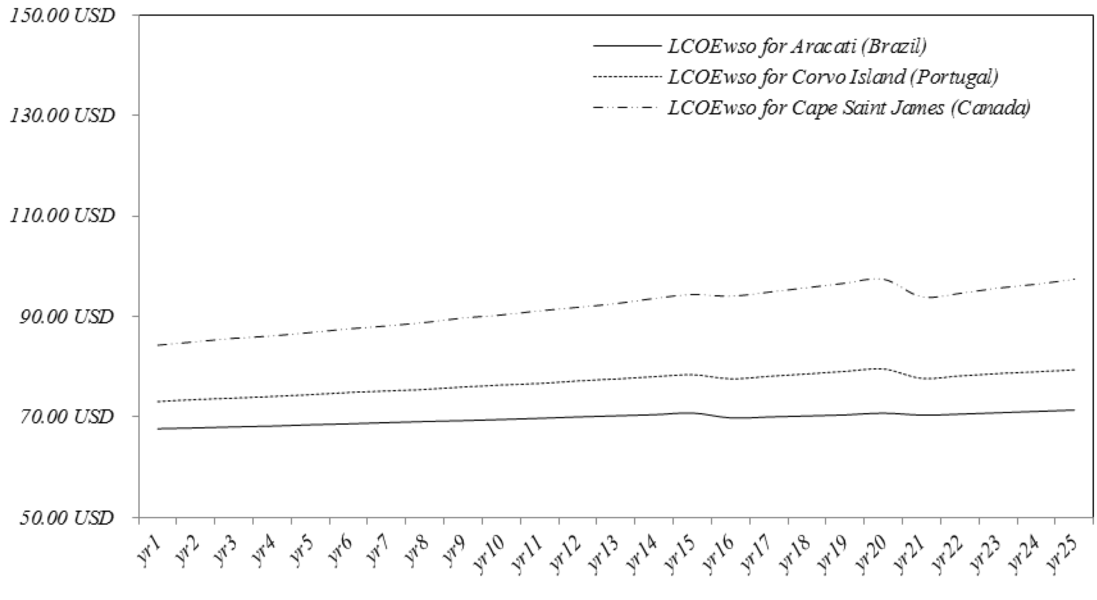

Figure 8.48 Final values of $LCOE_{wso}$ for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration. Source: Own elaboration

In general, the results from the $LCOE_{wso}$ model show that the necessity and importance of methodologies for cost-effective analysis in the Renewable Energy Technologies (RETs), case of wind power and we can confirm, mutatis mutandis, that $LCOE_{wso}$ is equivalent to *LCOE/NREL* and the results are similar according to Figure 7.7.

An analysis of the fundamental variables of the $LCOE_{wso}$ cost model has resulted in a well-considered approach of cost modeling within the wind power project, both onshore and offshore. A breakdown of costs into a summation of components can lead to a straightforward accumulation of inaccuracies and every level of precision can be obtained with precise input data *(so the data considered must be from a secure source)*. A breakdown of energy production in a multiplication of efficiencies has an inherent error, associated with the correlation between contributions to energy loss *(in this numerical simulation and validation was considered constant)*.

The core of the $LCOE_{wso}$ model can be simplified and does not need to specify the cost breakdown. However, this simplification must be done considering the historical data applied to that sub-model. Furthermore, each data-component must be specified clearly to ensure a comprehensive and consistent breakdown of costs and performance of the power system analyzed.

For this Ph.D. research work a *generic fixed* breakdown has been defined and the cost models have been implemented while some corrections were done in equations developed. The final definition of the sub-model and the results that are generated for each component has not been applied without comparing within the official data, in order not increases risk of inconsistency. Future implementations or corrections should reduce the possibility to incorporate inconsistent data due to the several inputs needed. Costs of energy levelized are calculated according to the suggested algorithm (Eqn. 6.2) and with the input parameter.

According to Botterud (2003) the models can be applied by individual power plants in the power system to evaluate investment projects for new power generation capacity. The models can also serve as a *decision support tool* on a *regulatory level*, providing analyses of the long-term performance of the power system under different regulations and market designs into the different energy policy instruments.

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"By three methods we may learn wisdom: First, by reflection, which is noblest; second, by imitation, which is easiest; and third by experience, which is the bitterest."

Confucius

CHAPTER 9

CONCLUSIONS AND IMPLICATIONS

This final chapter presents a brief introduction about the research work design. Main findings and contributions of this Ph.D. research work are discussed within some recommendations for future researches and a general summary and conclusions of the whole thesis is summarized. The references used in this chapter are also presented in the end.

9.1 INTRODUCTION

The increased use of wind power requires modifications in methodologies of cost analysis for planning and management purposes, because it includes more a component of uncertainty that need to be properly studied in RETs∴However, many studies that evaluate the COE of WECS in reliability still represent it as conventional power plants. As discussed in this Ph.D. work, due to *wind speed variations*, *intermittent nature*, and its *specificities* should be considered. This research had as objective the *development of an algorithm for Economic Optimization of Wind Farms in Function of the Cost of Energy* for representation in reliability and feasibility studies of implementation of wind power plants.

Currently there is a *high investment* in the production of energy through renewable resources∴Thus, high investment in wind power plants, either in Europe or in the United States of America, as shown in Chapter 3. Essentially, the production of *electrical energy-electricity* through wind resources due to the maturity of their technology and resources available.

The wind energy conversion systems (WECS) were studied extensively in Chapter 4, due the necessity of understanding the multiple conversion chain performance by this technology∴As we have to detail the WECS and how this mechanism can transform kinetic energy into electrical energy form, so, how we can get the *final energy production* (AEP_{avail}) of a power plant.

During the extensive literature review, we have defined the *thematic areas of this research work* (see Figure 6.4), and go forward in the *economic measures and optimization models* discussed in Chapter 5. After that we could be able to understand what kind of *economic metric* could fit to the objective of this research work, the *LCOE methodology*, developed by NREL (1995)∴As deeper we analyze the *LCOE/NREL* we notice that we possible could modify it or adapt it to the objective of this research work.

In Chapter 6, we discussed about the *theoretical framework and hypotheses development* (section 6.4.3) and *research design* (section 6.4.4) within the *mathematical model structuring* (section 6.4.4.2)∴The $LCOE_{wso}$ was developed in order to *maximize the wind farm production* (AEP_{avail}) and *minimize the cost of energy produced* (COE), in the context of the *lifetime of the power plant*. We have to explain that is not a question of exchanging methodologies, even, it is an equivalence question! That is why it was necessary to make a numerical simulation and validation of the $LCOE_{wso}$ methodology.

The *numerical simulation and validation* process designed in Chapter 7 considering the details and conditions in order to be more objective and realist and try to *"imitate a real wind power plant and its costs reliability and operation"*. The results of $LCOE_{wso}$ simulations shown in Chapter 8 were used to validate de alternative methodology, in other words, we took this *"road"* because we could not test this methodology in a real wind farm. This final chapter is organized in five sections∴It starts with the *introduction* (section 9.1), main findings and contributions are shown in section 9.2, some recommendations for future researches are also shown in section 9.3 and we finalize this Ph.D. research work with *general summary and conclusions* (section 9.4) and the *references* used in this chapter (section 9.5).

9.2 MAIN FINDINGS AND CONTRIBUTIONS

According to Figure 1.1, the Ph.D. research work is organized in 9 chapters, so we decided to declare the *main findings and contributions* in the same way∴The *introduction* part of this research work is set to Chapter 1, so we started from Chapter 2.

9.2.1 CHAPTER 2

1. *Humankind evolution is closely linked to energy* — the primitive history of Egypt is an excellent example of the role that energy, measured in surplus food/energy, played in the structure and activities of a primitive society∴Although the structures of the societies of today are much more complex, the energy continues to be an important factor in the development of mankind;

2. *Energy production and consumption is strongly associated with the environmental pressure on the planet* — For example, emissions of SO_2 (sulfur dioxide), greenhouse gases and other CO_2 and NO_x (nitrogen oxides) for a certain period, depends on the amount of electricity produced and the technological mix of plants operating in each electrical system for some period;

3. *Renewable energies have generally lower emissions than conventional power stations* — properly assess the potential effects of wind on the system cost of electricity compared to other existing production systems should take into account the fuel savings and emissions avoided∴Both the amount of CO_2 reduction and additional costs attributed to the system depends on the characteristics of the electricity system under analysis.

In general, renewable energy technologies, named the wind power can provide an important contribution to reducing fossil fuel consumption and meet international environmental commitments∴However, interconnection capacity, the combination of the existing capacity of production and characteristics of the wind power system to have a significant effect on how the variable production is assimilated by the system and on the extent of their contribution to meet the needs of modern society.

9.2.2 CHAPTER 3

1. *Organizational model in wind energy industry* — WECS are type of CoPS (Complex Product System), high-cost, engineering-intensive systems∴Today, wind power is often subsidized, but it is approaching a cost level that makes it economically attractive compared to established energy production methods, assuming good wind conditions∴The *technology development stages* of wind energy industry are *R&D*, *Demonstration*, *Deployment* and *Diffusion/Commercialization;*

2. *Wind resources worldwide* — North America and Antarctica are the best locations for electricity production by wind energy technology∴But they are also very favorable to electricity production by wind energy technology in the northern Europe, especially along the North Sea, the southern tip of South America *(Tierra del Fuego or Fireland)* and Tasmania, in Oceania;

3. *Trends in wind power technology* — the main markets driving growth are Europe and Asia, which installed 96.6 GW and 82 GW respectively in the end of 2011∴Vestas and GE Energy have the largest market shares of wind energy converters (wind turbines). According to WWEA (2011) by the end of the year 2010, about 670 000 people were employed worldwide directly and indirectly in the many areas in the wind industry. During the last five years, the number of jobs almost tripled, from 235 000 in 2005.

In comparison to other RETs, wind energy is certainly the one that is closest to making the transition from niche to mass market∴It is strongly linked with long-term prosperity∴For Pablo (2008) *investment* explains the productive capacity of an economy. Investments made in the renewable energy industry have in addition a strong influence on the degree of dependence among economies, their competitiveness, sustainability, and on all kinds of environmental issues including climate change.

9.2.3 CHAPTER 4

1. *Wind energy technology* — the power of the wind has been utilized for at least 3 000 years and this energy captured by wind turbines is highly dependent on the local average wind speed∴The concept of the windmill-device was described by Heron of Alexandria. The working principle of WECS involves two main conversion processes, which are carried out by its main components: *the rotor, which extracts kinetic energy from the wind and converts it into a mechanical torque*, and the producing system (generator), which converts this torque into electricity;

2. *Wind farm planning* — the wind farm planning is a long and complex process which each phase is remarkable for the whole wind power plant lifetime∴A major issue in the planning of a wind farm is to identify the optimal rating and design of the installation. Several phenomena limits the maximum possible capacity of wind farms;

3. *Wind energy production* — the calculation of the annual theoretical production of electrical power from a wind farm is resulting from the product of electrical power installed, total hours of production for one year and capacity factor of the wind farm∴The capacity factor is due to production losses, stops for maintenance and periods where the wind speed is not suitable for the production of electricity by wind turbines.

The success of wind power as a renewable energy sources is obviously a direct function of the economics of production of WECS∴In this regard, the role of improved power output through the development of better aerodynamic performance offers some potential return; however, the focus is on the cost of the entire system. However, WECS is not free of negative impacts, although the public attitude in relation to *wind energy* is generally positive, local people may react negatively to specific projects. In the particular case of wind energy impacts on the ecosystem, noise pollution (noise) and negative impacts on the landscape have been reported.

9.2.4 CHAPTER 5

1. *Wind energy cost identification for economic evaluations* — for wind energy projects, the costs are classified and structured *investment costs*, *operating costs*, *maintenance costs* and *financial costs*∴All these classes and cost structure have their own characteristics depending on the location, size, types of financing and regulations;

2. *Investment analysis of wind energy projects* — wind energy projects *NPV* is a function of *AAR* and the *ICC*. As a result, to maximize *NPV* also maximizes the absolute *wealth* created by investment. Because of this, *NPV* is biased toward larger investments. While on return is greater than the discount rate. The analysis of the *NPV* will push the decision to bigger projects, even if the relative profitability is smaller. The *SPB*, *DPB* and *IRR* are functions of *ICC/AAR*;

3. *Cost analysis of wind energy projects* — the cost analysis of a wind power plant must be done by *cost centers*, classified into *wind turbines cost center*, *electrical system cost center* and *grid interface cost center*. These cost centers change its costs and sub-divisions depending on the kind of application of wind power plant (Dicorato, Forte, Pisani, & Trovato, 2011). Characterization of the boundaries of wind projects under study has impact and different values for LCOE.

4. *Optimization models for energy systems* — the optimization process of an energy system can be considered at three levels *(Design optimization, Synthesis optimization* and *Operation optimization)* (Frangopoulos, 2003). The cost per kWh from a power plant, a wind farm, must be understood as a result from a systemic components interlinked.

In order to improve the reliability of projected and REPs already in operation the key players of renewable energy industry, case of wind energy sector, more and more adopt simulation and optimization methods. The simulation and optimization methods since the end of nineties decade, as shown in Figure 5.9 have increased exponentially. Techniques for simulation and optimization of RETs vary greatly depending on the exact problem setting. The case of RE projects the local conditions such as orography, (micro) climate, local population and government must be taken into consideration. Many systems simulation and optimization in areas such as *manufacturing, distribution, financial evaluations,* are too complex to be analyzed discretely.

9.2.5 CHAPTER 6

1. *Nature of the research for wind power systems* — this Ph.D. research work fits to this kind of research. Operations research helps the manager/investor to achieve its goals using scientific methods and can be used in particular for wind farm design decisions. It is often concerned with optimizing of some objectives (maximum of profit, performance, etc. or minimum of loss, risk, cost, etc.) at limited resources;

2. *LCOE driven-variables influence* — based on *LCOE/NREL* methodology the variables were grouped into four categories: *(1) Wind speed (v_{wc}); (2) Wind turbines layouts (L_{wt}); (3) Operations and Maintenance management ($O\&M_{manag}$)* and *(4) Energy policy instruments (E_{pi})*. The reason for grouping these variables into these categories was based on research hypotheses presented at Table 6.3. The variables relationship and research boundary (see Figure 6.14) were explained in section 6.4.4.1 which driven the simulation procedures done and shown in Chapter 7;

3. *$LCOE_{wso}$ development and constitution* — the $LCOE_{wso}$ methodology was developed with six main modules: *Wind Farm Life-Cycle Capital Cost Model ($LCCCM_{WF}$); Wind Farm O&M Cost Model ($O\&M_{WFCM}$); Levelized Replacement Cost Model (LRCM); Wind Farm Removal Cost Model (RCM_{WF}); Renewable Energy Public Incentive Model (REPIM)* and *Wind Farm Life-Cycle Production Model ($LCPM_{WF}$)*. Each of them was integrated into sub-models, as shown in Figure 6.16;

4. *Main difference between $LCOE_{wso}$ and LCOE/NREL — $LCOE_{wso}$* takes into consideration the *LRCM* or *Levelized Replacement Cost Model*, related to a cost item treated as "*saving account"* for the wind power project as the *LCOE/NREL, but not obsolescence cost effect*. *$LCOE_{wso}$* designed with two sub-models: the *Annual Replacement Cost Model (AR_{CM})* (see Eqn 6.2.2.1) and *Technological Obsolescence Cost Model (TO_{CM})* (see Eqn 6.2.2.2). This model was developed in order to *guarantee at a certain period (5, 10 and 15 years)* funds enough to make the necessary review in the producing power system.

During the elaboration of *$LCOE_{wso}$* methodology we notice the necessity to verify if the model and sub-models would be a real *response* to the *research question* and *objectives* designed for this research work, so we have to make the *parameterization* of the data for the *inputs* to feed the *$LCOE_{wso}$* calculations.

9.2.6 CHAPTER 7

1. *Power system parameters used for simulations* — a 50 MW_e onshore wind farm with 25 wind turbines (Vestas V90-2MW). The electrical generators of wind turbines contain 4-pole Doubly-Fed Asynchronous Generator (DFIG) with wound rotor (see Chapter 4, Figure 4.8 and Table 4.3). The numerical simulation and validation of *$LCOE_{wso}$* performanced according to Tables 7.2, 7.3, 7.4, 7.5, 7.6, 7.7, 7.7, 7.8, 7.9, 7.10, 7.11,

7.12, 7.13 and 7.14. We have also considered the total of 15km^2 for wind farm installations. The types of layouts simulated were *5D4D, 5D7D, 5D10D and 6D12D;*

2. *Economic and financial aspects of the wind project* — even the economic and financial assumptions considered *constant* in the simulations done, the variables chosen *(*v_{wc}, L_{wt}, $O\&M_{manag}$ and E_{pi}*)* promote *an oscillation* on the final value of $LCOE_{wso}$ in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Many researchers (Cory & Schwabe, 2009; George & Schweizer, 2008; Lantz & Tegen, 2008; Lantz, Wiser, & Hand, 2012; Milligan & Graham, 1997; Tegen et al., 2012; Tidball, Bluestein, Rodriguez, & Knoke, 2010) agree that economic classical variables impacts directly the cost of electricity produced from a wind farm (e.g. inflation rate, discount rate, debt rate, debt ratio, price of electricity sold, capital structure, and others);

3. *O&M assumptions for wind project simulations* — the O&M costs were associated to $O\&M_{WFCM}$ with two alternatives of O&M programs (see Table 7.12). In the proposed $O\&M_{WFCM}$ was done a separation of *O&M* costs because we believe that the costs for *O&M* could have two types of behavior, one related to the power plant itself (size, land area, and other administrative expenses) and other related to the production of the wind farm. Christopher (2003) has highlighted the effort to minimize wind turbine *O&M* costs must start with a better understanding of the current costs and other factors that drive these costs;

4. *Energy policy assumptions for wind project simulations* — in $LCOE_{wso}$ methodology the energy policy instruments are computed in *REPIM* model. This model includes the following sub-models: *(1) Renewable Energy Investment Credit Mode* (REI_{CM}); *(2) Renewable Energy Production Credit Mode (*REP_{CM}*); (3) Other REPs Credit Mode (*$OREP_{CM}$*)* and *(4) GHG Reduction Credit Model (*$GHG.R_{CM}$*).* Strong focus on capacity installations might result in the construction of projects with little productive efficiency. Production incentives, in contrast, help to specially stimulate the development of efficient projects, resulting in a higher output of renewable energy per supporting capital involved (Enzensberger, Wietschel, & Rentz, 2002);

5. *General simulations procedures* — the simulations were done for 25 years of wind farm operation. The sensitivity analysis was organized in two parts. The first part the variables are analyzed individually (see section 8.4.1). In this part is analyzes the impact of v_{wc}, $O\&M_{manag}$, L_{wt} and E_{pi} on $LCOE_{wso}$. The second part of the sensitivity analysis a multiple variable analysis is made (see section 8.4.2)∴We have analyzed the impact of v_{wc} and L_{wt}; $O\&_{Mmanag}$ and E_{pi}*)* on $LCOE_{wso}$.

The effect of the parameters/data variations impact on $LCOE_{wso}$ that is why we need to run (900 interactions) within a sensitivity analysis for numerical simulation and validation process, as detailed in section 7.6∴The sensitivity analysis was defined and undertaken as explained in sections 7.6.1, 7.6.2 and 7.6.3.

9.2.7 CHAPTER 8

1. *Distribution of wind speed series* — the wind profile during one year, according to the data shown in Figure 6.11, 6.12, 6.13 and Table 7.5 shows some evidences in relation the wind speed behavior∴Figure 8.3 shows the annual wind speed behavior in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Corvo Island (Portugal) and Cape Saint James (Canada) present a similar wind speed behavior during the year analyzed. Wind speed series of Aracati (Brazil) and Cape Saint James (Canada) make interception in *August* and *September*∴The wind speeds are 9.6 m/s and 9.7 m/s in *August* for Aracati (Brazil) and Cape Saint James (Canada). In *September* occurs the same as in August and September, the wind speed of 10.1 m/s and 10.4 m/s for Aracati (Brazil) and Cape Saint James (Canada), respectively. The behavior of wind speed in Aracati (Brazil) and Corvo Island (Portugal) present similarities∴In *June* and *October* the monthly wind speed is 7.9 m/s and 7.1 m/s and 9.7 m/s and 8.9 m/s, respectively;

2. *Simulations analysis results* — the *total AAR* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) varies from *134 959 772 US$M* to *958 516 231 US$M*. We can resume the main results of *AAR* for each site analyzed, as: (1) in Aracati (Brazil) varies from *4 297 170 US$M/yr* to *6 873 465 US$M/yr* with *SD=713 406 US$M and 5 398 391 US$M/yr (Mean); (2) i*n Corvo Island (Portugal) varies from *14 970 925 US$M/yr* to *24 203 932 US$M/yr* with *SD=2 524 373 US$M* and *18 990 481 US$M/yr (Mean); (3) i*n Cape Saint James (Canada) varies from *30 129 143 US$M/yr* to *48 311 614 US$M/yr* with *SD=5 069 795 US$M* and *38 174 169 US$M/yr (Mean); for* $O\&M_{WFCM}$: (1) in Aracati (Brazil) varies from *0.0808 US$ kWh/yr* to *0.1323 US$ kWh/yr* with *SD=0.0161 US$ kWh* and *0.1081 US$ kWh/yr (Mean); (2) i*n Corvo Island (Portugal) varies from *0.0969 US$ kWh/yr* to *0.1549 US$ kWh/yr* with *SD=0.0180 US$ kWh* and *0.1280 US$ kWh/yr (Mean);(3) i*n Cape Saint James (Canada) varies from *0.0969 US$ kWh/yr* to *0.1549 US$ kWh/yr* with *SD=0.0180 US$ kWh* and *0.1280 US$ kWh/yr (Mean); for LRCM: (1) in Aracati (Brazil) varies from 863 268 US$ kW/yr to 1 219 776 US$ kW/yr with SD=109 970 US$ kW and 1 032 004 US$ kW/yr (Mean);(2) in Corvo Island (Portugal) varies from 863 268 US$ kW/yr to 1 219 776 US$ kW/yr with SD=109 970 US$ kW and 1 032 004 US$ kW/yr (Mean); (3) in Cape Saint James (Canada) varies from 863 268 US$ kW/yr to 1 219 776 US$ kW/yr with SD=109 970 US$ kW and 1 032 004 US$ kW/yr (Mean); for* RCM_{WF}: (1) in Aracati (Brazil) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW* and *3 582 109 US$ kW/yr (Mean); (2) i*n Corvo Island (Portugal) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW* and *3 582 109 US$ kW/yr (Mean); (3) i*n Cape Saint James (Canada) varies from *2 621 739 US$ kW/yr* to *4 742 007 US$ kW/yr* with *SD=635 804 US$ kW* and *3 582 109 US$ kW/yr (Mean); for REPIM: Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) the* REI_{CM} *is about 221 313 US$/*$kW_e$*;* REP_{CM} *is about 16 285 US$/*$kW_eh$ *(for Aracati (Brazil)), 16 879 US$/*$kW_eh$ *(for Corvo Island (Portugal)) and 1 403 US$/*$kW_eh$ *(Cape Saint James (Canada));* $OREP_{CM}$ *is about 163 497 US$/*$kW_e$ *(for Aracati (Brazil)), 265 188 US$/*$kW_e$ *(for Corvo Island (Portugal)) and 711 018 US$/*$kW_e$ *(Cape Saint James*

(Canada)); GHG.R_{CM} is about 7 495 US\$/tCO_2 (for Aracati (Brazil)), 3 893 US\$/tCO_2 (for Corvo Island (Portugal)) and 21 268 US\$/tCO_2 (Cape Saint James (Canada));

3. *Sensitivity analysis results* — For these three different sites, we have noticed that when *wind speed (v_{wc}) increases in 23.0%,* we get *10.2%* of increasing on *$LCOE_{wso}$* (from Aracati-Brazil to Corvo Island-Portugal)∴The same situation occurs in relation to Corvo Island (Portugal) and Cape Saint James (Canada) when the *wind speed increases 37.4%* reflects and *increases 19.4% on $LCOE_{wso}$*; The *wind farm availability* increases in *0.44% for $O\&M_{manag(A)}$* and *0.24% for $O\&M_{manag(B)}$* in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada); For *$O\&M_{manag}$*: In the case of Aracati (Brazil) the option *$O\&M_{manag(B)}$* can be adopted, because there is no effect on the *$LCOE_{wso}$*, but if we get the *$O\&M_{manag(A)}$* the cost of electricity produced increases in *0.02%*; For Corvo Island (Portugal) both *$O\&M_{manag(A)}$* and *$O\&M_{manag(B)}$* increase the *$LCOE_{wso}$* in *0.07%.* The *$O\&M_{manag(STD)}$* is the optimized strategy for O&M costs; In Cape Saint James (Canada) occurs the same situation of Corvo Island (Portugal), but we get an increasing of *0.13% for $O\&M_{manag(A)}$* and *0.07% for $O\&M_{manag(B)}$*. Also the *$O\&M_{manag(STD)}$* is the optimized strategy for O&M costs; For *L_{wt}*: in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). The *5D7D, 5D10D and 6D12D layouts* can increase the *$LCCCM_{WF}$* in *0.25%, 0.51% and 1.10%,* respectively; In the case of Aracati (Brazil) the option *5D4D* can be adopted, because it is cheapest alternative *(effect on $LCOE_{wso}$)*, but if we get the *5D7D, 5D10D or 6D12D* the cost of electricity produced increases in *0.22%,0.44% and 0.95%*, respectively; For Corvo Island (Portugal) both we can see a similar situation with Aracati (Brazil) with the cost of electricity produced increases in *0.20%,0.40% and 0.86%,* respectively; In Cape Saint James (Canada) occurs the same situation of Corvo Island (Portugal) and Aracati (Brazil) with the cost of electricity produced increases in *0.17%,0.33% and 0.72%,* respectively; We can confirm, *mutatis mutandis,* among the layouts alternatives analyzed that *5D4D* is the *optimized solution* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) and the other alternative layouts*; For E_{pi}: in the case of Aracati (Brazil) only the Case $_2$ makes the cost of electricity produced increases in 10.24%; For Corvo Island (Portugal) and Cape Saint James (Canada) the cost of electricity produced remains in the same level as the base-case; The base-case situation is the optimized solution for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada); for v_{wc}* and *L_{wt}*: the *$LCOE_{wso}$* mean is *79.5529 US\$/MWh, 79.7054 US\$/MWh* and *80.0613 US\$/MWh* for *5D7D, 5D10D and 6D12D*, respectively; *$LCOE_{wso}$ increases 0.19%, 0.38% and 0.83%* considering the *5D4D layout* as reference, as we already said before, for *5D7D, 5D10D and 6D12D,* respectively; *$O\&M_{manag}$* and *E_{pi}*: *$O\&M_{manag(A)}$* and *E_{pi} (Case 1, 2 and 3)* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) we found an increasing of *0.03%, 0.07%* and *0.13%,* respectively, in relation to reference situation; *$O\&M_{manag(B)}$* and *E_{pi} (Case 1, 2* and *3)* for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada) we found an increasing of *0.01%, 0.07%* and *0.07%,* respectively, in relation to reference situation; *$O\&M_{manag(A\text{-}B)}$*: the relation between the *$LCOE_{wso}$* for each site and the mean of *$LCOE_{wso}$* is *-14.0%, 10.2%* and *31.6%* for Aracati (Brazil), Corvo Island (Portugal) and Cape

Saint James (Canada), respectively; For *O&M programs* ($O\&M_{manag(A)}$ *and* $O\&M_{manag(B)}$) and E_{pi} *(Cases* $_1$, $_2$ and $_3$*)*, in Aracati (Brazil) and Cape Saint James (Canada) increase *0.0117 US$/MWh* and *0.0574 US$/MWh*, respectively; in Corvo Island (Portugal) shows no variation between $O\&M_{manag(A)}$ and $O\&M_{manag(B)}$, but as we already said, increases *0.0528 US$/MWh* in relation to reference situation; *O&M management* ($O\&M_{manag}$) and *energy policy instruments* (E_{pi}) combined have a positive impact on $LCOE_{wso}$. We have to remember that the *optimized solution* for these variables analyzes is the *reference situation*;

4. *Conclusions and future analysis on cost of wind energy* — in relation to the *energy production cost*, there is a *strong evidence of direct dependence* of the *average wind speed* (v_{wc}). As an example, the *energy production cost* at an average wind speed of *7.4m/s* was increased in *10.2%* as the cost for an average wind speed of *9.1m/s*. It was also found that the *energy production cost decreases* when the power of the wind farm increases; $O\&M_{MANAG}$ impacts on AEP_{avail} ($LCPM_{WF}$) because is connected directly to *period of electricity production* (H_{prod}) by the wind farm; in the simple variable analysis the $O\&M_{manag}$ impacted on *total AAR* differently for each wind farm and program analyzed. In the case of $O\&M_{manag(A)}$ increases the *total AAR* in *0.45%*, *0.43%* and *0.44%*, respectively for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). $O\&M_{manag(B)}$ also increases the *total AAR* in *0.24%*, *0.43%* and *0.23%*, respectively for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada); In the multiples variables analyzes when we consider the combination of $O\&M_{manag(A)}$, $O\&M_{manag(B)}$, E_{pi} *(Cases* $_1$, $_2$ and $_3$*)*. For the first group of variables ($O\&M_{manag(A)}$+ *Case* $_{1,2,3}$) there is an increasing on *total AAR* of *0.45%, 0.43%* and *0.44%*, respectively for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Although in second group of variables ($O\&M_{manag(B)}$+ *Case* $_{1,2,3}$) we also have an increasing on *total AAR* of *0.24%, 0.43%* and *0.23%*, respectively, for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada).

An analysis of the fundamental variables of the $LCOE_{wso}$ cost model has resulted in a well-considered approach of cost modeling within the wind power project, both onshore and offshore. A breakdown of costs into a summation of components can lead to a straightforward accumulation of inaccuracies and every level of precision can be obtained with precise input data *(so the data considered must be from a secure source)*. A breakdown of energy production in a multiplication of efficiencies has an inherent error, associated with the correlation between contributions to energy loss *(in this numerical simulation and validation was considered constant)*.

9.3 RECOMMENDATIONS FOR FUTURE RESEARCHES

9.3.1 FOR V_{WC}

The wind speed behavior analyzed at any particular time and site is one measure of the elements of the current weather conditions. If we keep analyzing the same wind behavior during years, now get its climatology. We have considered the same and generally accepted definitions of *weather* and *climate* according to Petersen, Mortensen, Landberg, Højstrup, and Frank (1998):

- ✡ *Weather* is the totality of instantaneous atmospheric conditions at any particular site and time. The elements of the weather are such as *temperature, atmospheric pressure, wind, humidity, cloudiness, rain; sunshine and visibility* make the difference from a place to another, and

- ✡ *Climate* is the sum of the weather experienced at a site in the course of the year and over the years. Because the average conditions of the weather elements change from year to year, climate can only be defined in terms of some period of time. Some chosen run of years, a particular decade or some decades.

After defined the concept of *weather* and *climate*, we suggest as *wind speed* research focus:

1. Develop more efficient methods for determining wind resources and identifying regions rich in poorly-exploited wind resources, in order to enable increased and more cost-effective wind farm assets by energy policy instruments;

2. Add in the $LCOE_{wso}$ methodology the *wind speed variability* as the "*elasticity wind speed-cost"* in function of the production variation *($\$/m.s^{-1}$)*;

3. Determine the impact on $LCOE_{wso}$ of wind speeds higher than the rated wind speed of the wind turbine and high production hours.

9.3.2 FOR L_{WT}

4. Studying of the impact on $LCOE_{wso}$ from different *wind turbines sizes* and *hub heights* in a same wind farm;

5. A potential field of further studies, though not one examined in detail in this Ph.D. research work may be the *building of more sustainable wind power plants* in function of the alternative wind turbines layouts;

6. Developing and linking a decision making model for a wind power plant to the $LCOE_{wso}$ predictions and verifying it with the real $/kWh produced;

7. Developing *layout efficiency indicator* based on $LCOE_{wso}$ results for different wind farms according to the installed capacity;

8. Designed and optimized *wind turbines layouts* can be analyzed with $LCOE_{wso}$ as analysis tool for better predictions of *initial investment reduction*;

9.3.3 FOR $O\&M_{MANAG}$

9. Developing a wind farm index from $O\&M_{MANAG}$ and $LCOE_{WSO}$ data for sites with good wind resources that are also predictable;

10. Developing an *economic safety index* for wind farms of O&M programs and $LCOE_{wso}$ during the operational phase;

11. Developing a *component reliability model* for predict the unscheduled maintenance and efforts the scheduled maintenance for *reducing the downtime of onshore and offshore wind turbines*, so, reduce the LCOE;

12. Quantifying the impact of different $O\&M_{MANAG}$ on $O\&M_{WFCM}$ over the time by a standard reporting scheme among organizations, and many of the historical records may be viewed from the wind power industry associations;

9.3.4 FOR E_{PI}

13. Developing a *social tax incentive* in $LCOE_{wso}$ methodology in function of the number of direct employs created where the wind farm operates;

14. Analysis of the impact of *inflation rate* on E_{pi}, and how the *macroeconomic environment* can change the quantitative variables of the energy policy instrument analyzed *(*REI_{CM}, REP_{CM}, $OREP_{CM}$ and $GHG.R_{CM}$*)*;

15. Measurement of transmission, tax, environmental, and other policies that also affect the economics of wind power in the $LCOE_{wso}$ methodology context;

9.3.5 FOR *OTHERS*

16. Applying the $LCOE_{wso}$ *in a real case*, in other words, in a wind farm for consolidation of the methodology and corrections, if needed, and compare with other types of economic controls currently used in the wind market sector;

17. Analysis of *elasticity* of $LCOE_{wso}$ in function of the *cost of financing* variations in the financing period for the same wind farm;

18. Studying the size effect of wind farms on *LCOEwso*, as many studies suggest that a large wind farm is more economical than a small one;

19. In $LCOE_{wso}$ only internal costs were considered, as externalities *(environmental & social impacts)* are analytically different from internal costs, would be interesting modify the proposed methodology and compare the final values of LCOE (Simas & Pacca, 2013);

20. Studying the *lifetime effect* on $LCOE_{wso}$ for determining the optimized lifetime of a certain wind farm as have been studied by Ohunakin, Oyewola, and Adaramola (2013).

9.4 GENERAL SUMMARY AND CONCLUSIONS

In summary, the proposed methodology for LCOE, *life-cycle cost of energy* for wind power system planning and management, provides a *new methodology* and effective way to evaluate the *cost of a project*, a wind project, in the private point of view. However, it is worth noting that the accuracy of $LCOE_{wso}$ model is totaly dependent on the data/inputs for calculation and the uncertainties, which might be discussed in the future research about cost-effectiveness analysis.

The success of developing a wind project will be unique to the macroeconomic environment and renewable energy policies it is subject to. We noticed that the *price of electricity sold* is a fundamental question *(PPAR and EMP)*, due to this approach is also depending on *AAR* of the wind project. These will include government subsidies *(REPIM)* that help the installation and running of the wind farm as well as the site location and terrain that influence the *investment costs* ($LCCCM_{WF}$). However different each project might be *(understood when we compare Aracati-Brazil, Corvo Island-Portugal and Cape Saint James-Canada)*, it is important to have a general method for evaluating them.

Before the installation of a wind farm begins, agreements need to be formulated to remove or reduce some uncertainties. These agreements include a connection and power purchasing agreement *(PPA)* with a utility company, a loan agreement from a financial institution, an operation and maintenance agreement ($O\&M_{ccm}$ *and* n_w), site and construction agreements, as well as insurance agreements. Investors will hire *financial analysts* to value the wind projects feasibility and worth, and to help set the *benchmarks* when contracting agreements. Apart from the *total revenues (total AAR)* and cost projections, the financial analyst will want to perform standard risk measures *(DPB, IRR, NPV and others)*. This will be subject to the investors risk tolerance, and should be thought about carefully when making the decision to invest or not.

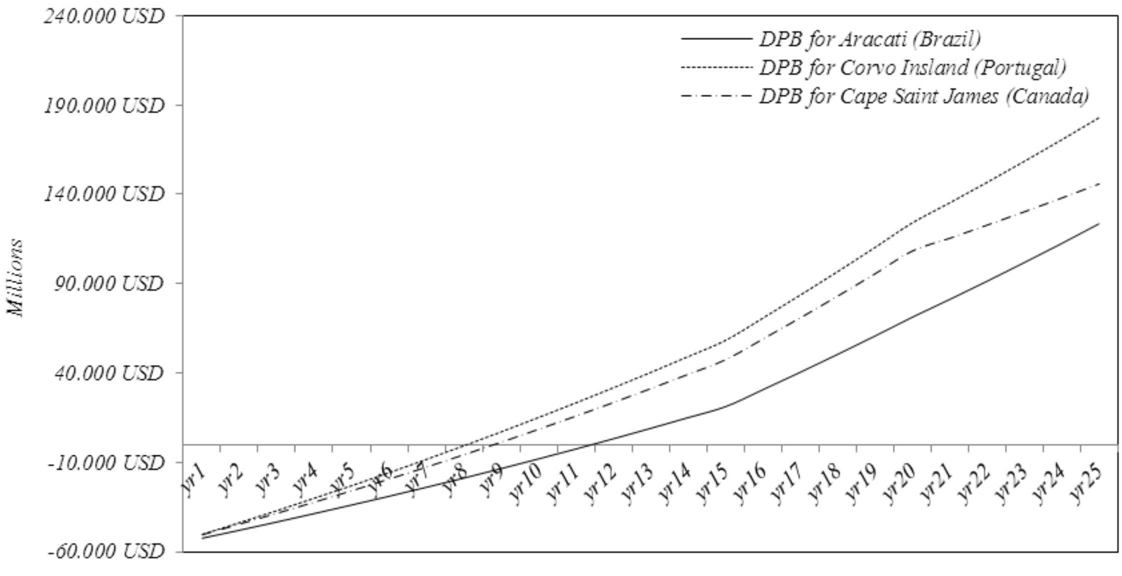

Figure 9.1 Comparison of paybacks for Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada). Source: Own elaboration

Figure 9.1 shows the payback period for the same wind project but installed in Aracati (Brazil), Corvo Island (Portugal) and Cape Saint James (Canada), within the respectively *PPARs*. The DPB found is *12*, *9* and *9* years, respectively for the same sites. What wind project should we invest, if we have to exclude some of the alternatives? Curiously the wind farms in Corvo Island (Portugal) and Cape Saint James (Canada) expected to have a production totally different (see Figure 8.13).

Simulating the electricity production costs by the $LCOE_{wso}$ was the most challenging when forecasting the wind farm revenues. It is possible to leave out the simulation effort and assume a set price of electricity over the horizon of the wind project and consider the renewable market trends. However, this is a highly simplified methodology and does not take into consideration the volatility of energy markets prices and costs.

In this Ph.D. thesis we consider as *limitations* for this methodology proposed some aspects after the simulations and general conclusions:

1. The $LCOE_{wso}$ methodology does not adequately reflect the market realities characterized by uncertainties and dynamic pricing;

2. The $LCOE_{wso}$ methodology provides production costs at the power plant level and does not include the distribution costs of the production (AEP);

3. The $LCOE_{wso}$ methodology reveals little information on the contribution of a given technology to addressing energy security and environmental sustainability;

4. The $LCOE_{wso}$ methodology does not indicate the relative likely stability of production costs over a plant's lifetime, and therefore the potential contribution to cost and possibly price stability.

During this Ph.D. research work, in other words, it was a long trip, we arrived at a number of crossings which forced us to choose how to move on, without knowing very well where each of the possibilities would lead us. The *light* always arrived in the right moment and were discovered different ways to continue the walking in order to help evaluation their merits for selecting the most promising option to follow. Furthermore, the hard and extensive review of the literature until the end of this research work, in fact, this behavior and felling, "*constant search for the best way to go"* gave me more power to help me healing the psychical and psychological pains obtained during my *journey for getting the knowledge* as one day I had dreamt about it. So now it is finished the research work, but never the search for the true light, *the wisdom*!

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APPENDICES

From Appendix *A to V*

APPENDIX A

Table A.1 Summary of basic notation of Table 5.8

Item	Nomenclature
1.1.1	*$cost_{tot}$= cost total; $cost_{gy}$= cost per generator per year; N = total number of turbines; e = 2.718282 (Euler number); s = estimated selling price for a kWh; E_{tot} = total expected energy output [kWh] of the wind farm per year.*
1.1.2	*E_{cost}= energy production cost [EUR/kWh]; Invest = investment [EUR];* P_{out,AVG^T} = *average output power [kW]; r = interest rate [-]; N = lifetime of the wind farm [years]; PR = profit in %; K = constant*
1.1.3	$C_{w,i}(w_i)$ = *cost of wind-generated power;* d_i = *direct cost coefficient for the* w_i *wind generator*
1.1.4	*cost = total cost/year for the entire wind farm; N= total number of turbines; e = 2.718282 (Euler number)*
1.1.5	C_t = *total annual cost per kilowatt installed;* n = *the lifetime of a wind turbine;* C_{in} = *annual installation cost;* $C_{O\&M}$ = *annual O&M cost*
1.1.6	C = *total cost;* C_i = *contributions from the different wind turbine main componentes;* R_i = *percentage cost for the ith component;* b_i = *cost fixed part contribution;* m_i = *design loads factor*
1.1.7	C_{cp} = *installation cost;* C_{op} = *operational cost; N = number of turbines;* ℓ = *cost constant calculation*
1.1.8	*LPC = levelized production cost; CC = Capital Cost;* $C_{O\&M,a}$ = *annual operation and maintenance; a = annuity factor;* E_a = *annual energy production*
1.1.9	*g = objective function;* $cost_m$ = *per unit value of cost/year of the whole wind farm;* P_{total} = *total energy produced in one year (MWatt);* w_1 *and* w_2 = *arbitrarily chosen weights*
1.1.10	$C_{i,t}$ = *total cost of the hybrid system;* $C_{i,PV}$ = *capital costs of PV solar array ;* $C_{i,W}$ = *capital cost of wind machines;* $C_{i,Q}$ = *capital cost of battery storage system; A= area (m^2); C = number of cloudy days;* A_{PV} = *area of the PV array (m^2);* X_i = *solar/wind power ratio; WC = capital cost of the wind machine; BC = cost of energy storage capacity; Q = total energy storage requirement*
1.1.11	$profit_{max}$ = *maximaze profite; k = estimated selling price for a kilowatt-hour of electricity in a given market;* $cost_{tot}$ = *total cost ;* P_{tot} = *total power output*
1.1.12	*LCE = levelized cost of energy; CO_{PV} = sum of capital cost and maintenance cost in the lifespan of the whole PV system; CO_W = sum of capital cost and replacement or maintenance cost in the lifespan of the whole wind power generation system; CO_{Bat} = sum of capital cost and the lifespan maintenance cost of baterry bank;* Y_{PV} = *lifetime year of PV system; Y_W = lifetime year of wind system; Y_{Bat} = the lifetime year of battery bank;* $E_{an}(\gamma,\beta,h)$ = *annual energy supplied from the hybrid solar-wind system;* β = *slope angle of the plane (radians);* γ = *azimuth angle of the plane (radians) and* h = *hour of production*

Source: Own elaboration

Table A.2 Summary of basic notation of Table 5.8 (Continuation)

Item	Nomenclature
1.1.13	*ACS = annualized cost of system;* C_{acap} *= annualized capital cost;* C_{arep} *= annualized replacement cost;* C_{amain} *= annualized maintenance cost;* P_V *= PV array;* W_{ind} *= wind turbine;* B_{at} *= battery;* T_{ower} *= wind turbine tower*
1.1.14	*OBJ = Objective optimization function; LPC = levelized production cost;* β *= weight factor for reliability;* R_s *= system reliability of the wind farm*
1.1.15	c_s *= PV cost per unit area (\$/m²);* α_s *= PV size (m²);* c_w *= WG cost per unit area (\$/m²);* α_w *= WG size (m²)*
1.1.16	*TC = total cost;* $\mathrm{F_i}$ *= fixed cost (\$);* C_i *= nameplate capacity of generator i;* pf_i *= price of fuel (\$/GJ) used by generator i;* $E_{t,i}$ *= fuel consumption (GJ) of generator i at time t;* $\mathrm{c_i}$ *= non-fuel variable (or operating and maintenance, O&M) costs of generator i (\$/MWh);* $Q_{t,i}$ *= electricity output (MW) delivered by generator (power plant) i at time t*
1.1.17	*C = total generation cost;* F_j *= cost function of generator j;* P_j *= electrical output of generator j;* a_j *,* b_j *e* c_j *= cost coefficients of generator j; J = set for all generators*

Source: Own elaboration

APPENDIX B

Table B.1 Summary of basic notation of Table 5.9

Item	Nomenclature
2.1.1	*$f(x_1)$ = fitness function 1;* P_{total} *= total energy from the wind farm;* P_{max} *= energy sum of the isolated wind turbine for the same wind conditions at the flat terrain;* $f(x_2)$ *= fitness function 2; costs = annual total costs of the wind farm*
2.1.2	*Obj = objective function; cost = total cost;* P_{tot} *= total power production; N = number of wind turbines;* u *= initial wind speed;* u_0 *= mean wind speed;* u_i *= final wind speed;*
2.1.3	E_{WF} *= electric energy generated by a wind farm; T = number of hours in a year (T=8760 h);* N_t *= number of turbines;* V_{ci} *= cut-in wind speed;* V_{co} *= cut-out wind speed;* $P_{gen}\,j(v)$ *= wind generator type considered in the wind farm*
2.1.4	*P = wind park power production per year;* h_y *= number of the hours over the year;* η *= nominal power utilization coefficient; N= number of wind park turbines;* P_{wt} *= wind turbine power rating;* N_{row} *= rows turbines numbers;* N_{col} *= columns turbines numbers;* L_x *= area with length (for row);* SD_x *= ;* k_{row} *and* k_{col} *= coefficients for wind turbines placement in rows and columns, respectively; D = wind turbine rotor diameter;* L_y *= area with length (for column)*
2.1.5	$P_{tot}(t)$ *= total power of the system;* $P_{PV}(t)$ *= power generated by the PV generator;* $P_{WD}(t)$ *= power generated by the wind turbine; t = hour t*
2.1.6	$P_{tot}(t)$ *= total power of the system;* N_h, N_w *and* N_s *= total no. of micro-hydro, wind, solar PV, respectively;* P_h, P_w *and* P_s *= electrical power generated by the micro-hydro, wind and solar PV unit, respectively;*
2.1.7	e_{CO2} *;* e_{CH4} *and* e_{N_2O} *= emissions factors for the fuele/source considered for* CO_2*,* CH_4 *and* N_2O*, respectvely;* GWP_{CO2}*,* GWP_{CH4} *and* GWP_{N_2O} *= global warming potentials for* CO_2*,* CH_4 *and* N_2O*, respectvely;* η *= is the fuel conversion efficiency;* λ *= fraction of electricity lost in transmission and distribution*
2.1.8	P_{tot} *= total power generation for all the turbines in the wind farm; N = total number of turbines placed in the wind farm;* P_i *= turbine i power rating*
2.1.9	$E_{windfarm}$ *= Amount of electricity produced by the windfarm; IC = installed capacity; CF = capacity factor;* h_{year} *= number of hours in a year*
2.1.10	E_{AP} *= annual electrical energy output (kWh);* S_R *= swept area of the rotor (m²); f (V) = Weibull probability density function of wind speed;* C_P *(V) = coefficient of performance;* η_{GB} *= gearbox efficiency;* η_G *=generator efficiency;* ρ_{air} *= air density (kg/m³)*
2.1.11	P_{opt} *= target (optimum) power; k = mechanical and electrical restrictions;* ω_r *= rotation speed*
2.1.12	*MAWPC = Maximal Available Wind Park Capacity;* FOR_t *= Forced Outage Rate, interpreted as a probability of unavailability; IWPC = Installed Wind Park Capacity*

Source: Own elaboration

Table B.2 Summary of basic notation of Table 5.9 (Continuation)

Item	Nomenclature
2.1.13	*N = total number of wind turbines; n = unit cell solution; R = wind farm radius; X_p = receptor density for the wind farm*
2.1.14	*V = wind speed at the hub; V_{ref} = reference wind speed at the reference hub height; Hub_{Ht} = hub height; H_{ref} = reference hub height (70 m)*
2.1.15	*E_y = annual energy production of the wind farm; E_i = gross energy production; W_{ake} = wake effect of wind farm; $coll_{ection}$ = production collection; a_{vail} = availability of the wind farm; $trans_{mission}$ = production transmission*
2.1.16	$\mathrm{P}_{i,j}$ *= monthly solar/wind hybrid power production; P_{sj} = hourly-calculated solar power in the month J; X_i = monthly basis solar energy percentage; P_{wj} = wind power in the month J*
2.1.17	*C_p = power curve of wind turbines; C_{pr} = nominal power coefficient; u = wind speed (m/s); u_r = nominal wind speed (m/s); s = operating range of wind speed (m/s)*

Source: Own elaboration

APPENDIX C

Table C.1 Glossary of terms

Capacity factor (C_f)	*The term "capacity factor" refers to the capability of a wind turbine to produce energy in a year. It is defined as the ratio of the actual energy output to the energy that would be produced if it is operated at rated power throughout the year.* $C_f = \frac{\text{Annual energy output}}{\text{rated power} \times \text{time in a years}}$ *Eqn (AC_1)*
Gearbox	*To convert the kinetic energy of the rotor into electrical energy, for conventional converters equipped with common four or six-pole synchronous or asynchronous generators, generally revolutions of 1,000 or 1,500 r/min are required when adhering as much as possible to grid specifications (50 Hz). Current rotor revolutions of 10 to 50 r/min with wind energy converters of installed capacities ranging from several 100 kW up to the multi-megawatt range thus require a transmission gear if no specific generators are applied (Ragheb & Ragheb, 2010).*
Generator	*The generator converts the mechanical rotation energy of the power train into electrical energy. For this purpose slightly adapted commercially available generators are used for conventional converters while especially designed three-phase alternators are applied for gearless converters. The main commonly applied generator types are synchronous and asynchronous generators (Bang, Polinder, Shrestha, & Ferreira, 2008).*
Rotor	*The system component of a modern wind energy converter that transforms the energy contained in the wind into mechanical rotations is referred to as rotor. It consists of one or several rotor blades and the rotor hub. The rotor blades extract part of the kinetic energy from the moving air masses according to the lift principle. The current maximum efficiency of the kinetic energy of the free flow in relation to the rotor surface amounts to 50%; usually, the so-called aerodynamic efficiency of state-of-the-art rotors amounts to between 42 and 48 % at the turbine design point (Barlas & van Kuik, 2010; Fuglsang & Madsen, 1999; Tangler, 2000).*
1/7th wind power law	*The wind speed and power available in the wind increases with increasing elevation. The relationship is commonly referred to as the one seventh power law (Rehman & Al-Abbadi, 2005).*

Source: Own elaboration

APPENDIX D

Table D.1 Electricity emission factors *(EF_{el})* for different countries for 2007-2009

Region/Country	tCO2/MWh	Region/Country	tCO2/MWh	Region/Country	tCO2/MWh	Region/Country	tCO2/MWh
OECD Americas	0.485	Armenia	0.145	Singapore	0.523	Marocco	0.690
USA (average)	0.531	Azerbaijan	0.462	Sri Lanka	0.425	Mozambique	0.000
Canada	0.184	Belarus	0.300	Thailand	0.530	Namibiae	0.253
Mexico	0.455	Bosnia-Herzegovina	0.908	Vietnam	0.409	Nigeria	0.396
Chile	0.398	Bulgaria	0.492	Other Asia	0.274	Senegal	0.594
OECD Europe	0.341	Croatie	0.337	**Middle East**	0.687	South Africa	0.900
Austria	0.183	Estonia	0.735	Bahrain	0.718	Sudan	0.470
Belgium	0.239	FYR of Macedonia	0.753	Cyprus	0.755	Togo	0.271
Czech Republic	0.534	Georgia	0.127	Iraq	0.731	Tunisia	0.547
Denmark	0.311	Gibraltar	0.756	Islamic Rep. Of Iran	0.609	United Rep. Of Tanzania	0.257
Finland	0.207	Kazakhstan	0.485	Israel	0.721	Zambia	0.003
France	0.089	Kyrgyzstan	0.087	Jordan	0.586	Zimbabwe	0.619
Germany	0.447	Latvia	0.160	Kuwait	0.810	Other Africa	0.489
Greece	0.739	Lithuania	0.116	Lebanon	0.698	**America**	0.178
Hungary	0.326	Malta	0.904	Oman	0.859	Argentina	0.358
Iceland	0.001	Republic of Moldova	0.513	Qatar	0.496	Bolivia	0.368
Ireland	0.482	Romania	0.436	Saudi Arabia	0.740	Brazil	0.075
Italy	0.416	Russia	0.322	Syria	0.649	Colombia	0.136
Luxembourg	0.382	Serbia	0.662	United Arab Emirates	0.694	Costa Rica	0.058
Netherlands	0.389	Slovenia	0.337	Yemen	0.649	Cuba	0.735
Norway	0.010	Tajikistan	0.031	**Africa**	0.641	Dominican Republic	0.633
Poland	0.652	Turkmenistan	0.810	Algeria	0.590	Ecuador	0.301
Portugal	0.379	Ukraine	0.373	Angola	0.220	El Salvador	0.304
Slovak Republic	0.223	Uzbekistan	0.462	Benine	0.695	Guatemala	0.354
Spain	0.337	Bangladesh	0.575	Botswanae	1.916	Haiti	0.513
Sweden	0.041	Brunei Darussalam	0.738	Cameroon	0.228	Honduras	0.391
Switzerland	0.040	China (incl. Hong Kong)	0.765	Congoe	0.139	Jamaica	0.478
Turkey	0.484	Chinese Taipei	0.647	Côte d'Ivoire	0.428	Netherlands Antilles	0.707
United Kingdom	0.480	DPR of Korea	0.483	DR of Congo	0.003	Nicaragua	0.506
OECD Asia	0.503	India	0.950	Egypt	0.459	Panama	0.297
Australia	0.862	Indonesia	0.757	Eritrea	0.665	Paraguay	0.000
Japan	0.435	Malaysia	0.638	Ethiopia	0.094	Peru	0.225
Korea	0.471	Myanmar	0.249	Gabon	0.366	Trinidad and Tobago	0.725
New Zealand	0.191	Nepal	0.004	Ghana	0.254	Uruguay	0.221
Non-OECD	0.503	Pakistan	0.447	Kenya	0.321	Venezuela	0.203
Albania	0.023	Philippines	0.471	Libya	0.868	Other Latin America	0.242

Source: IEA (2011)

APPENDIX E

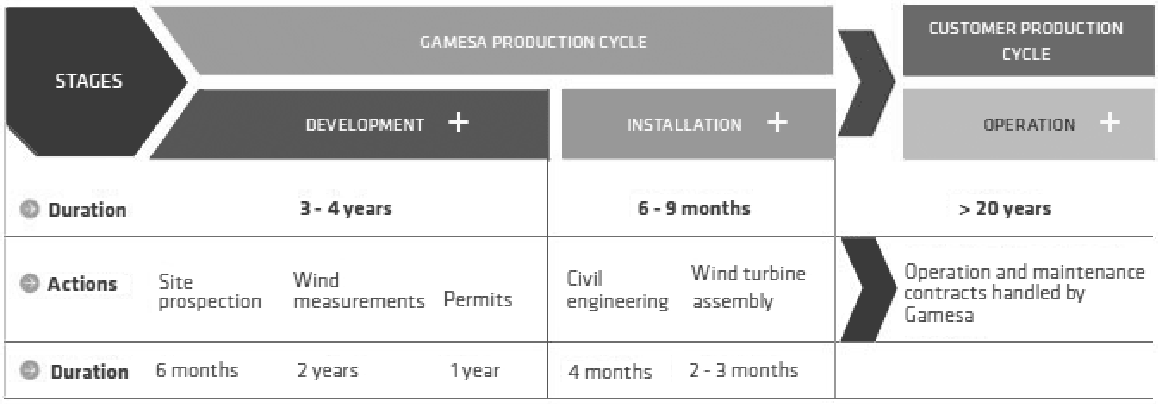

Figure E.1 Value creation stages for Gamesa. Source: Gamesa (2012)

Table E.1 KW to MW conversion table

Power (kilowatts)	Power (megawatts)
0 kW	*0 MW*
1 kW	*0.001 MW*
10 kW	*0.01 MW*
100 kW	*0.1 MW*
1000 kW	*1 MW*
10000 kW	*10 MW*
100000 kW	*100 MW*
1000000 kW	*1000 MW*

Source: SI

APPENDIX F

(a) *(b)*

(c)

Figure F.1 Photos of current MW-onshore wind farms at Aracati (Brazil)[(a)], Corvo Island (Portugal)[(b)] and Cape Saint James (Canada)[(c)]. Sources: Grupo Servtec (2013); DGGE (2009) and CanWEA (2012)

APPENDIX G

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80,00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4,00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0,08581	[$/kWh]
Expected Market Price	0,06007	[$/kWh]
PPAR and EMP ratio	70,00%	[%]
	885.254	

Financial Indexes		Notes
Inflation rate (ifr)	2,50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
UCRF	0,070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2.000	[kW]
Wind Farm Capacity (WF_{cap})	50.000	[kW]
Rotor Diamenter (D)	90,0	[m]
Swept Area per Turbine (A)	6.361,7	[m²]
Hub height (H)	105,0	[m]
Wind speed measured at (H_0)	10,0	[m]
Terrain rugosity factor (a)	0,14	[–]
Betz Limit`s coefficient (C_{PBetz})	0,5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11,2%	[%]
Availability	97,9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16,8442	[$/kW]
$Depr_{WT_{inst}}$	76,9840	[$/kW]
WT_{CM}	553,7256	[$/kW]
T_{CM}	484,3859	[$/kW]
N	25	[yr]
ifr	2,50%	[%/yr]
$Depr_{Y_{RC}}$	60,1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0,000033	[$/kW]
TI	1.798.743	[$/kW]
V	237.699.000	[kW]
V_0	6.100.000	[kW]
c_0	1.457,72	[$/kW]
PR	0,70	[–]
b	-1,94	[–]
LRCM	**16,8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1.339,9154	[$/kW]
RM_{WT}	22,3284	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85,00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2,0	[d]
$C_{md_{RMWT}}$	2.500,00	[$/d]
RM_{CT}	20,1954	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3,0	[m-h]
$C_{Mhr_{RCT}}$	85,00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2,0	[d]
$C_{md_{RMCT}}$	3.500,00	[$/d]
$S\&RV$	1.297,3916	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
A_{WT}	43,00	[m²/wt]
$M_{hr_{S\&RV}}$	3,0	[m-h]
$C_{Mhr_{S\&RV}}$	85,00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3,0	[d]
$C_{md_{S\&RV}}$	3.500,00	[$/d]
RVM_{WF}	61,0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1,4442	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
WT_{weight}	200.000	[kg]
C_{steel}	0,1900	[$/kg]
TS_{VM}	0,9965	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
T_{mass}	138.000	[kg]
RCM_{WF}	**1.278,8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70,8203	[$/kW$_e$]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$LRCM$	16,8443	[$/kW]
ifr	2,50%	[%/yr]
ψ_{total}	30,00%	[%]
n_ψ	6	[yr]
REP_{CM}	0,00002627	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5.695	[kW/yr]
ifr	2,50%	[%/yr]
ε	0,1496	[$/kW$_e$h]
ε_0	0,116883	[$/kW$_e$h]
n_ε	10	[yr]
$OREP_{CM}$	13,0797	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	2,7664	[$/kW]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
ψ_{total}	30,0%	[%]
ifr	2,5%	[%/yr]
n_ψ	10	[yr]
CR_f	80,0%	[%]
$GHG.R_{CM}$	1.596,4321	[$/tCO₂]
$LCER_{CO_2}$	18,6	[tCO₂/MW$_e$h]
$\sum AEP_{avail\ yr_1+...+yr_n}$	48.856	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0,00041	[tCO₂/MW$_e$h]
$GHG_{EM_{wecs\ CO_2}}$	0,00003	[tCO₂/MW$_e$h]
ε_c	46,3820	[$/tCO₂]
REPIM distribution	100,0%	[%]
ξ_1 REI_{CM}	25,0%	[%]
ξ_2 REP_{CM}	25,0%	[%]
ξ_3 $OREP_{CM}$	25,0%	[%]
ξ_4 $GHG.R_{CM}$	25,0%	[%]
REPIM	**420,0830**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50.000	[kW$_e$/yr]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
WT_{rated}	2.000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90,0	[m]
$L_{x_{row}}$	1.800	[m]
$L_{x_{col}}$	2.430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8.760	[h/yr]
PC_{PM}		
AEP_{avail}	48.856.319	[kW$_e$h/yr]
η_{wecs}	20,98%	[%]
$\eta_{wecs_{(ref)}}$	25,00%	[%]
$P\&D_{LM\ factor}$	0,839325	[–]
N_{WT}	25	[–]
A	6.361,7	[m²]
AEP_{rated}	438.000.000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7,00%	[%]
$\lambda_{s\&i}$	0,00%	[%]
λ_d	5,00%	[%]
λ_m	5,00%	[%]
$LCPM_{WF}$	**48.856.319**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553,7256	[$/kW]
CM_{WT}	265,32	[$/kW]
RC_{WT}	73,70%	[%/$/kW]
C_{kW}	400,00	[$/kW]
IPT	10,00%	[%]
T_{CM}	484,3859	[$/kW]
T_{mass}	138.000	[kg]
RC_T	26,30%	[%/$/kW]
C_{steel}	0,1900	[$/kg]
$LWTG_{CM}$	39,1957	[$/m/kW]
WF_{cap}	50.000	[kW]
L_g	13.950	[m]
CAB_{cost}	2.000,00	[$/m]
CP_{CM}	30,9069	[$/kW]
EF_c	400,00	[$/kW]
ς	0,08%	[%]
TS_{CM}	11,4566	[$/kW$_e$]
TL_c	0,0400	[$/m]
TL_r	1.200	[1/kW]
L_t	3.000	[m]
SB_c	113,00	[$/kWh]
SI_{CM}	42,7345	[$/m²/kW]
WF_{cap}	50.000	[kW]
WT_{inst}	42,5238	[$/kW]
Bld_{cost}	500,00	[$/m²]
Bld_{area}	300,0	[m²]
PO_{CM}	35,9374	[$/kW]
FS	19,88	[$/kW]
DT	87,22	[$/kW]
EG	404,52	[$/kW]
F_{CM}	3,7712	[$/kW]
$WACC_{proj}$	4,900%	[%/yr]
n_{fin}	1,0	[yr]
$W_{F_{CM}}$	0,30%	[%]
CCC_{CM}	2,4042	[$/kW]
κ	0,20%	[%]
$LCCCM_{WF}$	**1.204,5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0,098275	[$/kWh]
$LCCCM_{WF}$	1.204,5180	[$/kW]
ϖ	0,0000001%	[%]
LLC	0,0530	[$/kWh]
N	25	[yr]
ifr	2,50%	[%/yr]
$O\&M_{variable_{CM}}$	0,025858	[$/kWh]
MLC	71,5608	[$/h]
TLC	124,5688	[$/h]
R_{taxes}	30,00%	[%]
ifr	2,50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	4.192.361	[$M]
AEP_{avail}	48.856.319	[kWh/yr]
$O\&M_{WFCM}$	**0,124133**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0,000105**	**[$/kWh]**
Work days	3,0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72,0	[h]
$USC_{O\&M}$	**0,000287**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1,5	[per yr]
Repair time	3,0	[h]
Hours required	112,5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184,5**	**[h/yr]**
	0,000392	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8.760**	**8.579**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1,3252	[–]
$CAN/USD_{dec2010}$	0,9998	[–]
$BRL/USD_{dec2010}$	0,5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	[1/0]
(%) ccm	80,0%	[%]
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	[1/0]
ξ_2 REP_{CM}	1	[1/0]
ξ_3 $OREP_{CM}$	1	[1/0]
ξ_4 $GHG.R_{CM}$	1	[1/0]
$P\&D_{LM}$		
λ_a	1	[1/0]
$\lambda_{s\&i}$	0	[1/0]
λ_d	1	[1/0]
λ_m	1	[1/0]
	p.s.: 1= yes and 0=no	

Project Financing		Notes
Debt ratio	50,0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5,00%	[%/yr]
Debt value	29.920.545	[$]
Debt payments	3.022.692	[$/yr]
Equity ratio	50,0%	[%]
Equity value	29.920.545	[$]
Discount rate	9,00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67,6603	yr_1	70,7762	yr_{15}
67,8118	yr_2	69,8077	yr_{15}
68,0210	yr_3	69,9988	yr_{16}
68,1822	yr_4	70,1987	yr_{17}
68,4349	yr_5	70,3955	yr_{18}
68,6241	yr_6	70,7564	yr_{19}
68,8710	yr_7	70,3686	yr_{20}
69,0863	yr_8	70,5514	yr_{21}
69,2587	yr_9	70,8222	yr_{22}
69,4873	yr_{10}	71,1051	yr_{23}
69,7236	yr_{11}	71,3664	yr_{25}
70,0026	yr_{12}	69,6792	Mean
70,2282	yr_{13}	1,0823	SD
70,4423	yr_{14}	-0,4514	Υ (skewness)
$LCOE_{wso}$	**69,6792**	**US$/MWh**	valid !
	0,069679	**US$/kWh**	

Figure G.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical $50MW_e$ wind farm in Aracati (Brazil) with reference situation. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2.000	[kW]
Wind Farm Capacity (WF_{cap})	50.000	[kW]
Rotor Diamenter (D)	90,0	[m]
Swept Area per Turbine (A)	6.361,7	[m²]
Hub height (H)	105,0	[m]
Wind speed measured at (H_0)	10,0	[m]
Terrain rugosity factor (α)	0,14	[–]
Betz Limit's coefficient (C_{PBetz})	0,5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20,5%	[%]
Availability	97,9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553,7256	[$/kW]
CM_{WT}	265,32	[$/kW]
RC_{WT}	73,70%	[%/$/kW]
C_{kW}	400,00	[$/kW]
IPT	10,00%	[%]
T_{CM}	484,3859	[$/kW]
T_{mass}	138.000	[kg]
RC_T	26,30%	[%/$/kW]
C_{steel}	0,1900	[$/kg]
$LWTG_{CM}$	39,1957	[$/m/kW]
WF_{cap}	50.000	[kW]
L_g	13.950	[m]
CAB_{cost}	2.000,00	[$/m]
CP_{CM}	30,9069	[$/kW]
EF_c	400,00	[$/kW]
ς	0,08%	[%]
TS_{CM}	11,4566	[$/kWe]
TL_c	0,0400	[$/m]
TL_r	1.200	[1/kW]
L_t	3.000	[m]
SB_c	113,00	[$/kWh]
SI_{CM}	42,7345	[$/m²/kW]
WF_{cap}	50.000	[kW]
WT_{inst}	42,5238	[$/kW]
Bld_{cost}	500,00	[$/m²]
Bld_{area}	300,0	[m²]
PO_{CM}	35,9374	[$/kW]
FS	19,88	[$/kW]
DT	87,22	[$/kW]
EG	404,52	[$/kW]
F_{CM}	3,7712	[$/kW]
$WACC_{proj}$	4,900%	[%/yr]
n_{fin}	1,0	[yr]
$W_{F_{CM}}$	0,30%	[%]
CCC_{CM}	2,4042	[$/kW]
κ	0,20%	[%]
$LCCCM_{WF}$	**1.204,5180**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80,00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16,8442	[$/kW]
$Depr_{WT_{wo}}$	76,9840	[$/kW]
WT_{CM}	553,7256	[$/kW]
T_{CM}	484,3859	[$/kW]
N	25	[yr]
ifr	2,50%	[%/yr]
$Depr_{T_c}$	60,1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0,000033	[$/kW]
TI	1.798.743	[$/kW]
V	237.699.000	[kW]
V_0	6.100.000	[kW]
c_0	1.457,72	[$/kW]
PR	0,70	[–]
b	-1,94	[–]
LRCM	**16,8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0,098275	[$/kWh]
$LCCCM_{WF}$	1.204,5180	[$/kW]
ϖ	0,0000001%	[%]
LLC	0,0530	[$/kWh]
N	25	[yr]
ifr	2,50%	[%/yr]
$O\&M_{variable_{CM}}$	0,048935	[$/kWh]
MLC	71,5608	[$/h]
TLC	124,5688	[$/h]
R_{taxes}	30,00%	[%]
ifr	2,50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	14.605.780	[$M]
AEP_{avail}	89.657.257	[kWh/yr]
$O\&M_{WFCM}$	**0,147210**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0,000057**	**[$/kWh]**
Work days	3,0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72,0	[h]
$USC_{O\&M}$	**0,000156**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1,5	[per yr]
Repair time	3,0	[h]
Hours required	112,5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184,5**	**[h/yr]**
	0,000214	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4,00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1.339,9154	[$/kW]
RM_{WT}	22,3284	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
M_{hr}	100	[m-h]
C_{MW}	85,00	[$/m-h]
N_m	3	[–]
D_m	2,0	[d]
C_{md}	2.500,00	[$/d]
RM_{CT}	20,1954	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
M_{hr}	3,0	[m-h]
C_{MW}	85,00	[$/m-h]
N_m	3	[–]
D_m	2,0	[d]
C_{md}	3.500,00	[$/d]
S&RV	1.297,3916	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
A_{WT}	43,00	[m²/wt]
M_{hr}	3,0	[m-h]
C_{MW}	85,00	[$/m-h]
N_m	3	[–]
D_m	3,0	[d]
C_{md}	3.500,00	[$/d]
RVM_{WF}	61,0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1,4442	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
WT_{weight}	200.000	[kg]
C_{steel}	0,1900	[$/kg]
TS_{VM}	0,9965	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
T_{mass}	138.000	[kg]
RCM_{WF}	**1.278,8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February(*)	672	639
March	744	735
April	720	711
May	744	735
June(*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November(*)	720	687
December	744	735
Total [h/yr]	**8.760**	**8.579**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0,16291	[$/kWh]
Expected Market Price	0,11403	[$/kWh]
PPAR and EMP ratio	70,00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70,8203	[$/kWe]
$LCCCM_{WF}$	1.204,5180	[$/kW]
LRCM	16,8443	[$/kW]
ifr	2,50%	[%/yr]
ψ_{total}	30,00%	[%]
n_ψ	6	[yr]
REP_{CM}	0,00001039	[$/kWeh]
AEP_{avail}/H_{prod}	10.451	[kW/yr]
ifr	2,50%	[%/yr]
ε	0,1086	[$/kWeh]
ε_0	0,075000	[$/kWeh]
n_ε	15	[yr]
$OREP_{CM}$	21,2151	[$/kWe]
$LCCCM_{WF_{OREG_{CM}}}$	2,4451	[$/kW]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
ψ_{total}	30,0%	[%]
ifr	2,5%	[%/yr]
n_ψ	15	[yr]
CR_f	80,0%	[%]
$GHG.R_{CM}$	821,1245	[$/tCO2]
$LCER_{CO_2}$	34,1	[tCO_2/MW_eh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	89.657	[MW_eh]
n_ψ	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0,00041	[tCO_2/MW_eh]
$GHG_{EM_{wecs\,CO_2}}$	0,00003	[tCO_2/MW_eh]
ε_c	13,0000	[$/tCO2]
REPIM distribution	100,0%	[%]
ξ_1 REI_{CM}	25,0%	[%]
ξ_2 REP_{CM}	25,0%	[%]
ξ_3 $OREP_{CM}$	25,0%	[%]
ξ_4 $GHG.R_{CM}$	25,0%	[%]
REPIM	**228,2900**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1,3252	[–]
$CAN/USD_{dec2010}$	0,9998	[–]
$BRL/USD_{dec2010}$	0,5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80,0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2,50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
UCRF	0,070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50.000	[kWe/yr]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
WT_{rated}	2.000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90,0	[m]
$L_{x_{row}}$	1.800	[m]
$L_{x_{col}}$	2.430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8.760	[h/yr]
PC_{PM}		
AEP_{avail}	89.657.257	[kW_eh/yr]
η_{wecs}	20,98%	[%]
$\eta_{wecs_{(ref)}}$	25,00%	[%]
$P\&D_{LM\,factor}$	0,839325	[–]
N_{WT}	25	[–]
A	6.361,7	[m²]
AEP_{rated}	438.000.000	[kW_eh/yr]
$P\&D_{LM}$		
λ_a	7,00%	[%]
$\lambda_{s\&i}$	0,00%	[%]
λ_d	5,00%	[%]
λ_m	5,00%	[%]
$LCPM_{WF}$	**89.657.257**	**[kW_eh/yr]**

Project Financing		Notes
Debt ratio	50,0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5,00%	[%/yr]
Debt value	29.869.699	[$]
Debt payments	3.017.556	[$/yr]
Equity ratio	50,0%	[%]
Equity value	29.869.699	[$]
Discount rate	9,00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73,0793	yr_1	78,4116	yr_{15}
73,4776	yr_2	77,5903	yr_{15}
73,7436	yr_3	78,1098	yr_{16}
74,0885	yr_4	78,5637	yr_{17}
74,4286	yr_5	79,0704	yr_{18}
74,8887	yr_6	79,5598	yr_{19}
75,1794	yr_7	77,6767	yr_{20}
75,4693	yr_8	78,1898	yr_{21}
75,9694	yr_9	78,6500	yr_{22}
76,3656	yr_{10}	78,9953	yr_{23}
76,6792	yr_{11}	79,3896	yr_{25}
77,1795	yr_{12}	76,8138	Mean
77,5814	yr_{13}	2,0085	SD
78,0080	yr_{14}	-0,4651	ϒ (skewness)
$LCOE_{wso}$	**76,8138**	**US$/MWh**	valid !
	0,076814	**US$/kWh**	

Figure G.2 *I-O system representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical $50MW_e$ wind farm in Corvo Island (Portugal) with reference situation. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80,00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4,00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0,13835	[$/kWh]
Expected Market Price	0,09684	[$/kWh]
PPAR and EMP ratio	70,00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2,50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
UCRF	0,070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2.000	[kW]
Wind Farm Capacity (WF_{cap})	50.000	[kW]
Rotor Diamenter (D)	90,0	[m]
Swept Area per Turbine (A)	6.361,7	[m²]
Hub height (H)	105,0	[m]
Wind speed measured at (H_0)	10,0	[m]
Terrain rugosity factor (a)	0,14	[–]
Betz Limit's coefficient (C_{PBetz})	0,5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48,5%	[%]
Availability	97,9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16,8442	[$/kW]
$Depr_{WT_{rec}}$	76,9840	[$/kW]
WT_{CM}	553,7256	[$/kW]
T_{CM}	484,3859	[$/kW]
N	25	[yr]
ifr	2,50%	[%/yr]
$Depr_{RC}$	60,1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0,000033	[$/kW]
TI	1.798.743	[$/kW]
V	237.699.000	[kW]
V_0	6.100.000	[kW]
c_0	1.457,72	[$/kW]
PR	0,70	[–]
b	-1,94	[–]
LRCM	**16,8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1.339,9154	[$/kW]
RM_{WT}	22,3284	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85,00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2,0	[d]
$C_{md_{RM_{WT}}}$	2.500,00	[$/d]
RM_{CT}	20,1954	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3,0	[m-h]
$C_{Mhr_{RCT}}$	85,00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2,0	[d]
$C_{md_{RM_{CT}}}$	3.500,00	[$/d]
S&RV	1.297,3916	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
A_{WT}	43,00	[m²/wt]
$M_{hr_{S\&RV}}$	3,0	[m-h]
$C_{Mhr_{S\&RV}}$	85,00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3,0	[d]
$C_{md_{S\&RV}}$	3.500,00	[$/d]
RVM_{WF}	61,0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1,4442	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
WT_{weight}	200.000	[kg]
C_{steel}	0,1900	[$/kg]
TS_{VM}	0,9965	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
T_{mass}	138.000	[kg]
RCM_{WF}	**1.278,8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70,8203	[$/kW$_e$]
$LCCCM_{WF}$	1.204,5180	[$/kW]
LRCM	16,8443	[$/kW]
ifr	2,50%	[%/yr]
Ψ_{total}	30,00%	[%]
n_{Ψ}	6	[yr]
REP_{CM}	0,00000052	[$/kW$_e$h]
AEP_{avail}/H_{prod}	24.766	[kW/yr]
ifr	2,50%	[%/yr]
ε	0,0128	[$/kW$_e$h]
ε_0	0,009998	[$/kW$_e$h]
n_{ε}	10	[yr]
$OREP_{CM}$	56,8814	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	2,7664	[$/kW]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
Ψ_{total}	30,0%	[%]
ifr	2,5%	[%/yr]
n_{Ψ}	10	[yr]
CR_f	80,0%	[%]
$GHG.R_{CM}$	4.490,4890	[$/tCO$_2$]
$LCER_{CO_2}$	80,7	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+\dots+yr_n}}$	212.467	[MW$_e$h]
n_{Ψ}	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0,00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\,CO_2}}$	0,00003	[tCO$_2$/MW$_e$h]
ε_c	30,0000	[$/tCO$_2$]
REPIM distribution	100,0%	[%]
ξ_1 REI_{CM}	25,0%	[%]
ξ_2 REP_{CM}	25,0%	[%]
ξ_3 $OREP_{CM}$	25,0%	[%]
ξ_4 $GHG.R_{CM}$	25,0%	[%]
REPIM	**1.154,5477**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50.000	[kW$_e$/yr]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
WT_{rated}	2.000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90,0	[m]
$L_{x_{row}}$	1.800	[m]
$L_{x_{col}}$	2.430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8.760	[h/yr]
PC_{PM}		
AEP_{avail}	212.467.325	[kW$_e$h/yr]
η_{wecs}	20,35%	[%]
$\eta_{wecs_{(ref)}}$	25,00%	[%]
$P\&D_{LM\,factor}$	0,814145	[–]
N_{WT}	25	[–]
A	6.361,7	[m²]
AEP_{rated}	438.000.000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7,00%	[%]
$\lambda_{s\&i}$	3,00%	[%]
λ_d	5,00%	[%]
λ_m	5,00%	[%]
$LCPM_{WF}$	**212.467.325**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553,7256	[$/kW]
CM_{WT}	265,32	[$/kW]
RC_{WT}	73,70%	[%/$/kW]
C_{kW}	400,00	[$/kW]
IPT	10,00%	[%]
T_{CM}	484,3859	[$/kW]
T_{mass}	138.000	[kg]
RC_T	26,30%	[%/$/kW]
C_{steel}	0,1900	[$/kg]
$LWTG_{CM}$	39,1957	[$/m/kW]
WF_{cap}	50.000	[kW]
L_g	13.950	[m]
CAB_{cost}	2.000,00	[$/m]
CP_{CM}	30,9069	[$/kW]
EF_c	400,00	[$/kW]
ς	0,08%	[%]
TS_{CM}	11,4566	[$/kW$_e$]
TL_c	0,0400	[$/m]
TL_r	1.200	[1/kW]
L_t	3.000	[m]
SB_c	113,00	[$/kWh]
SI_{CM}	42,7345	[$/m²/kW]
WF_{cap}	50.000	[kW]
WT_{inst}	42,5238	[$/kW]
Bld_{cost}	500,00	[$/m²]
Bld_{area}	300,0	[m²]
PO_{CM}	35,9374	[$/kW]
FS	19,88	[$/kW]
DT	87,22	[$/kW]
EG	404,52	[$/kW]
F_{CM}	3,7712	[$/kW]
$WACC_{proj}$	4,900%	[%/yr]
n_{fin}	1,0	[yr]
W_{FCM}	0,30%	[%]
CCC_{CM}	2,4042	[$/kW]
κ	0,20%	[%]
$LCCCM_{WF}$	**1.204,5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{cap}}$	0,098275	[$/kWh]
$LCCCM_{WF}$	1.204,5180	[$/kW]
ϖ	0,0000001%	[%]
LLC	0,0530	[$/kWh]
N	25	[yr]
ifr	2,50%	[%/yr]
$O\&M_{variable_{CM}}$	0,041531	[$/kWh]
MLC	71,5608	[$/h]
TLC	124,5688	[$/h]
R_{taxes}	30,00%	[%]
ifr	2,50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	29.394.286	[$M]
AEP_{avail}	212.467.325	[kWh/yr]
$O\&M_{WFCM}$	**0,139806**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0,000024**	**[$/kWh]**
Work days	3,0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72,0	[h]
$USC_{O\&M}$	**0,000066**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1,5	[per yr]
Repair time	3,0	[h]
Hours required	112,5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184,5**	**[h/yr]**
	0,000090	**[$/kWh/yr]**

Project Financing		Notes
Debt ratio	50,0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5,00%	[%/yr]
Debt value	29.646.785	[$]
Debt payments	2.995.036	[$/yr]
Equity ratio	50,0%	[%]
Equity value	29.646.785	[$]
Discount rate	9,00%	[%/yr]

Exchange rates		Notes
$EUR/USD_{dec2010}$	1,3252	[–]
$CAN/USD_{dec2010}$	0,9998	[–]
$BRL/USD_{dec2010}$	0,5986	[–]

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8.760**	**8.579**

(*) Period of less hours for production

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80,0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0=no	

Initial Results Summary of $LCOE_{wso}$			Notes
84,2996	yr_1	94,3718	yr_{15}
84,9743	yr_2	94,0482	yr_{15}
85,6626	yr_3	94,8532	yr_{16}
86,1247	yr_4	95,7496	yr_{17}
86,8183	yr_5	96,6483	yr_{18}
87,5429	yr_6	97,4272	yr_{19}
88,1156	yr_7	93,9167	yr_{20}
88,8127	yr_8	94,6168	yr_{21}
89,7238	yr_9	95,6632	yr_{22}
90,3120	yr_{10}	96,4289	yr_{23}
91,1318	yr_{11}	97,4427	yr_{25}
91,8409	yr_{12}	91,7081	Mean
92,5685	yr_{13}	4,1890	SD
93,6087	yr_{14}	-0,3343	Υ (skewness)
$LCOE_{wso}$	**91,7081**	**US$/MWh**	valid !
	0,091708	**US$/kWh**	

Figure G.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical $50MW_e$ wind farm in Cape Saint James (Canada) with reference situation. Source: Own elaboration

Table G.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
				AEP_{avail}(kWh)																								
January	5,8	1,1665	738	1.693.132	8.890.198	3.802.165	7.507.410	557.361	8.890.198	557.361	557.361	4.232.212	8.890.198	8.890.198	557.361	3.802.165	7.507.410	4.232.212	8.890.198	8.890.198	557.361	3.802.165	7.507.410	557.361	3.802.165	7.507.410	4.232.212	4.232.212
February	4,9	1,1666	639	847.940	6.783.520	3.662.567	6.783.520	777.316	6.783.520	777.316	777.316	4.713.419	6.783.520	6.783.520	777.316	3.662.567	6.783.520	482.342	482.342	3.290.403	4.713.419	7.693.599	1.572.412	1.572.412	7.693.599	6.783.520	4.713.419	4.713.419
March	4,0	1,1671	735	555.090	7.476.817	5.424.310	8.853.970	975.829	7.476.817	975.829	975.829	6.543.367	7.476.817	7.476.817	975.829	5.424.310	8.853.970	894.553	894.553	1.809.568	4.214.966	1.809.568	1.686.232	1.686.232	7.806.630	8.853.970	3.786.671	6.543.367
April	4,7	1,1667	711	865.098	6.327.908	6.327.908	4.076.176	1.630.708	6.327.908	1.630.708	1.630.708	7.230.621	6.327.908	6.327.908	1.749.983	6.327.908	4.076.176	943.697	943.697	1.630.708	6.327.908	1.630.708	3.661.984	943.697	7.230.621	6.327.908	1.749.983	7.230.621
May	6,0	1,1670	735	1.809.500	5.424.109	7.476.539	5.424.109	1.809.500	5.424.109	1.809.500	1.809.500	7.806.340	5.424.109	5.424.109	1.686.169	7.476.539	6.543.124	1.686.169	1.686.169	975.792	8.853.641	975.792	555.069	894.520	6.543.124	4.214.809	1.686.169	7.806.340
June	7,9	1,1686	687	3.944.904	3.944.904	7.306.444	6.124.120	3.544.051	3.944.904	3.544.051	3.544.051	8.286.679	3.944.904	3.944.904	3.544.051	7.306.444	5.076.764	1.693.625	1.693.625	837.237	7.306.444	837.237	837.237	3.544.051	5.076.764	5.076.764	913.305	8.286.679
July	8,6	1,1698	735	5.437.072	3.795.580	8.874.801	1.690.199	4.224.882	3.795.580	4.224.882	4.224.882	556.396	556.396	3.795.580	5.437.072	8.874.801	1.813.825	3.795.580	3.795.580	556.396	7.494.407	556.396	978.125	4.224.882	4.224.882	1.690.199	896.658	556.396
August	9,6	1,1677	735	7.480.694	1.810.506	1.810.506	1.810.506	8.858.561	1.810.506	5.427.123	5.427.123	895.017	895.017	1.810.506	4.217.151	1.810.506	1.687.106	5.427.123	7.810.678	7.810.678	895.017	4.217.151	7.810.678	5.427.123	1.810.506	1.810.506	555.378	895.017
September	10,1	1,1657	711	8.554.384	1.629.176	1.629.176	3.658.543	7.542.482	1.629.176	6.321.963	6.321.963	942.810	942.810	1.629.176	6.321.963	1.629.176	3.658.543	6.321.963	7.223.828	7.223.828	942.810	5.240.771	8.554.384	6.321.963	1.629.176	3.658.543	6.321.963	942.810
October	9,7	1,1645	735	7.789.201	973.650	973.650	553.851	7.460.125	973.650	7.460.125	7.460.125	1.682.467	1.682.467	973.650	8.834.203	973.650	553.851	7.460.125	6.528.759	6.528.759	1.805.528	6.528.759	4.205.556	7.460.125	973.650	973.650	8.834.203	1.682.467
November	9,2	1,1638	687	6.098.939	833.795	833.795	833.795	6.098.939	833.795	7.276.401	7.276.401	1.686.661	1.686.661	833.795	7.276.401	833.795	833.795	7.276.401	5.055.889	5.055.889	1.571.703	6.968.989	6.098.939	7.276.401	833.795	833.795	7.276.401	1.686.661
December	7,6	1,1651	735	3.780.365	554.166	554.166	974.204	5.415.277	554.166	8.839.226	8.839.226	3.780.365	3.780.365	554.166	7.464.366	554.166	974.204	8.839.226	4.207.946	4.207.946	3.780.365	7.793.630	5.415.277	8.839.226	554.166	554.166	7.464.366	3.780.365
Annual	7,4	1,1666	8.579	48.856.319	48.444.328	48.676.026	48.290.403	48.895.032	48.444.328	48.844.485	48.844.485	48.356.354	48.391.173	48.444.328	48.841.866	48.676.026	48.362.288	49.053.015	49.213.265	48.817.403	48.463.568	48.054.765	48.883.303	48.747.993	48.179.078	48.285.240	48.430.728	48.356.354

Table G.2 Energy production map of the wind farm for Corvo Island (Portugal)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
				AEP_{avail}(kWh)																								
January	11,7	1,2313	738	14.451.298	14.451.298	14.451.298	14.451.298	14.451.298	14.451.298	14.451.298	10.842.026	10.842.026	14.451.298	10.842.026	10.842.026	10.842.026	14.451.298	10.842.026	10.842.026	14.451.298	10.842.026	10.842.026	10.842.026	10.842.026	10.842.026	10.842.026	10.842.026	10.842.026
February	11,5	1,2345	639	11.923.902	4.233.203	11.923.902	11.923.902	11.923.902	3.369.392	11.923.902	12.538.268	1.770.714	3.369.392	12.538.268	1.770.714	9.115.121	11.923.902	6.580.843	12.538.268	4.233.203	5.409.699	3.369.392	2.776.293	11.923.902	2.077.293	6.580.843	11.923.902	12.538.268
March	10,5	1,2329	735	10.471.380	3.189.384	13.698.087	13.698.087	13.698.087	6.214.620	13.698.087	13.698.087	2.386.378	3.189.384	13.698.087	2.386.378	13.698.087	13.698.087	6.214.620	13.698.087	3.870.731	7.560.022	4.863.071	13.698.087	14.403.865	2.034.182	10.471.380	14.403.865	3.189.384
April	9,5	1,2317	711	7.305.887	7.305.887	10.443.175	10.443.175	10.443.175	7.305.887	10.443.175	4.699.596	3.082.171	7.305.887	13.237.618	3.082.171	13.237.618	4.699.596	4.699.596	13.237.618	3.082.171	10.119.379	3.082.171	13.919.671	13.237.618	3.082.171	3.082.171	13.237.618	3.740.614
May	8,2	1,2282	735	4.844.807	10.432.053	10.432.053	10.432.053	6.191.280	10.432.053	10.432.053	10.432.053	3.856.194	6.191.280	10.432.053	3.856.194	14.349.768	10.432.053	3.856.194	10.432.053	2.377.416	13.646.640	6.191.280	2.377.416	10.432.053	3.856.194	14.349.768	10.432.053	4.844.807
June	7,1	1,2224	687	2.955.541	12.693.755	7.005.728	7.005.728	7.005.728	10.014.121	4.506.515	12.693.755	4.506.515	10.014.121	7.005.728	4.506.515	7.005.728	2.211.411	2.955.541	7.005.728	1.885.038	12.693.755	7.005.728	1.885.038	7.005.728	4.506.515	12.693.755	7.005.728	5.758.970
July	6,1	1,2154	735	2.005.275	13.503.424	4.793.962	6.126.305	10.322.572	13.503.424	7.452.587	3.144.060	6.126.305	2.005.275	6.126.305	6.126.305	6.126.305	2.005.275	2.352.466	6.126.305	6.126.305	14.199.172	10.322.572	3.815.724	6.126.305	6.126.305	13.503.424	3.815.724	7.452.587
August	6,4	1,2075	735	2.337.182	10.583.661	3.790.935	3.790.935	3.790.935	13.415.696	6.086.504	3.790.935	7.404.169	2.337.182	4.762.817	7.404.169	4.762.817	10.583.661	1.992.247	4.762.817	13.415.696	1.992.247	13.415.696	4.762.817	4.762.817	7.404.169	4.762.817	3.123.634	10.255.509
September	7,6	1,2064	711	3.663.832	1.925.451	5.882.434	4.603.129	4.603.129	4.603.129	1.925.451	5.882.434	9.911.660	9.911.660	3.663.832	9.911.660	3.663.832	5.882.434	9.911.660	3.663.832	12.965.892	2.258.821	12.965.892	5.882.434	3.663.832	9.911.660	3.663.832	2.258.821	1.925.451
October	8,9	1,2126	735	6.112.412	6.112.412	3.136.930	2.000.727	3.136.930	2.000.727	2.347.131	7.435.686	13.472.801	13.472.801	3.136.930	13.472.801	3.136.930	7.435.686	13.472.801	3.136.930	10.628.711	3.136.930	2.000.727	7.435.686	3.136.930	13.472.801	2.347.131	2.000.727	2.347.131
November	10,6	1,2194	687	9.990.034	3.578.305	2.206.092	2.206.092	2.206.092	2.206.092	2.948.433	2.206.092	12.663.223	4.495.676	2.206.092	12.663.223	2.206.092	2.948.433	12.663.223	2.206.092	9.680.288	3.578.305	2.206.092	9.680.288	2.206.092	12.663.223	1.880.504	5.745.118	12.663.223
December	11,5	1,2237	735	13.595.706	2.368.542	2.018.979	3.165.547	2.018.979	3.165.547	3.841.801	2.018.979	14.296.210	13.595.706	2.018.979	14.296.210	2.018.979	3.841.801	14.296.210	2.018.979	7.503.518	4.826.724	14.296.210	13.595.706	2.018.979	14.296.210	6.168.172	4.826.724	13.595.706
Annual	9,1	1,2222	8.579	89.657.257	90.377.375	89.783.574	89.846.976	89.792.106	90.681.985	90.056.935	89.381.970	90.318.367	90.339.663	89.668.733	90.318.367	90.163.301	90.113.636	89.837.428	89.668.733	90.220.267	90.263.721	90.560.856	90.671.187	89.760.146	90.272.750	90.345.823	89.615.940	89.153.675

Table G.3 Energy production map of the wind farm for Cape Saint James (Canada)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
				AEP_{avail}(kWh)																								
January	15,4	1,2561	738	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	8.013.494	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	32.734.798	40.754.809	32.734.798	32.734.798	28.019.994	8.013.494	7.100.933
February	14,7	1,2522	639	24.248.099	14.467.424	6.912.583	26.228.520	14.467.424	14.467.424	26.228.520	26.228.520	6.912.583	14.467.424	14.467.424	7.749.925	26.228.520	6.912.583	17.377.262	6.912.583	6.912.583	6.912.583	6.912.583	22.462.574	26.228.520	26.228.520	28.959.584	7.749.925	17.351.256
March	12,7	1,2495	735	18.226.532	18.226.532	8.896.263	27.834.779	12.376.594	18.226.532	27.834.779	27.834.779	8.896.263	12.376.594	18.226.532	9.971.944	27.834.779	8.896.263	30.108.137	8.896.263	8.896.263	8.896.263	8.896.263	22.991.460	27.834.779	27.834.779	31.414.830	9.971.944	18.921.332
April	12,4	1,2490	711	16.057.711	19.287.404	9.641.890	24.828.913	9.641.890	19.287.404	24.828.913	24.828.913	9.641.890	9.641.890	19.287.404	9.641.890	24.828.913	9.641.890	26.913.496	9.641.890	29.111.609	9.641.890	9.641.890	22.185.639	19.971.909	24.828.913	24.919.931	9.641.890	18.139.032
May	11,2	1,2425	735	12.306.614	25.533.644	9.915.560	19.834.848	9.915.560	25.533.644	19.834.848	19.834.848	9.915.560	9.915.560	25.533.644	12.306.614	19.834.848	9.915.560	25.533.644	9.915.560	27.677.395	9.915.560	9.915.560	20.989.216	19.834.848	19.834.848	19.089.277	12.306.614	16.168.320
June	10,4	1,2351	687	9.212.474	25.714.865	11.433.985	16.838.388	8.218.718	25.714.865	16.838.388	16.838.388	11.433.985	8.218.718	25.714.865	15.342.558	16.838.388	11.433.985	16.838.388	11.433.985	23.723.122	11.433.985	11.433.985	16.955.390	16.838.388	16.838.388	16.760.685	15.342.558	14.949.503
July	10,0	1,2275	735	8.739.531	29.577.699	16.314.803	16.314.803	7.795.266	29.577.699	16.314.803	16.314.803	16.314.803	7.795.266	29.577.699	17.905.422	16.314.803	16.314.803	7.795.266	16.314.803	19.596.205	16.314.803	16.314.803	15.530.715	16.046.466	16.314.803	16.760.185	17.905.422	8.625.161
August	9,7	1,2216	735	7.757.712	12.099.972	17.819.161	12.099.972	17.819.161	12.099.972	12.099.972	12.099.972	17.819.161	17.819.161	12.099.972	19.501.798	12.099.972	17.819.161	8.697.428	17.819.161	17.819.161	17.819.161	17.819.161	12.903.119	15.377.861	12.099.972	12.588.985	19.501.798	7.111.908
September	10,4	1,2234	711	9.444.238	7.515.148	18.892.028	9.444.238	26.361.791	7.515.148	9.444.238	9.444.238	18.892.028	26.361.791	7.515.148	24.319.940	9.444.238	18.892.028	9.444.238	18.892.028	15.728.541	18.892.028	18.892.028	12.321.085	13.275.521	9.444.238	8.842.059	24.319.940	19.029.793
October	13,1	1,2327	735	19.679.010	8.776.461	29.702.682	9.837.656	25.333.032	8.776.461	9.837.656	9.837.656	29.702.682	25.333.032	8.776.461	27.459.940	9.837.656	25.333.032	9.837.656	25.333.032	12.209.924	29.702.682	25.333.032	12.242.414	8.858.686	9.837.656	8.122.639	27.459.940	21.596.003
November	14,3	1,2429	687	23.874.256	9.271.165	25.878.688	8.271.078	27.992.285	9.271.165	8.271.078	8.271.078	25.878.688	27.992.285	9.271.165	27.992.285	8.271.078	25.878.688	11.506.828	25.878.688	9.271.165	25.878.688	25.878.688	7.423.013	8.271.078	8.271.078	8.870.902	27.992.285	21.951.058
December	15,1	1,2528	735	30.186.350	9.997.848	25.745.545	7.955.677	19.999.456	9.997.848	7.955.677	7.955.677	25.745.545	19.999.456	9.997.848	32.498.621	7.955.677	30.186.350	16.650.529	30.186.350	9.997.848	25.745.545	30.186.350	6.350.393	7.955.677	7.955.677	9.163.644	32.498.621	42.475.115
Annual	12,5	1,2404	8.579	212.467.325	213.202.961	213.887.985	212.223.670	212.655.974	213.202.961	212.223.670	212.223.670	213.887.985	212.655.974	213.202.961	212.704.429	212.223.670	213.959.139	213.437.670	213.959.139	213.678.613	213.887.985	213.959.139	213.109.827	213.228.530	212.223.670	213.512.714	212.704.429	213.419.415

Table G.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil)

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5,8	5,8	10,1	7,6	9,6	4,0	10,1	4,0	4,0	7,9	10,1	10,1	4,0	7,6	9,6	7,9	10,1	10,1	4,0	7,6	9,6	4,0	7,6	9,6	7,9	7,9
February	4,9	4,9	9,7	7,9	9,7	4,7	9,7	4,7	4,7	8,6	9,7	9,7	4,7	7,9	9,7	4,0	4,0	7,6	8,6	10,1	6,0	6,0	10,1	9,7	8,6	8,6
March	4,0	4,0	9,6	8,6	10,1	4,9	9,6	4,9	4,9	9,2	9,6	9,6	4,9	8,6	10,1	4,7	4,7	6,0	7,9	6,0	5,8	5,8	9,7	10,1	7,6	9,2
April	4,7	4,7	9,2	9,2	7,9	5,8	9,2	5,8	5,8	9,6	9,2	9,2	6,0	9,2	7,9	4,9	4,9	5,8	9,2	5,8	7,6	4,9	9,6	9,2	6,0	9,6
May	6,0	6,0	8,6	9,6	8,6	6,0	8,6	6,0	6,0	9,7	8,6	8,6	5,8	9,6	9,2	5,8	5,8	4,9	10,1	4,9	4,0	4,7	9,2	7,9	5,8	9,7
June	7,9	7,9	7,9	9,7	9,2	7,6	7,9	7,6	7,6	10,1	7,9	7,9	7,6	9,7	8,6	6,0	6,0	4,7	9,7	4,7	4,7	7,6	8,6	8,6	4,9	10,1
July	8,6	8,6	7,6	10,1	5,8	7,9	7,6	7,9	7,9	4,0	4,0	7,6	8,6	10,1	6,0	7,6	7,6	4,0	9,6	4,0	4,9	7,9	7,9	5,8	4,7	4,0
August	9,6	9,6	6,0	6,0	6,0	10,1	6,0	8,6	8,6	4,7	4,7	6,0	7,9	6,0	5,8	8,6	9,7	9,7	4,7	7,9	9,7	8,6	6,0	6,0	4,0	4,7
September	10,1	10,1	5,8	5,8	7,6	9,7	5,8	9,2	9,2	4,9	4,9	5,8	9,2	5,8	7,6	9,2	9,6	9,6	4,9	8,6	10,1	9,2	5,8	7,6	9,2	4,9
October	9,7	9,7	4,9	4,9	4,0	9,6	4,9	9,6	9,6	5,8	5,8	4,9	10,1	4,9	4,0	9,6	9,2	9,2	6,0	9,2	7,9	9,6	4,9	4,9	10,1	5,8
November	9,2	9,2	4,7	4,7	4,7	9,2	4,7	9,7	9,7	6,0	6,0	4,7	9,7	4,7	4,7	9,7	8,6	8,6	5,8	9,6	9,2	9,7	4,7	4,7	9,7	6,0
December	7,6	7,6	4,0	4,0	4,9	8,6	4,0	10,1	10,1	7,6	7,6	4,0	9,6	4,0	4,9	10,1	7,9	7,9	7,6	9,7	8,6	10,1	4,0	4,0	9,6	7,6
Annual	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4

Table G.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal)

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11,7	11,7	11,7	11,7	11,7	11,7	11,7	11,7	10,6	10,6	11,7	10,6	10,6	10,6	11,7	10,6	10,6	11,7	10,6	10,6	10,6	10,6	10,6	10,6	10,6	10,6
February	11,5	11,5	8,2	11,5	11,5	11,5	7,6	11,5	11,7	6,1	7,6	11,7	6,1	10,5	11,5	9,5	11,7	8,2	8,9	7,6	7,1	11,5	6,4	9,5	11,5	11,7
March	10,5	10,5	7,1	11,5	11,5	11,5	8,9	11,5	11,5	6,4	7,1	11,5	6,4	11,5	11,5	8,9	11,5	7,6	9,5	8,2	11,5	11,7	6,1	10,5	11,7	7,1
April	9,5	9,5	9,5	10,6	10,6	10,6	9,5	10,6	8,2	7,1	9,5	11,5	7,1	11,5	8,2	8,2	11,5	7,1	10,5	7,1	11,7	11,5	7,1	7,1	11,5	7,6
May	8,2	8,2	10,5	10,5	10,5	8,9	10,5	10,5	10,5	7,6	8,9	10,5	7,6	11,7	10,5	7,6	10,5	6,4	11,5	8,9	6,4	10,5	7,6	11,7	10,5	8,2
June	7,1	7,1	11,5	9,5	9,5	9,5	10,6	8,2	11,5	8,2	10,6	9,5	8,2	9,5	6,4	7,1	9,5	6,1	11,5	9,5	6,1	9,5	8,2	11,5	9,5	8,9
July	6,1	6,1	11,5	8,2	8,9	10,5	11,5	9,5	7,1	8,9	6,1	8,9	8,9	8,9	6,1	6,4	8,9	8,9	11,7	10,5	7,6	8,9	8,9	11,5	7,6	9,5
August	6,4	6,4	10,6	7,6	7,6	7,6	11,5	8,9	7,6	9,5	6,4	8,2	9,5	8,2	10,6	6,1	8,2	11,5	6,1	11,5	8,2	8,2	9,5	8,2	7,1	10,5
September	7,6	7,6	6,1	8,9	8,2	8,2	8,2	6,1	8,9	10,5	10,5	7,6	10,5	7,6	8,9	10,5	7,6	11,5	6,4	11,5	8,9	7,6	10,5	7,6	6,4	6,1
October	8,9	8,9	8,9	7,1	6,1	7,1	6,1	6,4	9,5	11,5	11,5	7,1	11,5	7,1	9,5	11,5	7,1	10,6	7,1	6,1	9,5	7,1	11,5	6,4	6,1	6,4
November	10,6	10,6	7,6	6,4	6,4	6,4	6,4	7,1	6,4	11,5	8,2	6,4	11,5	6,4	7,1	11,5	6,4	10,5	7,6	6,4	10,5	6,4	11,5	6,1	8,9	11,5
December	11,5	11,5	6,4	6,1	7,1	6,1	7,1	7,6	6,1	11,7	11,5	6,1	11,7	6,1	7,6	11,7	6,1	9,5	8,2	11,7	11,5	6,1	11,7	8,9	8,2	11,5
Annual	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1

Table G.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada)

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	9,7	15,4	15,4	15,4	15,4	15,4	15,4	15,4	16,6	15,4	15,4	14,7	9,7	9,3
February	14,7	14,7	12,4	9,7	15,1	12,4	12,4	15,1	15,1	9,7	12,4	12,4	10,0	15,1	9,7	13,1	9,7	9,7	9,7	9,7	14,3	15,1	15,1	15,6	10,0	13,1
March	12,7	12,7	12,7	10,0	14,7	11,2	12,7	14,7	14,7	10,0	11,2	12,7	10,4	14,7	10,0	15,1	10,0	10,0	10,0	10,0	13,8	14,7	14,7	15,3	10,4	12,9
April	12,4	12,4	13,1	10,4	14,3	10,4	13,1	14,3	14,3	10,4	10,4	13,1	10,4	14,3	10,4	14,7	10,4	15,1	10,4	10,4	13,8	13,3	14,3	14,3	10,4	12,9
May	11,2	11,2	14,3	10,4	13,1	10,4	14,3	13,1	13,1	10,4	10,4	14,3	11,2	13,1	10,4	14,3	10,4	14,7	10,4	10,4	13,4	13,1	13,1	13,0	11,2	12,3
June	10,4	10,4	14,7	11,2	12,7	10,0	14,7	12,7	12,7	11,2	10,0	14,7	12,4	12,7	11,2	12,7	11,2	14,3	11,2	11,2	12,8	12,7	12,7	12,7	12,4	12,2
July	10,0	10,0	15,1	12,4	12,4	9,7	15,1	12,4	12,4	12,4	9,7	15,1	12,7	12,4	12,4	9,7	12,4	13,1	12,4	12,4	12,2	12,3	12,4	12,5	12,7	10,0
August	9,7	9,7	11,2	12,7	11,2	12,7	11,2	11,2	11,2	12,7	12,7	11,2	13,1	11,2	12,7	10,0	12,7	12,7	12,7	12,7	11,4	12,1	11,2	11,4	13,1	9,4
September	10,4	10,4	9,7	13,1	10,4	14,7	9,7	10,4	10,4	13,1	14,7	9,7	14,3	10,4	13,1	10,4	13,1	12,4	13,1	13,1	11,4	11,7	10,4	10,2	14,3	13,2
October	13,1	13,1	10,0	15,1	10,4	14,3	10,0	10,4	10,4	15,1	14,3	10,0	14,7	10,4	14,3	10,4	14,3	11,2	15,1	14,3	11,2	10,1	10,4	9,8	14,7	13,5
November	14,3	14,3	10,4	14,7	10,0	15,1	10,4	10,0	10,0	14,7	15,1	10,4	15,1	10,0	14,7	11,2	14,7	10,4	14,7	14,7	9,7	10,0	10,0	10,3	15,1	13,9
December	15,1	15,1	10,4	14,3	9,7	13,1	10,4	9,7	9,7	14,3	13,1	10,4	15,4	9,7	15,1	12,4	15,1	10,4	14,3	15,1	9,0	9,7	9,7	10,1	15,4	16,9
Annual	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5

Table G.7 kWh per H_{prod}

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5.695	5.647	5.674	5.629	5.699	5.647	5.694	5.694	5.637	5.641	5.647	5.693	5.674	5.637	5.718	5.737	5.690	5.649	5.602	5.698	5.682	5.616	5.628	5.645	5.637
Corvo Island (Portugal)	10.451	10.535	10.466	10.473	10.467	10.570	10.498	10.419	10.528	10.530	10.452	10.528	10.510	10.504	10.472	10.452	10.517	10.522	10.556	10.569	10.463	10.523	10.531	10.446	10.392
Cape Saint James (Canada)	24.766	24.852	24.932	24.738	24.788	24.852	24.738	24.738	24.932	24.788	24.852	24.794	24.738	24.940	24.879	24.940	24.908	24.932	24.940	24.841	24.855	24.738	24.888	24.794	24.877

Table G.8 Cashflow for 25 years of the wind farm project 50.000 kW Aracati (Brazil) reference situation

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60.225.901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27.686.278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24.219.295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1.959.783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1.545.346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572.832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2.136.726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1.796.870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188.559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120.211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48.856.319	48.444.328	48.676.026	48.290.403	48.895.032	48.444.328	48.844.485	48.844.485	48.356.354	48.391.173	48.444.328	48.841.866	48.676.026	48.362.288	49.053.015	49.213.265	48.817.403	48.463.568	48.054.765	48.883.303	48.747.993	48.179.078	48.285.240	48.430.728	48.356.354
(+) AAR ($M/yr)	-	4.297.170	4.367.456	4.498.053	4.573.979	4.747.030	4.820.855	4.982.192	5.106.747	5.182.105	5.315.483	5.454.354	5.636.591	5.757.889	5.863.796	6.096.233	6.269.053	6.374.091	6.486.088	6.592.161	6.873.465	4.918.060	4.982.181	5.117.988	5.261.744	5.385.005
PPAR	-	4.297.170	4.367.456	4.498.053	4.573.979	4.747.030	4.820.855	4.982.192	5.106.747	5.182.105	5.315.483	5.454.354	5.636.591	5.757.889	5.863.796	6.096.233	6.269.053	6.374.091	6.486.088	6.592.161	6.873.465	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.918.060	4.982.181	5.117.988	5.261.744	5.385.005
(-) $O\&M_{WFCM}$	-	3.949.353	4.013.810	4.133.691	4.203.326	4.362.211	4.455.205	4.603.526	4.717.835	4.786.682	4.909.110	5.036.591	5.204.091	5.315.304	5.412.299	5.626.056	5.784.761	5.880.906	5.983.464	6.080.550	6.339.242	5.846.637	5.922.095	6.082.752	6.252.834	6.398.541
$O\&M_{fixed}$	-	2.654.579	2.697.997	2.778.672	2.825.574	2.932.474	2.978.078	3.077.743	3.154.685	3.201.236	3.283.628	3.369.414	3.481.989	3.556.919	3.622.341	3.765.927	3.872.684	3.937.570	4.006.754	4.072.279	4.246.052	4.340.155	4.396.739	4.516.586	4.643.449	4.752.224
$O\&M_{variable}$	-	1.294.774	1.315.813	1.355.018	1.377.752	1.429.737	1.477.127	1.525.784	1.563.150	1.585.447	1.625.482	1.667.177	1.722.102	1.758.385	1.789.958	1.860.129	1.912.077	1.943.336	1.976.710	2.008.271	2.093.190	1.506.483	1.525.356	1.566.166	1.609.385	1.646.316
(+) LRCM	-	863.268	884.850	906.971	929.646	952.887	976.709	1.001.127	1.026.155	1.051.809	1.078.104	1.105.057	1.132.683	1.161.000	1.190.025	1.219.776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2.453.485	2.514.822	2.577.692	2.642.135	2.708.188	2.775.893	2.845.290	2.916.422	2.989.333	3.064.066	3.140.668	3.219.185	3.299.664	3.382.156	3.466.710	3.553.377	3.642.212	3.733.267	3.826.599	3.922.264	4.020.320	4.120.828	4.223.849	4.329.445	4.437.681
(=) Profit before tax	-	3.664.570	3.753.318	3.849.027	3.942.434	4.045.894	4.118.251	4.225.083	4.331.489	4.436.565	4.548.543	4.663.487	4.784.368	4.903.249	5.023.678	5.156.663	4.037.669	4.135.397	4.235.892	4.338.210	4.456.487	3.091.743	3.180.914	3.259.085	3.338.355	3.424.146
(-) Revenue tax	-	1.289.151	1.310.237	1.349.416	1.372.194	1.424.109	1.446.256	1.494.658	1.532.024	1.554.632	1.594.645	1.636.306	1.690.977	1.727.367	1.759.139	1.828.870	1.880.716	1.912.227	1.945.827	1.977.648	2.062.040	1.475.418	1.494.654	1.535.396	1.578.523	1.615.502
(+) REPIM	384.810	2.045	1.989	1.961	1.910	1.898	1.847	1.829	1.797	1.748	1.720	280	289	296	301	313	322	327	333	339	353	361	365	375	386	395
REI_{CM}	221.313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1.825	1.765	1.730	1.675	1.654	1.599	1.573	1.535	1.482	1.447	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	163.497	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	221	224	231	235	244	248	256	262	266	273	280	289	296	301	313	322	327	333	339	353	361	365	375	386	395
(=) Profit after tax w/out interest	-	2.377.464	2.445.071	2.501.572	2.572.150	2.623.683	2.673.841	2.732.254	2.801.262	2.883.681	2.955.618	3.027.461	3.093.680	3.176.178	3.264.840	3.328.106	2.157.275	2.223.497	2.290.398	2.360.900	2.394.800	1.616.686	1.686.625	1.724.064	1.760.218	1.809.039
(-) Debt payments	-	-	3.175.716	3.255.109	3.336.487	3.419.899	3.505.396	3.593.031	3.682.857	3.774.928	3.869.302	3.966.034	4.065.185	4.166.815	4.270.985	4.377.760	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2.621.739	2.687.282	2.754.464	2.823.326	2.893.909	2.966.257	3.040.413	3.116.424	3.194.334	3.274.193	3.356.047	3.439.949	3.525.947	3.614.096	3.704.448	3.797.060	3.891.986	3.989.286	4.089.018	4.191.243	4.296.024	4.403.425	4.513.511	4.626.348	4.742.007
(+) Depreciation		2.453.485	2.514.822	2.577.692	2.642.135	2.708.188	2.775.893	2.845.290	2.916.422	2.989.333	3.064.066	3.140.668	3.219.185	3.299.664	3.382.156	3.466.710	3.553.377	3.642.212	3.733.267	3.826.599	3.922.264	4.020.320	4.120.828	4.223.849	4.329.445	4.437.681
(=) Free net cashflow	-59.841.090	7.452.688	4.471.459	4.578.620	4.701.124	4.805.881	4.910.595	5.024.926	5.151.251	5.292.420	5.424.575	5.558.142	5.687.628	5.834.975	5.990.107	6.121.504	9.507.712	9.757.695	10.012.951	10.276.517	10.508.307	9.933.031	10.210.879	10.461.423	10.716.012	10.988.728
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52.388.403	-47.916.944	-43.338.324	-38.637.200	-33.831.319	-28.920.725	-23.895.799	-18.744.548	-13.452.128	-8.027.552	-2.469.410	3.218.218	9.053.193	15.043.300	21.164.804	30.672.516	40.430.211	50.443.162	60.719.678	71.227.986	81.161.017	91.371.895	101.833.319	112.549.330	123.538.058
	$LCOE_{wso}$	67,66	67,81	68,02	68,18	68,43	68,62	68,87	69,09	69,26	69,49	69,72	70,00	70,23	70,44	70,78	69,81	70,00	70,20	70,40	70,76	70,37	70,55	70,82	71,11	71,37

Table G.9 Cashflow for 25 years of the wind farm project 50.000 kW Corvo Island (Portugal) reference situation

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60.225.901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27.686.278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24.219.295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1.959.783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1.545.346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572.832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2.136.726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1.796.870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188.559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120.211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	89.657.257	90.377.375	89.783.574	89.846.976	89.792.106	90.681.985	90.056.935	89.381.970	90.318.367	90.339.663	89.668.733	90.318.367	90.163.301	90.113.636	89.837.428	89.668.733	90.220.267	90.263.721	90.560.856	90.671.187	89.760.146	90.272.750	90.345.823	89.615.940	89.153.675
(+) AAR ($M/yr)	-	14.970.925	15.468.449	15.750.988	16.156.163	16.549.954	17.131.821	17.439.078	17.741.084	18.375.119	18.838.939	19.166.502	19.787.994	20.247.871	20.742.636	21.196.034	21.685.138	22.363.982	22.934.122	23.584.858	24.203.932	17.191.828	17.722.258	18.180.019	18.483.975	18.848.346
PPAR	-	14.970.925	15.468.449	15.750.988	16.156.163	16.549.954	17.131.821	17.439.078	17.741.084	18.375.119	18.838.939	19.166.502	19.787.994	20.247.871	20.742.636	21.196.034	21.685.138	22.363.982	22.934.122	23.584.858	24.203.932	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17.191.828	17.722.258	18.180.019	18.483.975	18.848.346
(-) $O\&M_{WFCM}$	-	9.368.374	9.679.566	9.856.225	10.109.621	10.355.890	10.719.839	10.911.955	11.100.782	11.497.361	11.787.429	11.992.241	12.380.956	12.668.548	12.977.965	13.261.497	13.567.366	13.991.943	14.348.504	14.755.487	15.142.655	13.154.746	13.560.473	13.910.592	14.143.024	14.421.679
$O\&M_{fixed}$	-	4.871.474	5.033.363	5.125.297	5.257.137	5.385.272	5.574.606	5.674.583	5.772.851	5.979.160	6.130.081	6.236.666	6.438.893	6.588.532	6.749.522	6.897.052	7.056.201	7.277.090	7.462.607	7.674.349	7.875.789	7.991.568	8.238.134	8.450.920	8.592.210	8.761.584
$O\&M_{variable}$	-	4.496.901	4.646.203	4.730.927	4.852.484	4.970.618	5.145.234	5.237.372	5.327.931	5.518.200	5.657.348	5.755.575	5.942.063	6.080.016	6.228.443	6.364.445	6.511.165	6.714.853	6.885.898	7.081.137	7.266.866	5.163.178	5.322.339	5.459.672	5.550.813	5.660.095
(+) LRCM	-	863.268	884.850	906.971	929.646	952.887	976.709	1.001.127	1.026.155	1.051.809	1.078.104	1.105.057	1.132.683	1.161.000	1.190.025	1.219.776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2.449.315	2.510.548	2.573.312	2.637.645	2.703.586	2.771.176	2.840.455	2.911.466	2.984.253	3.058.859	3.135.331	3.213.714	3.294.057	3.376.408	3.460.818	3.547.339	3.636.022	3.726.923	3.820.096	3.915.598	4.013.488	4.113.826	4.216.671	4.322.088	4.430.140
(=) Profit before tax	-	8.915.134	9.184.281	9.375.046	9.613.833	9.850.537	10.159.866	10.368.705	10.577.923	10.913.820	11.188.473	11.414.649	11.753.435	12.034.380	12.331.104	12.615.131	11.665.110	12.008.061	12.312.540	12.649.468	12.976.875	8.050.570	8.275.610	8.486.098	8.663.040	8.856.807
(-) Revenue tax	-	4.491.277	4.640.535	4.725.296	4.846.849	4.964.986	5.139.546	5.231.723	5.322.325	5.512.536	5.651.682	5.749.951	5.936.398	6.074.361	6.222.791	6.358.810	6.505.541	6.709.195	6.880.237	7.075.458	7.261.179	5.157.549	5.316.677	5.454.006	5.545.193	5.654.504
(+) REPIM	486.502	1.438	1.420	1.382	1.355	1.327	1.314	1.280	1.245	1.235	1.212	1.180	1.167	1.144	1.123	1.100	164	170	174	179	183	186	192	197	200	204
REI_{CM}	221.313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1.325	1.303	1.263	1.233	1.202	1.184	1.147	1.111	1.095	1.069	1.035	1.017	991	966	939	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	265.188	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	113	117	119	122	125	130	132	134	139	143	145	150	153	157	161	164	170	174	179	183	186	192	197	200	204
(=) Profit after tax w/out interest	-	4.425.295	4.545.166	4.651.132	4.768.339	4.886.878	5.021.634	5.138.261	5.256.843	5.402.519	5.538.003	5.665.878	5.818.204	5.961.163	6.109.437	6.257.421	5.159.734	5.299.037	5.432.478	5.574.189	5.715.879	2.893.208	2.959.125	3.032.289	3.118.047	3.202.507
(-) Debt payments	-	-	3.170.319	3.249.577	3.330.817	3.414.087	3.499.439	3.586.925	3.676.598	3.768.513	3.862.726	3.959.294	4.058.277	4.159.734	4.263.727	4.370.320	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2.621.739	2.687.282	2.754.464	2.823.326	2.893.909	2.966.257	3.040.413	3.116.424	3.194.334	3.274.193	3.356.047	3.439.949	3.525.947	3.614.096	3.704.448	3.797.060	3.891.986	3.989.286	4.089.018	4.191.243	4.296.024	4.403.425	4.513.511	4.626.348	4.742.007
(+) Depreciation		2.449.315	2.510.548	2.573.312	2.637.645	2.703.586	2.771.176	2.840.455	2.911.466	2.984.253	3.058.859	3.135.331	3.213.714	3.294.057	3.376.408	3.460.818	3.547.339	3.636.022	3.726.923	3.820.096	3.915.598	4.013.488	4.113.826	4.216.671	4.322.088	4.430.140
(=) Free net cashflow	-59.739.399	9.496.349	6.572.677	6.729.331	6.898.493	7.070.286	7.259.627	7.432.204	7.608.134	7.812.593	8.008.328	8.197.962	8.413.589	8.621.433	8.836.214	9.052.367	12.504.132	12.827.045	13.148.686	13.483.303	13.822.721	11.202.721	11.476.375	11.762.471	12.066.484	12.374.654
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50.243.050	-43.670.372	-36.941.041	-30.042.549	-22.972.263	-15.712.636	-8.280.432	-672.297	7.140.296	15.148.624	23.346.586	31.760.175	40.381.608	49.217.822	58.270.189	70.774.321	83.601.366	96.750.053	110.233.356	124.056.076	135.258.797	146.735.173	158.497.644	170.564.127	182.938.782
	$LCOE_{wso}$	73,08	73,48	73,74	74,09	74,43	74,89	75,18	75,47	75,97	76,37	76,68	77,18	77,58	78,01	78,41	77,59	78,11	78,56	79,07	79,56	77,68	78,19	78,65	79,00	79,39

Table G.10 Cashflow for 25 years of the wind farm project 50.000 kW Cape Saint James (Canada) reference situation

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60.225.901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27.686.278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24.219.295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1.959.783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1.545.346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572.832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2.136.726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1.796.870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188.559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120.211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212.467.325	213.202.961	213.887.985	212.223.670	212.655.974	213.202.961	212.223.670	212.223.670	213.887.985	212.655.974	213.202.961	212.704.429	212.223.670	213.959.139	213.437.670	213.959.139	213.678.613	213.887.985	213.959.139	213.109.827	213.228.530	212.223.670	213.512.714	212.704.429	213.419.415
(+) AAR ($M/yr)	-	30.129.143	30.989.297	31.866.088	32.408.583	33.286.465	34.206.386	34.900.500	35.773.012	36.954.893	37.660.580	38.701.386	39.576.163	40.473.880	41.824.978	42.766.117	43.942.368	44.981.873	46.151.597	47.321.124	48.311.614	34.682.891	35.382.431	36.487.277	37.257.877	38.317.694
PPAR	-	30.129.143	30.989.297	31.866.088	32.408.583	33.286.465	34.206.386	34.900.500	35.773.012	36.954.893	37.660.580	38.701.386	39.576.163	40.473.880	41.824.978	42.766.117	43.942.368	44.981.873	46.151.597	47.321.124	48.311.614	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34.682.891	35.382.431	36.487.277	37.257.877	38.317.694
(-) $O\&M_{WFCM}$	-	20.588.652	21.176.288	21.775.288	22.145.848	22.745.587	23.374.047	23.848.205	24.444.263	25.251.713	25.733.770	26.444.813	27.042.405	27.655.668	28.578.721	29.221.647	30.025.220	30.735.351	31.534.456	32.333.422	33.010.054	29.394.775	29.987.509	30.923.746	31.576.700	32.474.765
$O\&M_{fixed}$	-	11.544.286	11.873.856	12.209.801	12.417.656	12.754.019	13.106.489	13.372.438	13.706.743	14.159.584	14.429.968	14.828.755	15.163.927	15.507.888	16.025.565	16.386.164	16.836.847	17.235.134	17.683.316	18.131.422	18.510.929	18.984.265	19.367.163	19.971.913	20.393.707	20.973.809
$O\&M_{variable}$	-	9.044.366	9.302.432	9.565.487	9.728.192	9.991.568	10.267.558	10.475.767	10.737.520	11.092.129	11.303.802	11.616.058	11.878.478	12.147.781	12.553.156	12.835.484	13.188.373	13.500.217	13.851.140	14.202.000	14.499.125	10.410.511	10.620.346	10.951.834	11.182.993	11.500.957
(+) LRCM	-	863.268	884.850	906.971	929.646	952.887	976.709	1.001.127	1.026.155	1.051.809	1.078.104	1.105.057	1.132.683	1.161.000	1.190.025	1.219.776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2.431.036	2.491.812	2.554.108	2.617.960	2.683.409	2.750.494	2.819.257	2.889.738	2.961.982	3.036.031	3.111.932	3.189.730	3.269.474	3.351.210	3.434.991	3.520.865	3.608.887	3.699.109	3.791.587	3.886.377	3.983.536	4.083.125	4.185.203	4.289.833	4.397.079
(=) Profit before tax	-	12.834.796	13.189.672	13.551.879	13.810.341	14.177.175	14.559.542	14.872.678	15.244.642	15.716.970	16.040.945	16.473.561	16.856.171	17.248.685	17.787.492	18.199.236	17.438.014	17.855.409	18.316.250	18.779.289	19.187.937	9.271.652	9.478.046	9.748.733	9.971.010	10.240.007
(-) Revenue tax	-	9.038.743	9.296.789	9.559.826	9.722.575	9.985.940	10.261.916	10.470.150	10.731.904	11.086.468	11.298.174	11.610.416	11.872.849	12.142.164	12.547.493	12.829.835	13.182.710	13.494.562	13.845.479	14.196.337	14.493.484	10.404.867	10.614.729	10.946.183	11.177.363	11.495.308
(+) REPIM	932.331	777	791	806	812	827	843	853	868	890	901	797	815	834	862	881	905	927	951	975	995	1.021	1.041	1.074	1.096	1.128
REI_{CM}	221.313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	156	153	150	145	142	138	134	131	129	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	711.018	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	621	638	656	668	686	705	719	737	761	776	797	815	834	862	881	905	927	951	975	995	1.021	1.041	1.074	1.096	1.128
(=) Profit after tax w/out interest	-	3.796.830	3.893.674	3.992.859	4.088.578	4.192.062	4.298.470	4.403.382	4.513.607	4.631.393	4.743.672	4.863.942	4.984.138	5.107.355	5.240.860	5.370.282	4.256.209	4.361.773	4.471.722	4.583.926	4.695.448	-1.132.195	-1.135.642	-1.196.376	-1.205.256	-1.254.173
(-) Debt payments	-	-	3.146.660	3.225.326	3.305.959	3.388.608	3.473.323	3.560.156	3.649.160	3.740.389	3.833.899	3.929.747	4.027.990	4.128.690	4.231.907	4.337.705	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2.621.739	2.687.282	2.754.464	2.823.326	2.893.909	2.966.257	3.040.413	3.116.424	3.194.334	3.274.193	3.356.047	3.439.949	3.525.947	3.614.096	3.704.448	3.797.060	3.891.986	3.989.286	4.089.018	4.191.243	4.296.024	4.403.425	4.513.511	4.626.348	4.742.007
(+) Depreciation		2.431.036	2.491.812	2.554.108	2.617.960	2.683.409	2.750.494	2.819.257	2.889.738	2.961.982	3.036.031	3.111.932	3.189.730	3.269.474	3.351.210	3.434.991	3.520.865	3.608.887	3.699.109	3.791.587	3.886.377	3.983.536	4.083.125	4.185.203	4.289.833	4.397.079
(=) Free net cashflow	-59.293.569	8.849.605	5.926.109	6.076.105	6.223.905	6.380.773	6.541.898	6.702.895	6.870.608	7.047.319	7.219.997	7.402.175	7.585.826	7.774.086	7.974.259	8.172.016	11.574.134	11.862.647	12.160.117	12.464.531	12.773.068	7.147.366	7.350.908	7.502.337	7.710.925	7.884.912
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50.443.964	-44.517.855	-38.441.751	-32.217.845	-25.837.073	-19.295.175	-12.592.280	-5.721.672	1.325.648	8.545.644	15.947.820	23.533.646	31.307.732	39.281.991	47.454.007	59.028.140	70.890.787	83.050.904	95.515.435	108.288.503	115.435.868	122.786.776	130.289.113	138.000.038	145.884.950
	$LCOE_{wso}$	84,30	84,97	85,66	86,12	86,82	87,54	88,12	88,81	89,72	90,31	91,13	91,84	92,57	93,61	94,37	94,05	94,85	95,75	96,65	97,43	93,92	94,62	95,66	96,43	97,44

APPENDIX H

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80,00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4,00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0,08581	[$/kWh]
Expected Market Price	0,06007	[$/kWh]
PPAR and EMP ratio	70,00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2,50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
UCRF	0,070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2.000	[kW]
Wind Farm Capacity (WF_{cap})	50.000	[kW]
Rotor Diamenter (D)	90,0	[m]
Swept Area per Turbine (A)	6.361,7	[m²]
Hub height (H)	105,0	[m]
Wind speed measured at (H_0)	10,0	[m]
Terrain rugosity factor (α)	0,14	[–]
Betz Limit's coefficient (C_{PBetz})	0,5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11,2%	[%]
Availability	98,4%	[%]
	359	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16,8442	[$/kW]
$Depr_{WT_{inst}}$	76,9840	[$/kW]
WT_{CM}	553,7256	[$/kW]
T_{CM}	484,3859	[$/kW]
N	25	[yr]
ifr	2,50%	[%/yr]
$Depr_{Y_{RC}}$	60,1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0,000033	[$/kW]
TI	1.798.743	[$/kW]
V	237.699.000	[kW]
V_0	6.100.000	[kW]
c_0	1.457,72	[$/kW]
PR	0,70	[–]
b	-1,94	[–]
LRCM	***16,8443***	***[$/kW]***

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1.339,9154	[$/kW]
RM_{WT}	22,3284	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85,00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2,0	[d]
$C_{md_{RM_{WT}}}$	2.500,00	[$/d]
RM_{CT}	20,1954	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3,0	[m-h]
$C_{Mhr_{RCT}}$	85,00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2,0	[d]
$C_{md_{RM_{CT}}}$	3.500,00	[$/d]
$S\&RV$	1.297,3916	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
A_{WT}	43,00	[m²/wt]
$M_{hr_{S\&RV}}$	3,0	[m-h]
$C_{Mhr_{S\&RV}}$	85,00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3,0	[d]
$C_{md_{S\&RV}}$	3.500,00	[$/d]
RVM_{WF}	61,0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1,4442	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
WT_{weight}	200.000	[kg]
C_{steel}	0,1900	[$/kg]
TS_{VM}	0,9965	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
T_{mass}	138.000	[kg]
RCM_{WF}	***1.278,8970***	***[$/kW]***

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70,8203	[$/kW$_e$]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$LRCM$	16,8443	[$/kW]
ifr	2,50%	[%/yr]
Ψ_{total}	30,00%	[%]
n_{Ψ}	6	[yr]
REP_{CM}	0,00002628	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5.693	[kW/yr]
ifr	2,50%	[%/yr]
ε	0,1496	[$/kW$_e$h]
ε_0	0,116883	[$/kW$_e$h]
n_{ε}	10	[yr]
$OREP_{CM}$	13,0764	[$/kW$_e$]
$LCCCM_{WF_{OREG_{CM}}}$	2,7664	[$/kW]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
Ψ_{total}	30,0%	[%]
ifr	2,5%	[%/yr]
n_{Ψ}	10	[yr]
CR_f	80,0%	[%]
$GHG.R_{CM}$	1.602,9913	[$/tCO₂]
$LCER_{CO_2}$	18,6	[tCO₂/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	49.057	[MW$_e$h]
n_{Ψ}	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0,00041	[tCO₂/MW$_e$h]
$GHG_{EM_{wecs\,CO_2}}$	0,00003	[tCO₂/MW$_e$h]
ε_c	46,3820	[$/tCO₂]
REPIM distribution	100,0%	[%]
ξ_1 REI_{CM}	25,0%	[%]
ξ_2 REP_{CM}	25,0%	[%]
ξ_3 $OREP_{CM}$	25,0%	[%]
ξ_4 $GHG.R_{CM}$	25,0%	[%]
REPIM	***421,7220***	***[$/proj]***

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50.000	[kW$_e$/yr]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
WT_{rated}	2.000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90,0	[m]
$L_{x_{row}}$	1.800	[m]
$L_{x_{col}}$	2.430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8.760	[h/yr]
PC_{PM}		
AEP_{avail}	49.057.055	[kW$_e$h/yr]
η_{wecs}	20,98%	[%]
$\eta_{wecs_{(ref)}}$	25,00%	[%]
$P\&D_{LM\,factor}$	0,839325	[–]
N_{WT}	25	[–]
A	6.361,7	[m²]
AEP_{rated}	438.000.000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7,00%	[%]
$\lambda_{s\&i}$	0,00%	[%]
λ_d	5,00%	[%]
λ_m	5,00%	[%]
$LCPM_{WF}$	***49.057.055***	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553,7256	[$/kW]
CM_{WT}	265,32	[$/kW]
RC_{WT}	73,70%	[%/$/kW]
C_{kW}	400,00	[$/kW]
IPT	10,00%	[%]
T_{CM}	484,3859	[$/kW]
T_{mass}	138.000	[kg]
RC_T	26,30%	[%/$/kW]
C_{steel}	0,1900	[$/kg]
$LWTG_{CM}$	39,1957	[$/m/kW]
WF_{cap}	50.000	[kW]
L_g	13.950	[m]
CAB_{cost}	2.000,00	[$/m]
CP_{CM}	30,9069	[$/kW]
EF_c	400,00	[$/kW]
ς	0,08%	[%]
TS_{CM}	11,4566	[$/kW$_e$]
TL_c	0,0400	[$/m]
TL_r	1.200	[1/kW]
L_t	3.000	[m]
SB_c	113,00	[$/kWh]
SI_{CM}	42,7345	[$/m²/kW]
WF_{cap}	50.000	[kW]
WT_{inst}	42,5238	[$/kW]
Bld_{cost}	500,00	[$/m²]
Bld_{area}	300,0	[m²]
PO_{CM}	35,9374	[$/kW]
FS	19,88	[$/kW]
DT	87,22	[$/kW]
EG	404,52	[$/kW]
F_{CM}	3,7712	[$/kW]
$WACC_{proj}$	4,900%	[%/yr]
n_{fin}	1,0	[yr]
$W_{F_{CM}}$	0,30%	[%]
CCC_{CM}	2,4042	[$/kW]
κ	0,20%	[%]
$LCCCM_{WF}$	***1.204,5180***	***[$/kW]***

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0,098275	[$/kWh]
$LCCCM_{WF}$	1.204,5180	[$/kW]
ϖ	0,0000001%	[%]
LLC	0,0530	[$/kWh]
N	25	[yr]
ifr	2,50%	[%/yr]
$O\&M_{variable_{CM}}$	0,025840	[$/kWh]
MLC	71,5608	[$/h]
TLC	124,5688	[$/h]
R_{taxes}	30,00%	[%]
ifr	2,50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	4.209.586	[$M]
AEP_{avail}	49.057.055	[kWh/yr]
$O\&M_{WFCM}$	***0,124115***	***[$/kWh/yr]***

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	***0,000070***	***[$/kWh]***
Work days	2,0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48,0	[h]
$USC_{O\&M}$	***0,000254***	***[$/kWh]***
N_{WT}	25	[–]
Frequency	1,0	[per yr]
Repair time	4,0	[h]
Hours required	100,0	[h]
$SC_{O\&M}+USC_{O\&M}$	***148,0***	***[h/yr]***
	0,000324	***[$/kWh/yr]***

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8.760**	**8.616**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1,3252	[–]
$CAN/USD_{dec2010}$	0,9998	[–]
$BRL/USD_{dec2010}$	0,5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80,0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Project Financing		Notes
Debt ratio	50,0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5,00%	[%/yr]
Debt value	29.920.566	[$]
Debt payments	3.022.694	[$/yr]
Equity ratio	50,0%	[%]
Equity value	29.920.566	[$]
Discount rate	9,00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67,6756	yr_1	70,7929	yr_{15}
67,8295	yr_2	69,8226	yr_{15}
68,0385	yr_3	70,0172	yr_{16}
68,2028	yr_4	70,2229	yr_{17}
68,4513	yr_5	70,4241	yr_{18}
68,6399	yr_6	70,7751	yr_{19}
68,8858	yr_7	70,3899	yr_{20}
69,1016	yr_8	70,5764	yr_{21}
69,2789	yr_9	70,8470	yr_{22}
69,5063	yr_{10}	71,1302	yr_{23}
69,7421	yr_{11}	71,3951	yr_{25}
70,0200	yr_{12}	69,6991	Mean
70,2471	yr_{13}	1,0849	SD
70,4639	yr_{14}	-0,4478	Υ (skewness)
$LCOE_{wso}$	**69,6991**	**US$/MWh**	valid !
	0,069699	**US$/kWh**	

Figure H.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)}$. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2.000	[kW]
Wind Farm Capacity (WF_{cap})	50.000	[kW]
Rotor Diamenter (D)	90,0	[m]
Swept Area per Turbine (A)	6.361,7	[m^2]
Hub height (H)	105,0	[m]
Wind speed measured at (H_0)	10,0	[m]
Terrain rugosity factor (a)	0,14	[–]
Betz Limit`s coefficient (C_{PBetz})	0,5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20,6%	[%]
Availability	98,4%	[%]
	359	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553,7256	[$/kW]
CM_{WT}	265,32	[$/kW]
RC_{WT}	73,70%	[%/$/kW]
C_{kW}	400,00	[$/kW]
IPT	10,00%	[%]
T_{CM}	484,3859	[$/kW]
T_{mass}	138.000	[kg]
RC_T	26,30%	[%/$/kW]
C_{steel}	0,1900	[$/kg]
$LWTG_{CM}$	39,1957	[$/m/kW]
WF_{cap}	50.000	[kW]
L_g	13.950	[m]
CAB_{cost}	2.000,00	[$/m]
CP_{CM}	30,9069	[$/kW]
EF_c	400,00	[$/kW]
ς	0,08%	[%]
TS_{CM}	11,4566	[$/kW$_e$]
TL_c	0,0400	[$/m]
TL_r	1.200	[1/kW]
L_t	3.000	[m]
SB_c	113,00	[$/kWh]
SI_{CM}	42,7345	[$/m^2/kW]
WF_{cap}	50.000	[kW]
WT_{inst}	42,5238	[$/kW]
Bld_{cost}	500,00	[$/m^2]
Bld_{area}	300,0	[m^2]
PO_{CM}	35,9374	[$/kW]
FS	19,88	[$/kW]
DT	87,22	[$/kW]
EG	404,52	[$/kW]
F_{CM}	3,7712	[$/kW]
$WACC_{proj}$	4,900%	[%/yr]
n_{fin}	1,0	[yr]
$w_{F_{CM}}$	0,30%	[%]
CCC_{CM}	2,4042	[$/kW]
κ	0,20%	[%]
$LCCCM_{WF}$	**1.204,5180**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80,00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16,8442	[$/kW]
$Depr_{WT_{inst}}$	76,9840	[$/kW]
WT_{CM}	553,7256	[$/kW]
T_{CM}	484,3859	[$/kW]
N	25	[yr]
ifr	2,50%	[%/yr]
$Depr_{Y_{RC}}$	60,1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0,000033	[$/kW]
TI	1.798.743	[$/kW]
V	237.699.000	[kW]
V_0	6.100.000	[kW]
c_0	1.457,72	[$/kW]
PR	0,70	[–]
b	-1,94	[–]
LRCM	**16,8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0,098275	[$/kWh]
$LCCCM_{WF}$	1.204,5180	[$/kW]
ϖ	0,0000001%	[%]
LLC	0,0530	[$/kWh]
N	25	[yr]
ifr	2,50%	[%/yr]
$O\&M_{variable_{CM}}$	0,048925	[$/kWh]
MLC	71,5608	[$/h]
TLC	124,5688	[$/h]
R_{taxes}	30,00%	[%]
ifr	2,50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	14.679.146	[$M]
AEP_{avail}	90.107.610	[kWh/yr]
$O\&M_{WFCM}$	**0,147200**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0,000038**	**[$/kWh]**
Work days	2,0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48,0	[h]
$USC_{O\&M}$	**0,000138**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1,0	[per yr]
Repair time	4,0	[h]
Hours required	100,0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148,0**	**[h/yr]**
	0,000176	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4,00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1.339,9154	[$/kW]
RM_{WT}	22,3284	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85,00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2,0	[d]
$C_{md_{RMWT}}$	2.500,00	[$/d]
RM_{CT}	20,1954	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3,0	[m-h]
$C_{Mhr_{RCT}}$	85,00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2,0	[d]
$C_{md_{RMCT}}$	3.500,00	[$/d]
$S\&RV$	1.297,3916	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
A_{WT}	43,00	[m^2/wt]
$M_{hr_{S\&RV}}$	3,0	[m-h]
$C_{Mhr_{S\&RV}}$	85,00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3,0	[d]
$C_{md_{S\&RV}}$	3.500,00	[$/d]
RVM_{WF}	61,0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1,4442	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
WT_{weight}	200.000	[kg]
C_{steel}	0,1900	[$/kg]
TS_{VM}	0,9965	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
T_{mass}	138.000	[kg]
RCM_{WF}	**1.278,8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8.760**	**8.616**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0,16291	[$/kWh]
Expected Market Price	0,11403	[$/kWh]
PPAR and EMP ratio	70,00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70,8203	[$/kW$_e$]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$LRCM$	16,8443	[$/kW]
ifr	2,50%	[%/yr]
ψ_{total}	30,00%	[%]
n_{ψ}	6	[yr]
REP_{CM}	0,00001039	[$/kW$_e$h]
AEP_{avail}/H_{prod}	10.458	[kW/yr]
ifr	2,50%	[%/yr]
ε	0,1086	[$/kW$_e$h]
ε_0	0,075000	[$/kW$_e$h]
n_{ε}	15	[yr]
$OREP_{CM}$	21,2289	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	2,4451	[$/kW]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
ψ_{total}	30,0%	[%]
ifr	2,5%	[%/yr]
n_{ψ}	15	[yr]
CR_f	80,0%	[%]
$GHG.R_{CM}$	825,2491	[$/t$CO_2$]
$LCER_{CO_2}$	34,2	[tCO_2/MW$_e$h]
$\sum AEP_{avail\ yr_1+...+yr_n}$	90.108	[MW$_e$h]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0,00041	[tCO_2/MW$_e$h]
$GHG_{EM_{wecs\ CO_2}}$	0,00003	[tCO_2/MW$_e$h]
ε_c	13,0000	[$/t$CO_2$]
REPIM distribution	100,0%	[%]
ξ_1 REI_{CM}	25,0%	[%]
ξ_2 REP_{CM}	25,0%	[%]
ξ_3 $OREP_{CM}$	25,0%	[%]
ξ_4 $GHG.R_{CM}$	25,0%	[%]
REPIM	**229,3246**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1,3252	[–]
$CAN/USD_{dec2010}$	0,9998	[–]
$BRL/USD_{dec2010}$	0,5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80,0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2,50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
$UCRF$	0,070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50.000	[kW$_e$/yr]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
WT_{rated}	2.000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90,0	[m]
$L_{x_{row}}$	1.800	[m]
$L_{x_{col}}$	2.430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8.760	[h/yr]
PC_{PM}		
AEP_{avail}	90.107.610	[kW$_e$h/yr]
η_{wecs}	20,98%	[%]
$\eta_{wecs_{(ref)}}$	25,00%	[%]
$P\&D_{LM\ factor}$	0,839325	[–]
N_{WT}	25	[–]
A	6.361,7	[m^2]
AEP_{rated}	438.000.000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7,00%	[%]
$\lambda_{s\&i}$	0,00%	[%]
λ_d	5,00%	[%]
λ_m	5,00%	[%]
$LCPM_{WF}$	**90.107.610**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50,0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5,00%	[%/yr]
Debt value	29.869.613	[$]
Debt payments	3.017.547	[$/yr]
Equity ratio	50,0%	[%]
Equity value	29.869.613	[$]
Discount rate	9,00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73,1255	yr_1	78,4712	yr_{15}
73,5187	yr_2	77,6515	yr_{15}
73,7873	yr_3	78,1612	yr_{16}
74,1334	yr_4	78,6268	yr_{17}
74,4746	yr_5	79,1175	yr_{18}
74,9273	yr_6	79,6115	yr_{19}
75,2253	yr_7	77,7347	yr_{20}
75,5275	yr_8	78,2446	yr_{21}
76,0152	yr_9	78,7103	yr_{22}
76,4118	yr_{10}	79,0644	yr_{23}
76,7332	yr_{11}	79,4723	yr_{25}
77,2289	yr_{12}	76,8666	Mean
77,6321	yr_{13}	2,0151	SD
78,0589	yr_{14}	-0,4631	Υ (skewness)
$LCOE_{wso}$	**76,8666**	**US$/MWh**	valid !
	0,076867	**US$/kWh**	

Figure H.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)}$. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80,00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4,00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0,13835	[$/kWh]
Expected Market Price	0,09684	[$/kWh]
PPAR and EMP ratio	70,00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2,50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
UCRF	0,070243	[–]

Wind Project Information		Notes
Project Name	*Firestar Wind Farm*	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2.000	[kW]
Wind Farm Capacity (WF_{cap})	50.000	[kW]
Rotor Diamenter (*D*)	90,0	[m]
Swept Area per Turbine (*A*)	6.361,7	[m²]
Hub height (*H*)	105,0	[m]
Wind speed measured at (H_0)	10,0	[m]
Terrain rugosity factor (*a*)	0,14	[–]
Betz Limit`s coefficient (C_{PBetz})	0,5926	[–]
Lifetime of Wind Farm (*N*)	25	[yr]
Production Efficiency (WF_{PE})	48,7%	[%]
Availability	98,4%	[%]
	359	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16,8442	[$/kW]
$Depr_{WT_{inst}}$	76,9840	[$/kW]
WT_{CM}	553,7256	[$/kW]
T_{CM}	484,3859	[$/kW]
N	25	[yr]
ifr	2,50%	[%/yr]
$Depr_{Y_{RC}}$	60,1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0,000033	[$/kW]
TI	1.798.743	[$/kW]
V	237.699.000	[kW]
V_0	6.100.000	[kW]
c_0	1.457,72	[$/kW]
PR	0,70	[–]
b	-1,94	[–]
LRCM	**16,8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1.339,9154	[$/kW]
RM_{WT}	22,3284	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{WT}}$	100	[m-h]
$C_{Mhr_{WT}}$	85,00	[$/m-h]
$N_{m_{WT}}$	3	[–]
$D_{m_{WT}}$	2,0	[d]
$C_{md_{WT}}$	2.500,00	[$/d]
RM_{CT}	20,1954	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
$M_{hr_{CT}}$	3,0	[m-h]
$C_{Mhr_{CT}}$	85,00	[$/m-h]
$N_{m_{CT}}$	3	[–]
$D_{m_{CT}}$	2,0	[d]
$C_{md_{CT}}$	3.500,00	[$/d]
$S\&RV$	1.297,3916	[$/kW]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
A_{WT}	43,00	[m²/wt]
$M_{hr_{S\&RV}}$	3,0	[m-h]
$C_{Mhr_{S\&RV}}$	85,00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3,0	[d]
$C_{md_{S\&RV}}$	3.500,00	[$/d]
RVM_{WF}	61,0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1,4442	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
WT_{weight}	200.000	[kg]
C_{steel}	0,1900	[$/kg]
TS_{VM}	0,9965	[$/kW]
WF_{cap}	50.000	[kW]
ifr	2,50%	[%/yr]
N	25	[yr]
T_{mass}	138.000	[kg]
RCM_{WF}	**1.278,8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70,8203	[$/kW$_e$]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$LRCM$	16,8443	[$/kW]
ifr	2,50%	[%/yr]
ψ_{total}	30,00%	[%]
n_ψ	6	[yr]
REP_{CM}	0,00000052	[$/kW$_e$h]
AEP_{avail}/H_{prod}	24.780	[kW/yr]
ifr	2,50%	[%/yr]
ε	0,0128	[$/kW$_e$h]
ε_0	0,009998	[$/kW$_e$h]
n_ε	10	[yr]
$OREP_{CM}$	56,9120	[$/kW$_e$]
$LCCCM_{WF_{OREG_{CM}}}$	2,7664	[$/kW]
$LCCCM_{WF}$	1.204,5180	[$/kW]
$WACC_{proj}$	4,9000%	[%/yr]
ψ_{total}	30,0%	[%]
ifr	2,5%	[%/yr]
n_ψ	10	[yr]
CR_f	80,0%	[%]
$GHG.R_{CM}$	4.512,5219	[$/tCO$_2$]
$LCER_{CO_2}$	81,1	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail\ yr_1+...+yr_n}$	213.510	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0,00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ co_2}}$	0,00003	[tCO$_2$/MW$_e$h]
ε_c	30,0000	[$/tCO$_2$]
REPIM distribution	100,0%	[%]
$\xi_1\ REI_{CM}$	25,0%	[%]
$\xi_2\ REP_{CM}$	25,0%	[%]
$\xi_3\ OREP_{CM}$	25,0%	[%]
$\xi_4\ GHG.R_{CM}$	25,0%	[%]
REPIM	***1.160,0636***	***[$/proj]***

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50.000	[kW$_e$/yr]
WF_{cap}	50.000	[kW]
N_{WT}	25	[–]
WT_{rated}	2.000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90,0	[m]
$L_{x_{row}}$	1.800	[m]
$L_{x_{col}}$	2.430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8.760	[h/yr]
PC_{PM}		
AEP_{avail}	213.509.813	[kW$_e$h/yr]
η_{wecs}	20,35%	[%]
$\eta_{wecs_{(ref)}}$	25,00%	[%]
$P\&D_{LM\ factor}$	0,814145	[–]
N_{WT}	25	[–]
A	6.361,7	[m²]
AEP_{rated}	438.000.000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7,00%	[%]
$\lambda_{s\&i}$	3,00%	[%]
λ_d	5,00%	[%]
λ_m	5,00%	[%]
$LCPM_{WF}$	***213.509.813***	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553,7256	[$/kW]
CM_{WT}	265,32	[$/kW]
RC_{WT}	73,70%	[%/$/kW]
C_{kW}	400,00	[$/kW]
IPT	10,00%	[%]
T_{CM}	484,3859	[$/kW]
T_{mass}	138.000	[kg]
RC_T	26,30%	[%/$/kW]
C_{steel}	0,1900	[$/kg]
$LWTG_{CM}$	39,1957	[$/m/kW]
WF_{cap}	50.000	[kW]
L_g	13.950	[m]
CAB_{cost}	2.000,00	[$/m]
CP_{CM}	30,9069	[$/kW]
EF_c	400,00	[$/kW]
ς	0,08%	[%]
TS_{CM}	11,4566	[$/kW$_e$]
TL_c	0,0400	[$/m]
TL_r	1.200	[1/kW]
L_t	3.000	[m]
SB_c	113,00	[$/kWh]
SI_{CM}	42,7345	[$/m²/kW]
WF_{cap}	50.000	[kW]
WT_{inst}	42,5238	[$/kW]
Bld_{cost}	500,00	[$/m²]
Bld_{area}	300,0	[m²]
PO_{CM}	35,9374	[$/kW]
FS	19,88	[$/kW]
DT	87,22	[$/kW]
EG	404,52	[$/kW]
F_{CM}	3,7712	[$/kW]
$WACC_{proj}$	4,900%	[%/yr]
n_{fin}	1,0	[yr]
$w_{F_{CM}}$	0,30%	[%]
CCC_{CM}	2,4042	[$/kW]
κ	0,20%	[%]
$LCCCM_{WF}$	***1.204,5180***	***[$/kW]***

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0,098275	[$/kWh]
$LCCCM_{WF}$	1.204,5180	[$/kW]
ϖ	0,0000001%	[%]
LLC	0,0530	[$/kWh]
N	25	[yr]
ifr	2,50%	[%/yr]
$O\&M_{variable_{CM}}$	0,041527	[$/kWh]
MLC	71,5608	[$/h]
TLC	124,5688	[$/h]
R_{taxes}	30,00%	[%]
ifr	2,50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	29.538.512	[$M]
AEP_{avail}	213.509.813	[kWh/yr]
$O\&M_{WFCM}$	***0,139802***	***[$/kWh/yr]***

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	***0,000016***	***[$/kWh]***
Work days	2,0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48,0	[h]
$USC_{O\&M}$	***0,000058***	***[$/kWh]***
N_{WT}	25	[–]
Frequency	1,0	[per yr]
Repair time	4,0	[h]
Hours required	100,0	[h]
$SC_{O\&M}+USC_{O\&M}$	***148,0***	***[h/yr]***
	0,000074	***[$/kWh/yr]***

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February(*)	672	648
March	744	736
April	720	712
May	744	736
June(*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November(*)	720	696
December	744	736
Total [h/yr]	***8.760***	***8.616***

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1,3252	[–]
$CAN/USD_{dec2010}$	0,9998	[–]
$BRL/USD_{dec2010}$	0,5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80,0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**

p.s.: 1= yes and 0=no

Project Financing		Notes
Debt ratio	50,0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5,00%	[%/yr]
Debt value	29.646.593	[$]
Debt payments	2.995.017	[$/yr]
Equity ratio	50,0%	[%]
Equity value	29.646.593	[$]
Discount rate	9,00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84,3997	yr_1	94,4943	yr_{15}
85,0669	yr_2	94,1699	yr_{15}
85,7507	yr_3	94,9708	yr_{16}
86,2255	yr_4	95,8775	yr_{17}
86,9196	yr_5	96,7795	yr_{18}
87,6452	yr_6	97,5702	yr_{19}
88,2242	yr_7	94,0503	yr_{20}
88,9241	yr_8	94,7536	yr_{21}
89,8260	yr_9	95,8087	yr_{22}
90,4267	yr_{10}	96,5649	yr_{23}
91,2477	yr_{11}	97,5891	yr_{25}
91,9572	yr_{12}	91,8264	*Mean*
92,6946	yr_{13}	4,2043	*SD*
93,7245	yr_{14}	-0,3333	*Υ (skewness)*
$LCOE_{wso}$	**91,8264**	**US$/MWh**	*valid !*
	0,091826	**US$/kWh**	

Figure H.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)}$. Source: Own elaboration

Table H.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)}$

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5,8	1,1665	740	1.697.720	8.914.291	3.812.469	7.527.755	558.872	8.914.291	558.872	558.872	4.243.681	8.914.291	8.914.291	558.872	3.812.469	7.527.755	4.243.681	8.914.291	8.914.291	558.872	3.812.469	7.527.755	558.872	3.812.469	7.527.755	4.243.681	4.243.681
February	4,9	1,1666	648	859.945	6.879.561	3.714.421	6.879.561	788.321	6.879.561	788.321	788.321	4.780.152	6.879.561	6.879.561	788.321	3.714.421	6.879.561	489.171	489.171	3.336.988	4.780.152	7.802.526	1.594.674	1.594.674	7.802.526	6.879.561	4.780.152	4.780.152
March	4,0	1,1671	736	555.877	7.487.419	5.432.002	8.866.525	977.212	7.487.419	977.212	977.212	6.552.645	7.487.419	7.487.419	977.212	5.432.002	8.866.525	895.822	895.822	1.812.134	4.220.942	1.812.134	1.688.623	1.688.623	7.817.699	8.866.525	3.792.040	6.552.645
April	4,7	1,1667	712	866.366	6.337.184	6.337.184	4.082.151	1.633.098	6.337.184	1.633.098	1.633.098	7.241.220	6.337.184	6.337.184	1.752.548	6.337.184	4.082.151	945.080	945.080	1.633.098	6.337.184	1.633.098	3.667.352	945.080	7.241.220	6.337.184	1.752.548	7.241.220
May	6,0	1,1670	736	1.812.066	5.431.800	7.487.140	5.431.800	1.812.066	5.431.800	1.812.066	1.812.066	7.817.409	5.431.800	5.431.800	1.688.560	7.487.140	6.552.401	1.688.560	1.688.560	977.176	8.866.195	977.176	555.856	895.788	6.552.401	4.220.785	1.688.560	7.817.409
June	7,9	1,1686	696	3.996.852	3.996.852	7.402.657	6.204.764	3.590.720	3.996.852	3.590.720	3.590.720	8.395.800	3.996.852	3.996.852	3.590.720	7.402.657	5.143.616	1.715.927	1.715.927	848.262	7.402.657	848.262	848.262	3.590.720	5.143.616	5.143.616	925.332	8.395.800
July	8,6	1,1698	736	5.444.782	3.800.962	8.887.385	1.692.596	4.230.873	3.800.962	4.230.873	4.230.873	557.185	557.185	3.800.962	5.444.782	8.887.385	1.816.397	3.800.962	3.800.962	557.185	7.505.034	557.185	979.511	4.230.873	4.230.873	1.692.596	897.929	557.185
August	9,6	1,1677	736	7.491.301	1.813.073	1.813.073	1.813.073	8.871.123	1.813.073	5.434.819	5.434.819	896.286	896.286	1.813.073	4.223.131	1.813.073	1.689.499	5.434.819	7.821.753	7.821.753	896.286	4.223.131	7.821.753	5.434.819	1.813.073	1.813.073	556.165	896.286
September	10,1	1,1657	712	8.566.923	1.631.564	1.631.564	3.663.906	7.553.538	1.631.564	6.331.230	6.331.230	944.192	944.192	1.631.564	6.331.230	1.631.564	3.663.906	6.331.230	7.234.417	7.234.417	944.192	5.248.454	8.566.923	6.331.230	1.631.564	3.663.906	6.331.230	944.192
October	9,7	1,1645	736	7.800.246	975.031	975.031	554.636	7.470.703	975.031	7.470.703	7.470.703	1.684.853	1.684.853	975.031	8.846.730	975.031	554.636	7.470.703	6.538.016	6.538.016	1.808.088	6.538.016	4.211.519	7.470.703	975.031	975.031	8.846.730	1.684.853
November	9,2	1,1638	696	6.179.252	844.775	844.775	844.775	6.179.252	844.775	7.372.218	7.372.218	1.708.872	1.708.872	844.775	7.372.218	844.775	844.775	7.372.218	5.122.467	5.122.467	1.592.399	7.060.758	6.179.252	7.372.218	844.775	844.775	7.372.218	1.708.872
December	7,6	1,1651	736	3.785.725	554.951	554.951	975.585	5.422.956	554.951	8.851.759	8.851.759	3.785.725	3.785.725	554.951	7.474.950	554.951	975.585	8.851.759	4.213.913	4.213.913	3.785.725	7.804.681	5.422.956	8.851.759	554.951	554.951	7.474.950	3.785.725
Annual	7,4	1,1666	8.616	49.057.055	48.667.462	48.892.652	48.537.127	49.088.734	48.667.462	49.051.893	49.051.893	48.608.021	48.624.219	48.667.462	49.049.275	48.892.652	48.596.807	49.239.932	49.380.379	49.009.701	48.697.726	48.317.889	49.064.437	48.965.360	48.420.199	48.519.758	48.661.536	48.608.021

Table H.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)}$

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11,7	1,2313	740	14.490.462	14.490.462	14.490.462	14.490.462	14.490.462	14.490.462	14.490.462	10.871.408	10.871.408	14.490.462	10.871.408	10.871.408	10.871.408	14.490.462	10.871.408	10.871.408	14.490.462	10.871.408	10.871.408	10.871.408	10.871.408	10.871.408	10.871.408	10.871.408	10.871.408
February	11,5	1,2345	648	12.092.721	4.293.137	12.092.721	12.092.721	12.092.721	3.417.096	12.092.721	12.715.785	1.795.784	3.417.096	12.715.785	1.795.784	9.244.173	12.092.721	6.674.015	12.715.785	4.293.137	5.486.290	3.417.096	2.815.600	12.092.721	2.106.703	6.674.015	12.092.721	12.715.785
March	10,5	1,2329	736	10.486.228	3.193.907	13.717.510	13.717.510	13.717.510	6.223.433	13.717.510	13.717.510	2.389.762	3.193.907	13.717.510	2.389.762	13.717.510	13.717.510	6.223.433	13.717.510	3.876.220	7.570.742	4.869.967	13.717.510	14.424.289	2.037.067	10.486.228	14.424.289	3.193.907
April	9,5	1,2317	712	7.316.597	7.316.597	10.458.483	10.458.483	10.458.483	7.316.597	10.458.483	4.706.485	3.086.689	7.316.597	13.257.022	3.086.689	13.257.022	4.706.485	4.706.485	13.257.022	3.086.689	10.134.212	3.086.689	13.940.075	13.257.022	3.086.689	3.086.689	13.257.022	3.746.098
May	8,2	1,2282	736	4.851.676	10.446.845	10.446.845	10.446.845	6.200.059	10.446.845	10.446.845	10.446.845	3.861.662	6.200.059	10.446.845	3.861.662	14.370.115	10.446.845	3.861.662	10.446.845	2.380.787	13.665.991	6.200.059	2.380.787	10.446.845	3.861.662	14.370.115	10.446.845	4.851.676
June	7,1	1,2224	696	2.994.461	12.860.910	7.097.981	7.097.981	7.097.981	10.145.990	4.565.858	12.860.910	4.565.858	10.145.990	7.097.981	4.565.858	7.097.981	2.240.532	2.994.461	7.097.981	1.909.861	12.860.910	7.097.981	1.909.861	7.097.981	4.565.858	12.860.910	7.097.981	5.834.806
July	6,1	1,2154	736	2.008.118	13.522.571	4.800.760	6.134.992	10.337.209	13.522.571	7.463.154	3.148.518	6.134.992	2.008.118	6.134.992	6.134.992	6.134.992	2.008.118	2.355.801	6.134.992	6.134.992	14.219.306	10.337.209	3.821.135	6.134.992	6.134.992	13.522.571	3.821.135	7.463.154
August	6,4	1,2075	736	2.340.496	10.598.668	3.796.310	3.796.310	3.796.310	13.434.719	6.095.134	3.796.310	7.414.668	2.340.496	4.769.571	7.414.668	4.769.571	10.598.668	1.995.072	4.769.571	13.434.719	1.995.072	13.434.719	4.769.571	4.769.571	7.414.668	4.769.571	3.128.063	10.270.051
September	7,6	1,2064	712	3.669.202	1.928.273	5.891.057	4.609.876	4.609.876	4.609.876	1.928.273	5.891.057	9.926.189	9.926.189	3.669.202	9.926.189	3.669.202	5.891.057	9.926.189	3.669.202	12.984.898	2.262.132	12.984.898	5.891.057	3.669.202	9.926.189	3.669.202	2.262.132	1.928.273
October	8,9	1,2126	736	6.121.079	6.121.079	3.141.378	2.003.564	3.141.378	2.003.564	2.350.459	7.446.229	13.491.905	13.491.905	3.141.378	13.491.905	3.141.378	7.446.229	13.491.905	3.141.378	10.643.782	3.141.378	2.003.564	7.446.229	3.141.378	13.491.905	2.350.459	2.003.564	2.350.459
November	10,6	1,2194	696	10.121.586	3.625.425	2.235.143	2.235.143	2.235.143	2.235.143	2.987.258	2.235.143	12.829.976	4.554.876	2.235.143	12.829.976	2.235.143	2.987.258	12.829.976	2.235.143	9.807.761	3.625.425	2.235.143	9.807.761	2.235.143	12.829.976	1.905.267	5.820.771	12.829.976
December	11,5	1,2237	736	13.614.984	2.371.901	2.021.842	3.170.035	2.021.842	3.170.035	3.847.249	2.021.842	14.316.481	13.614.984	2.021.842	14.316.481	2.021.842	3.847.249	14.316.481	2.021.842	7.514.158	4.833.568	14.316.481	13.614.984	2.021.842	14.316.481	6.176.918	4.833.568	13.614.984
Annual	9,1	1,2222	8.616	90.107.610	90.769.774	90.190.491	90.253.921	90.198.973	91.016.328	90.443.405	89.858.042	90.685.374	90.700.678	90.078.677	90.685.374	90.530.336	90.473.134	90.246.888	90.078.677	90.557.464	90.666.434	90.855.213	90.985.978	90.162.393	90.643.598	90.743.354	90.059.500	89.670.577

Table H.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)}$

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15,4	1,2561	740	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	8.035.210	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	32.823.510	40.865.255	32.823.510	32.823.510	28.095.929	8.035.210	7.120.177
February	14,7	1,2522	648	24.591.404	14.672.254	7.010.451	26.599.864	14.672.254	14.672.254	26.599.864	26.599.864	7.010.451	14.672.254	14.672.254	7.859.649	26.599.864	7.010.451	17.623.290	7.010.451	7.010.451	7.010.451	7.010.451	22.780.600	26.599.864	26.599.864	29.369.594	7.859.649	17.596.916
March	12,7	1,2495	736	18.252.376	18.252.376	8.908.878	27.874.248	12.394.144	18.252.376	27.874.248	27.874.248	8.908.878	12.394.144	18.252.376	9.986.084	27.874.248	8.908.878	30.150.829	8.908.878	8.908.878	8.908.878	8.908.878	23.024.061	27.874.248	27.874.248	31.459.374	9.986.084	18.948.162
April	12,4	1,2490	712	16.081.249	19.315.677	9.656.023	24.865.308	9.656.023	19.315.677	24.865.308	24.865.308	9.656.023	9.656.023	19.315.677	9.656.023	24.865.308	9.656.023	26.952.947	9.656.023	29.154.282	9.656.023	9.656.023	22.218.160	20.001.184	24.865.308	24.956.459	9.656.023	18.165.621
May	11,2	1,2425	736	12.324.064	25.569.850	9.929.620	19.862.973	9.929.620	25.569.850	19.862.973	19.862.973	9.929.620	9.929.620	25.569.850	12.324.064	19.862.973	9.929.620	25.569.850	9.929.620	27.716.641	9.929.620	9.929.620	21.018.978	19.862.973	19.862.973	19.116.345	12.324.064	16.191.245
June	10,4	1,2351	696	9.333.787	26.053.485	11.584.551	17.060.120	8.326.944	26.053.485	17.060.120	17.060.120	11.584.551	8.326.944	26.053.485	15.544.593	17.060.120	11.584.551	17.060.120	11.584.551	24.035.514	11.584.551	11.584.551	17.178.664	17.060.120	17.060.120	16.981.395	15.544.593	15.146.363
July	10,0	1,2275	736	8.751.923	29.619.639	16.337.936	16.337.936	7.806.320	29.619.639	16.337.936	16.337.936	16.337.936	7.806.320	29.619.639	17.930.811	16.337.936	16.337.936	7.806.320	16.337.936	19.623.991	16.337.936	16.337.936	15.552.737	16.069.219	16.337.936	16.783.950	17.930.811	8.637.391
August	9,7	1,2216	736	7.768.712	12.117.129	17.844.428	12.117.129	17.844.428	12.117.129	12.117.129	12.117.129	17.844.428	17.844.428	12.117.129	19.529.451	12.117.129	17.844.428	8.709.760	17.844.428	17.844.428	17.844.428	17.844.428	12.921.415	15.399.666	12.117.129	12.606.836	19.529.451	7.121.992
September	10,4	1,2234	712	9.458.082	7.526.165	18.919.721	9.458.082	26.400.433	7.526.165	9.458.082	9.458.082	18.919.721	26.400.433	7.526.165	24.355.589	9.458.082	18.919.721	9.458.082	18.919.721	15.751.596	18.919.721	18.919.721	12.339.146	13.294.981	9.458.082	8.855.020	24.355.589	19.057.688
October	13,1	1,2327	736	19.706.914	8.788.905	29.744.799	9.851.605	25.368.953	8.788.905	9.851.605	9.851.605	29.744.799	25.368.953	8.788.905	27.498.877	9.851.605	25.368.953	9.851.605	25.368.953	12.227.237	29.744.799	25.368.953	12.259.773	8.871.247	9.851.605	8.134.157	27.498.877	21.626.625
November	14,3	1,2429	696	24.188.639	9.393.250	26.219.466	8.379.993	28.360.895	9.393.250	8.379.993	8.379.993	26.219.466	28.360.895	9.393.250	28.360.895	8.379.993	26.219.466	11.658.353	26.219.466	9.393.250	26.219.466	26.219.466	7.520.762	8.379.993	8.379.993	8.987.716	28.360.895	22.240.116
December	15,1	1,2528	736	30.229.153	10.012.025	25.782.051	7.966.958	20.027.814	10.012.025	7.966.958	7.966.958	25.782.051	20.027.814	10.012.025	32.544.702	7.966.958	30.229.153	16.674.139	30.229.153	10.012.025	25.782.051	30.229.153	6.359.397	7.966.958	7.966.958	9.176.637	32.544.702	42.535.343
Annual	12,5	1,2404	8.616	213.509.813	214.144.266	214.761.434	213.197.728	213.611.337	214.144.266	213.197.728	213.197.728	214.761.434	213.611.337	214.144.266	213.625.948	213.197.728	214.832.689	214.338.805	214.832.689	214.501.803	214.761.434	214.832.689	214.038.947	214.203.964	213.197.728	214.523.412	213.625.948	214.387.639

Table H.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)}$

Months	v_{wc}	*Wind speed data series for simulations (m/s)*																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5,8	5,8	10,1	7,6	9,6	4,0	10,1	4,0	4,0	7,9	10,1	10,1	4,0	7,6	9,6	7,9	10,1	10,1	4,0	7,6	9,6	4,0	7,6	9,6	7,9	7,9
February	4,9	4,9	9,7	7,9	9,7	4,7	9,7	4,7	4,7	8,6	9,7	9,7	4,7	7,9	9,7	4,0	4,0	7,6	8,6	10,1	6,0	6,0	10,1	9,7	8,6	8,6
March	4,0	4,0	9,6	8,6	10,1	4,9	9,6	4,9	4,9	9,2	9,6	9,6	4,9	8,6	10,1	4,7	4,7	6,0	7,9	6,0	5,8	5,8	9,7	10,1	7,6	9,2
April	4,7	4,7	9,2	9,2	7,9	5,8	9,2	5,8	5,8	9,6	9,2	9,2	6,0	9,2	7,9	4,9	4,9	5,8	9,2	5,8	7,6	4,9	9,6	9,2	6,0	9,6
May	6,0	6,0	8,6	9,6	8,6	6,0	8,6	6,0	6,0	9,7	8,6	8,6	5,8	9,6	9,2	5,8	5,8	4,9	10,1	4,9	4,0	4,7	9,2	7,9	5,8	9,7
June	7,9	7,9	7,9	9,7	9,2	7,6	7,9	7,6	7,6	10,1	7,9	7,9	7,6	9,7	8,6	6,0	6,0	4,7	9,7	4,7	4,7	7,6	8,6	8,6	4,9	10,1
July	8,6	8,6	7,6	10,1	5,8	7,9	7,6	7,9	7,9	4,0	4,0	7,6	8,6	10,1	6,0	7,6	7,6	4,0	9,6	4,0	4,9	7,9	7,9	5,8	4,7	4,0
August	9,6	9,6	6,0	6,0	6,0	10,1	6,0	8,6	8,6	4,7	4,7	6,0	7,9	6,0	5,8	8,6	9,7	9,7	4,7	7,9	9,7	8,6	6,0	6,0	4,0	4,7
September	10,1	10,1	5,8	5,8	7,6	9,7	5,8	9,2	9,2	4,9	4,9	5,8	9,2	5,8	7,6	9,2	9,6	9,6	4,9	8,6	10,1	9,2	5,8	7,6	9,2	4,9
October	9,7	9,7	4,9	4,9	4,0	9,6	4,9	9,6	9,6	5,8	5,8	4,9	10,1	4,9	4,0	9,6	9,2	9,2	6,0	9,2	7,9	9,6	4,9	4,9	10,1	5,8
November	9,2	9,2	4,7	4,7	4,7	9,2	4,7	9,7	9,7	6,0	6,0	4,7	9,7	4,7	4,7	9,7	8,6	8,6	5,8	9,6	9,2	9,7	4,7	4,7	9,7	6,0
December	7,6	7,6	4,0	4,0	4,9	8,6	4,0	10,1	10,1	7,6	7,6	4,0	9,6	4,0	4,9	10,1	7,9	7,9	7,6	9,7	8,6	10,1	4,0	4,0	9,6	7,6
Annual	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4	7,4

Table H.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)}$

Months	v_{wc}	*Wind speed data series for simulations (m/s)*																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11,7	11,7	11,7	11,7	11,7	11,7	11,7	11,7	11,7	10,6	10,6	11,7	10,6	10,6	10,6	11,7	10,6	10,6	11,7	10,6	10,6	10,6	10,6	10,6	10,6	10,6
February	11,5	11,5	8,2	11,5	11,5	11,5	7,6	11,5	11,7	6,1	7,6	11,7	6,1	10,5	11,5	9,5	11,7	8,2	8,9	7,6	7,1	11,5	6,4	9,5	11,5	11,7
March	10,5	10,5	7,1	11,5	11,5	11,5	8,9	11,5	11,5	6,4	7,1	11,5	6,4	11,5	11,5	8,9	11,5	7,6	9,5	8,2	11,5	11,7	6,1	10,5	11,7	7,1
April	9,5	9,5	9,5	10,6	10,6	10,6	9,5	10,6	8,2	7,1	9,5	11,5	7,1	11,5	8,2	8,2	11,5	7,1	10,5	7,1	11,7	11,5	7,1	7,1	11,5	7,6
May	8,2	8,2	10,5	10,5	10,5	8,9	10,5	10,5	10,5	7,6	8,9	10,5	7,6	11,7	10,5	7,6	10,5	6,4	11,5	8,9	6,4	10,5	7,6	11,7	10,5	8,2
June	7,1	7,1	11,5	9,5	9,5	9,5	10,6	8,2	11,5	8,2	10,6	9,5	8,2	9,5	6,4	7,1	9,5	6,1	11,5	9,5	6,1	9,5	8,2	11,5	9,5	8,9
July	6,1	6,1	11,5	8,2	8,9	10,5	11,5	9,5	7,1	8,9	6,1	8,9	8,9	8,9	6,1	6,4	8,9	8,9	11,7	10,5	7,6	8,9	8,9	11,5	7,6	9,5
August	6,4	6,4	10,6	7,6	7,6	7,6	11,5	8,9	7,6	9,5	6,4	8,2	9,5	8,2	10,6	6,1	8,2	11,5	6,1	11,5	8,2	8,2	9,5	8,2	7,1	10,5
September	7,6	7,6	6,1	8,9	8,2	8,2	8,2	6,1	8,9	10,5	10,5	7,6	10,5	7,6	8,9	10,5	7,6	11,5	6,4	11,5	8,9	7,6	10,5	7,6	6,4	6,1
October	8,9	8,9	8,9	7,1	6,1	7,1	6,1	6,4	9,5	11,5	11,5	7,1	11,5	7,1	9,5	11,5	7,1	10,6	7,1	6,1	9,5	7,1	11,5	6,4	6,1	6,4
November	10,6	10,6	7,6	6,4	6,4	6,4	6,4	7,1	6,4	11,5	8,2	6,4	11,5	6,4	7,1	11,5	6,4	10,5	7,6	6,4	10,5	6,4	11,5	6,1	8,9	11,5
December	11,5	11,5	6,4	6,1	7,1	6,1	7,1	7,6	6,1	11,7	11,5	6,1	11,7	6,1	7,6	11,7	6,1	9,5	8,2	11,7	11,5	6,1	11,7	8,9	8,2	11,5
Annual	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1	9,1

Table H.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)}$

Months	v_{wc}	*Wind speed data series for simulations (m/s)*																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	15,4	9,7	15,4	15,4	15,4	15,4	15,4	15,4	15,4	16,6	15,4	15,4	14,7	9,7	9,3
February	14,7	14,7	12,4	9,7	15,1	12,4	12,4	15,1	15,1	9,7	12,4	12,4	10,0	15,1	9,7	13,1	9,7	9,7	9,7	9,7	14,3	15,1	15,1	15,6	10,0	13,1
March	12,7	12,7	12,7	10,0	14,7	11,2	12,7	14,7	14,7	10,0	11,2	12,7	10,4	14,7	10,0	15,1	10,0	10,0	10,0	10,0	13,8	14,7	14,7	15,3	10,4	12,9
April	12,4	12,4	13,1	10,4	14,3	10,4	13,1	14,3	14,3	10,4	10,4	13,1	10,4	14,3	10,4	14,7	10,4	15,1	10,4	10,4	13,8	13,3	14,3	14,3	10,4	12,9
May	11,2	11,2	14,3	10,4	13,1	10,4	14,3	13,1	13,1	10,4	10,4	14,3	11,2	13,1	10,4	14,3	10,4	14,7	10,4	10,4	13,4	13,1	13,1	13,0	11,2	12,3
June	10,4	10,4	14,7	11,2	12,7	10,0	14,7	12,7	12,7	11,2	10,0	14,7	12,4	12,7	11,2	12,7	11,2	14,3	11,2	11,2	12,8	12,7	12,7	12,7	12,4	12,2
July	10,0	10,0	15,1	12,4	12,4	9,7	15,1	12,4	12,4	12,4	9,7	15,1	12,7	12,4	12,4	9,7	12,4	13,1	12,4	12,4	12,2	12,3	12,4	12,5	12,7	10,0
August	9,7	9,7	11,2	12,7	11,2	12,7	11,2	11,2	11,2	12,7	12,7	11,2	13,1	11,2	12,7	10,0	12,7	12,7	12,7	12,7	11,4	12,1	11,2	11,4	13,1	9,4
September	10,4	10,4	9,7	13,1	10,4	14,7	9,7	10,4	10,4	13,1	14,7	9,7	14,3	10,4	13,1	10,4	13,1	12,4	13,1	13,1	11,4	11,7	10,4	10,2	14,3	13,2
October	13,1	13,1	10,0	15,1	10,4	14,3	10,0	10,4	10,4	15,1	14,3	10,0	14,7	10,4	14,3	10,4	14,3	11,2	15,1	14,3	11,2	10,1	10,4	9,8	14,7	13,5
November	14,3	14,3	10,4	14,7	10,0	15,1	10,4	10,0	10,0	14,7	15,1	10,4	15,1	10,0	14,7	11,2	14,7	10,4	14,7	14,7	9,7	10,0	10,0	10,3	15,1	13,9
December	15,1	15,1	10,4	14,3	9,7	13,1	10,4	9,7	9,7	14,3	13,1	10,4	15,4	9,7	15,1	12,4	15,1	10,4	14,3	15,1	9,0	9,7	9,7	10,1	15,4	16,9
Annual	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5	12,5

Table H.7 kWh per H_{prod} with sensitivity analysis of $O\&M_{manag(A)}$

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	*5 693*	*5 648*	*5 674*	*5 633*	*5 697*	*5 648*	*5 693*	*5 693*	*5 641*	*5 643*	*5 648*	*5 693*	*5 674*	*5 640*	*5 715*	*5 731*	*5 688*	*5 652*	*5 608*	*5 694*	*5 683*	*5 620*	*5 631*	*5 648*	*5 641*
Corvo Island (Portugal)	*10 458*	*10 535*	*10 467*	*10 475*	*10 468*	*10 563*	*10 497*	*10 429*	*10 525*	*10 527*	*10 454*	*10 525*	*10 507*	*10 500*	*10 474*	*10 454*	*10 510*	*10 523*	*10 545*	*10 560*	*10 464*	*10 520*	*10 532*	*10 452*	*10 407*
Cape Saint James (Canada)	*24 780*	*24 853*	*24 925*	*24 743*	*24 791*	*24 853*	*24 743*	*24 743*	*24 925*	*24 791*	*24 853*	*24 793*	*24 743*	*24 933*	*24 876*	*24 933*	*24 895*	*24 925*	*24 933*	*24 841*	*24 860*	*24 743*	*24 897*	*24 793*	*24 882*

Table H.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)}$

Item	Years												
	0	1	2	3	4	5	6	7	8	9	10	11	12
(-) LCCCM $_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	49 057 055	48 667 462	48 892 652	48 537 127	49 088 734	48 667 462	49 051 893	49 051 893	48 608 021	48 624 219	48 667 462	49 049 275
(+) AAR ($M/yr)	-	4 314 826	4 387 573	4 518 071	4 597 349	4 765 836	4 843 059	5 003 348	5 128 432	5 209 075	5 341 081	5 479 477	5 660 527
PPAR	-	4 314 826	4 387 573	4 518 071	4 597 349	4 765 836	4 843 059	5 003 348	5 128 432	5 209 075	5 341 081	5 479 477	5 660 527
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	3 964 703	4 031 427	4 151 213	4 223 934	4 378 615	4 471 031	4 618 343	4 733 137	4 806 905	4 928 061	5 055 095	5 221 459
$O\&M_{fixed}$	-	2 665 486	2 710 424	2 791 038	2 840 010	2 944 091	2 991 795	3 090 812	3 168 081	3 217 896	3 299 441	3 384 934	3 496 775
$O\&M_{variable}$	-	1 299 217	1 321 003	1 360 175	1 383 923	1 434 523	1 479 236	1 527 531	1 565 056	1 589 009	1 628 620	1 670 162	1 724 683
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 453 486	2 514 824	2 577 694	2 642 137	2 708 190	2 775 895	2 845 292	2 916 424	2 989 335	3 064 068	3 140 670	3 219 187
(=) Profit before tax	-	3 666 877	3 755 819	3 851 524	3 945 197	4 048 298	4 124 632	4 231 424	4 337 875	4 443 314	4 555 193	4 670 108	4 790 938
(-) Revenue tax	-	1 294 448	1 316 272	1 355 421	1 379 205	1 429 751	1 452 918	1 501 004	1 538 530	1 562 723	1 602 324	1 643 843	1 698 158
(+) REPIM	384 768	2 046	1 991	1 963	1 912	1 899	1 849	1 830	1 798	1 751	1 722	281	291
REI_{CM}	221 313	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 825	1 766	1 731	1 676	1 654	1 600	1 573	1 535	1 484	1 448	-	-
$OREP_{CM}$	163 455	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	222	225	232	236	245	249	257	263	267	274	281	291
(=) Profit after tax w/out interest	-	2 374 476	2 441 539	2 498 065	2 567 905	2 620 446	2 673 562	2 732 250	2 801 143	2 882 342	2 954 591	3 026 547	3 093 071
(-) Debt payments	-	-	3 175 718	3 255 111	3 336 489	3 419 901	3 505 399	3 593 034	3 682 860	3 774 931	3 869 304	3 966 037	4 065 188
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 453 486	2 514 824	2 577 694	2 642 137	2 708 190	2 775 895	2 845 292	2 916 424	2 989 335	3 064 068	3 140 670	3 219 187
(=) Free net cashflow	-59 841 132	7 449 701	4 467 926	4 575 113	4 696 879	4 802 644	4 910 315	5 024 922	5 151 132	5 291 080	5 423 547	5 557 227	5 687 018
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 391 431	-47 923 505	-43 348 392	-38 651 514	-33 848 870	-28 938 555	-23 913 633	-18 762 502	-13 471 421	-8 047 874	-2 490 647	3 196 371
	$LCOE_{wso}$	*67.68*	*67.83*	*68.04*	*68.20*	*68.45*	*68.64*	*68.89*	*69.10*	*69.28*	*69.51*	*69.74*	*70.02*

Item	Years												
	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) LCCCM $_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	48 892 652	48 596 807	49 239 932	49 380 379	49 009 701	48 697 726	48 317 889	49 064 437	48 965 360	48 420 199	48 519 758	48 661 536	48 608 021
(+) AAR ($M/yr)	5 783 513	5 892 231	6 119 463	6 290 341	6 399 200	6 517 427	6 628 256	6 898 935	4 939 990	5 007 115	5 142 845	5 286 820	5 413 031
PPAR	5 783 513	5 892 231	6 119 463	6 290 341	6 399 200	6 517 427	6 628 256	6 898 935	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 939 990	5 007 115	5 142 845	5 286 820	5 413 031
(-) $O\&M_{WFCM}$	5 334 243	5 433 856	5 642 744	5 799 641	5 899 344	6 007 676	6 109 183	6 357 999	5 867 984	5 947 062	6 107 615	6 277 939	6 427 153
$O\&M_{fixed}$	3 572 748	3 639 907	3 780 277	3 885 835	3 953 081	4 026 113	4 094 576	4 261 785	4 359 507	4 418 743	4 538 523	4 665 578	4 776 957
$O\&M_{variable}$	1 761 494	1 793 950	1 862 467	1 913 806	1 946 264	1 981 563	2 014 606	2 096 214	1 508 477	1 528 319	1 569 092	1 612 361	1 650 196
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 299 666	3 382 158	3 466 712	3 553 380	3 642 214	3 733 270	3 826 601	3 922 267	4 020 323	4 120 831	4 223 852	4 329 448	4 437 685
(=) Profit before tax	4 909 937	5 030 558	5 163 206	4 044 079	4 142 070	4 243 020	4 345 675	4 463 202	3 092 329	3 180 884	3 259 082	3 338 329	3 423 563
(-) Revenue tax	1 735 054	1 767 669	1 835 839	1 887 102	1 919 760	1 955 228	1 988 477	2 069 680	1 481 997	1 502 134	1 542 854	1 586 046	1 623 909
(+) REPIM	297	303	314	323	329	335	340	354	362	367	377	388	397
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	297	303	314	323	329	335	340	354	362	367	377	388	397
(=) Profit after tax w/out interest	3 175 180	3 263 191	3 327 682	2 157 300	2 222 639	2 288 127	2 357 538	2 393 876	1 610 694	1 679 116	1 716 606	1 752 671	1 800 051
(-) Debt payments	4 166 818	4 270 988	4 377 763	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 299 666	3 382 158	3 466 712	3 553 380	3 642 214	3 733 270	3 826 601	3 922 267	4 020 323	4 120 831	4 223 852	4 329 448	4 437 685
(=) Free net cashflow	5 833 976	5 988 457	6 121 079	9 507 740	9 756 839	10 010 682	10 273 158	10 507 386	9 927 042	10 203 373	10 453 968	10 708 467	10 979 742
$\Sigma_{free\ net\ annual\ cashflow}$	9 030 347	15 018 804	21 139 884	30 647 624	40 404 463	50 415 145	60 688 302	71 195 688	81 122 730	91 326 103	101 780 071	112 488 539	123 468 281
$LCOE_{wso}$	*70.25*	*70.46*	*70.79*	*69.82*	*70.02*	*70.22*	*70.42*	*70.78*	*70.39*	*70.58*	*70.85*	*71.13*	*71.40*

Table H.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)}$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577
(+) AAR ($M/yr)	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
PPAR	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
(-) $O\&M_{WFCM}$	-	9 414 550	9 720 704	9 900 012	10 154 527	10 401 931	10 758 472	10 957 897	11 159 028	11 543 192	11 833 646	12 046 185	12 430 378	12 719 232	13 028 853	13 321 057	13 628 511	14 043 351	14 411 633	14 802 558	15 194 336	13 212 815	13 615 294	13 970 912	14 212 144	14 504 416
$O\&M_{fixed}$	-	4 895 943	5 055 217	5 148 526	5 280 948	5 409 674	5 595 159	5 698 935	5 803 599	6 003 456	6 154 579	6 265 179	6 465 057	6 615 352	6 776 449	6 928 488	7 088 460	7 304 288	7 495 901	7 699 294	7 903 132	8 027 381	8 271 977	8 488 105	8 634 738	8 812 382
$O\&M_{variable}$	-	4 518 607	4 665 487	4 751 486	4 873 579	4 992 258	5 163 313	5 258 962	5 355 430	5 539 736	5 679 068	5 781 006	5 965 321	6 103 880	6 252 405	6 392 569	6 540 051	6 739 063	6 915 732	7 103 264	7 291 205	5 185 434	5 343 317	5 482 807	5 577 406	5 692 034
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 449 308	2 510 541	2 573 304	2 637 637	2 703 578	2 771 167	2 840 447	2 911 458	2 984 244	3 058 850	3 135 322	3 213 705	3 294 047	3 376 398	3 460 808	3 547 329	3 636 012	3 726 912	3 820 085	3 915 587	4 013 477	4 113 814	4 216 659	4 322 075	4 430 127
(=) Profit before tax	-	8 944 151	9 210 296	9 402 638	9 642 095	9 879 479	10 184 390	10 397 593	10 614 162	10 942 647	11 217 531	11 448 320	11 784 412	12 066 110	12 362 956	12 652 168	11 703 095	12 040 228	12 351 722	12 679 045	13 009 213	8 069 533	8 293 583	8 505 760	8 685 395	8 883 337
(-) Revenue tax	-	4 513 837	4 660 683	4 746 712	4 868 802	4 987 484	5 158 496	5 254 175	5 350 673	5 534 936	5 674 267	5 776 238	5 960 521	6 099 089	6 247 616	6 387 792	6 535 283	6 734 270	6 910 933	7 098 455	7 286 389	5 180 661	5 338 519	5 478 004	5 572 639	5 687 288
(+) REPIM	486 675	1 439	1 420	1 382	1 355	1 327	1 313	1 279	1 247	1 234	1 211	1 180	1 167	1 144	1 123	1 100	165	170	175	179	184	187	193	198	201	205
REI_{CM}	221 313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 325	1 302	1 262	1 232	1 201	1 183	1 147	1 111	1 094	1 068	1 034	1 016	990	965	939	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	265 362	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	114	118	120	123	126	130	133	135	140	143	146	151	154	158	161	165	170	175	179	184	187	193	198	201	205
(=) Profit after tax w/out interest	-	4 431 752	4 551 033	4 657 307	4 774 648	4 893 322	5 027 207	5 144 697	5 264 735	5 408 945	5 544 475	5 673 263	5 825 058	5 968 165	6 116 463	6 265 476	5 167 976	5 306 128	5 440 964	5 580 769	5 723 009	2 889 059	2 955 257	3 027 954	3 112 957	3 196 254
(-) Debt payments	-	-	3 170 310	3 249 568	3 330 807	3 414 077	3 499 429	3 586 915	3 676 588	3 768 503	3 862 715	3 959 283	4 058 265	4 159 722	4 263 715	4 370 308	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 449 308	2 510 541	2 573 304	2 637 637	2 703 578	2 771 167	2 840 447	2 911 458	2 984 244	3 058 850	3 135 322	3 213 705	3 294 047	3 376 398	3 460 808	3 547 329	3 636 012	3 726 912	3 820 085	3 915 587	4 013 477	4 113 814	4 216 659	4 322 075	4 430 127
(=) Free net cashflow	-59 739 225	9 502 799	6 578 546	6 735 508	6 904 804	7 076 732	7 265 202	7 438 642	7 616 029	7 819 021	8 014 803	8 205 349	8 420 446	8 628 438	8 843 243	9 060 425	12 512 365	12 834 126	13 157 162	13 489 872	13 829 839	11 198 560	11 472 495	11 758 123	12 061 381	12 368 389
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 236 426	-43 657 880	-36 922 371	-30 017 567	-22 940 835	-15 675 633	-8 236 990	-620 962	7 198 060	15 212 862	23 418 211	31 838 657	40 467 095	49 310 338	58 370 764	70 883 128	83 717 254	96 874 416	110 364 287	124 194 126	135 392 686	146 865 181	158 623 305	170 684 685	183 053 074
	$LCOE_{wso}$	73.13	73.52	73.79	74.13	74.47	74.93	75.23	75.53	76.02	76.41	76.73	77.23	77.63	78.06	78.47	77.65	78.16	78.63	79.12	79.61	77.73	78.24	78.71	79.06	79.47

Table H.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)}$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	213 509 813	214 144 266	214 761 434	213 197 728	213 611 337	214 144 266	213 197 728	213 197 728	214 761 434	213 611 337	214 144 266	213 625 948	213 197 728	214 832 689	214 338 805	214 832 689	214 501 803	214 761 434	214 832 689	214 038 947	214 203 964	213 197 728	214 523 412	213 625 948	214 387 639
(+) AAR ($M/yr)	-	30 276 974	31 126 117	31 996 219	32 557 331	33 436 006	34 357 409	35 060 685	35 937 202	37 105 804	37 829 772	38 872 255	39 747 622	40 659 646	41 995 741	42 946 676	44 121 775	45 155 164	46 340 065	47 514 326	48 522 244	34 841 551	35 544 828	36 659 995	37 419 293	38 491 531
PPAR	-	30 276 974	31 126 117	31 996 219	32 557 331	33 436 006	34 357 409	35 060 685	35 937 202	37 105 804	37 829 772	38 872 255	39 747 622	40 659 646	41 995 741	42 946 676	44 121 775	45 155 164	46 340 065	47 514 326	48 522 244	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 841 551	35 544 828	36 659 995	37 419 293	38 491 531
(-) $O\&M_{WFCM}$	-	20 688 790	21 268 898	21 863 324	22 246 612	22 846 890	23 476 361	23 956 782	24 555 577	25 353 946	25 848 498	26 560 685	27 158 681	27 781 721	28 694 515	29 344 137	30 146 919	30 852 873	31 662 346	32 464 546	33 153 088	29 528 360	30 124 265	31 069 244	31 712 621	32 621 209
$O\&M_{fixed}$	-	11 600 929	11 926 280	12 259 661	12 474 651	12 811 317	13 164 355	13 433 815	13 769 654	14 217 407	14 494 795	14 894 225	15 229 623	15 579 065	16 090 994	16 455 346	16 905 588	17 301 532	17 755 529	18 205 449	18 591 634	19 071 110	19 456 054	20 066 453	20 482 061	21 068 961
$O\&M_{variable}$	-	9 087 862	9 342 619	9 603 663	9 771 962	10 035 573	10 312 006	10 522 968	10 785 923	11 136 539	11 353 703	11 666 460	11 929 059	12 202 656	12 603 521	12 888 791	13 241 331	13 551 341	13 906 817	14 259 097	14 561 454	10 457 250	10 668 211	11 002 791	11 230 560	11 552 248
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 431 021	2 491 796	2 554 091	2 617 943	2 683 392	2 750 477	2 819 239	2 889 720	2 961 963	3 036 012	3 111 912	3 189 710	3 269 453	3 351 189	3 434 969	3 520 843	3 608 864	3 699 085	3 791 563	3 886 352	3 983 510	4 083 098	4 185 176	4 289 805	4 397 050
(=) Profit before tax	-	12 882 473	13 233 865	13 593 957	13 858 308	14 225 394	14 608 234	14 924 268	15 297 500	15 765 630	16 095 389	16 528 538	16 911 334	17 308 377	17 842 439	18 257 283	17 495 699	17 911 155	18 376 804	18 841 343	19 255 508	9 296 701	9 503 661	9 775 927	9 996 478	10 267 372
(-) Revenue tax	-	9 083 092	9 337 835	9 598 866	9 767 199	10 030 802	10 307 223	10 518 205	10 781 161	11 131 741	11 348 931	11 661 677	11 924 287	12 197 894	12 598 722	12 884 003	13 236 533	13 546 549	13 902 019	14 254 298	14 556 673	10 452 465	10 663 448	10 997 999	11 225 788	11 547 459
(+) REPIM	932 714	780	794	809	815	830	846	857	871	893	904	801	819	838	865	885	909	930	955	979	1 000	1 025	1 046	1 079	1 101	1 133
REI_{CM}	221 313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	156	153	149	145	141	138	134	131	129	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	711 400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	624	641	659	671	689	708	722	740	764	779	801	819	838	865	885	909	930	955	979	1 000	1 025	1 046	1 079	1 101	1 133
(=) Profit after tax w/out interest	-	3 800 161	3 896 824	3 995 900	4 091 924	4 195 423	4 301 857	4 406 919	4 517 211	4 634 782	4 747 362	4 867 663	4 987 866	5 111 321	5 244 582	5 374 165	4 260 075	4 365 536	4 475 740	4 588 024	4 699 834	-1 154 739	-1 158 741	-1 220 992	-1 228 209	-1 278 955
(-) Debt payments	-	-	3 146 639	3 225 305	3 305 938	3 388 586	3 473 301	3 560 134	3 649 137	3 740 365	3 833 874	3 929 721	4 027 964	4 128 663	4 231 880	4 337 677	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 431 021	2 491 796	2 554 091	2 617 943	2 683 392	2 750 477	2 819 239	2 889 720	2 961 963	3 036 012	3 111 912	3 189 710	3 269 453	3 351 189	3 434 969	3 520 843	3 608 864	3 699 085	3 791 563	3 886 352	3 983 510	4 083 098	4 185 176	4 289 805	4 397 050
(=) Free net cashflow	-59 293 187	8 852 920	5 929 263	6 079 150	6 227 255	6 384 138	6 545 290	6 706 437	6 874 217	7 050 713	7 223 692	7 405 901	7 589 560	7 778 057	7 977 987	8 175 905	11 577 977	11 866 386	12 164 111	12 468 604	12 777 429	7 124 796	7 327 782	7 477 694	7 687 944	7 860 102
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 440 267	-44 511 004	-38 431 854	-32 204 599	-25 820 461	-19 275 171	-12 568 734	-5 694 516	1 356 197	8 579 888	15 985 789	23 575 349	31 353 406	39 331 393	47 507 298	59 085 275	70 951 661	83 115 772	95 584 376	108 361 805	115 486 601	122 814 383	130 292 077	137 980 021	145 840 124
	$LCOE_{wso}$	84.40	85.07	85.75	86.23	86.92	87.65	88.22	88.92	89.83	90.43	91.25	91.96	92.69	93.72	94.49	94.17	94.97	95.88	96.78	97.57	94.05	94.75	95.81	96.56	97.59

APPENDIX I

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	98.2%	[%]
	358	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{ins}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{RC}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025839	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	90	[h]
AAR	4 202 942	[$M]
AEP_{avail}	48 979 624	[kWh/yr]
$O\&M_{WFCM}$	**0.124114**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$		Notes
$SC_{O\&M}$	**0.000105**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000229**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.8	[per yr]
Repair time	2.0	[h]
Hours required	90.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**162.0**	**[h/yr]**
	0.000334	**[$/kWh/yr]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85.00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2.0	[d]
$C_{md_{RM_{WT}}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3.0	[m-h]
$C_{Mhr_{R_{CT}}}$	85.00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2.0	[d]
$C_{md_{RM_{CT}}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	641
March	744	737
April	720	713
May	744	737
June (*)	720	689
July	744	737
August	744	737
September	720	713
October	744	737
November (*)	720	689
December	744	737
Total [h/yr]	**8 760**	**8 600**

(*) Period of less hours for production

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70.8203	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
Ψ_{total}	30.00%	[%]
n_{Ψ}	6	[yr]
REP_{CM}	0.00002627	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5 696	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1496	[$/kW$_e$h]
ε_0	0.116883	[$/kW$_e$h]
n_{ε}	10	[yr]
$OREP_{CM}$	13.0813	[$/kW$_e$]
$LCCCM_{WF_{OREG_{CM}}}$	2.7664	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
Ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{Ψ}	10	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	1 600.4612	[$/tCO$_2$]
$LCER_{CO_2}$	18.6	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	48 980	[MW$_e$h]
n_{Ψ}	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0.00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\,CO_2}}$	0.00003	[tCO$_2$/MW$_e$h]
ε_c	46.3820	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**421.0907**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0=no	

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	48 979 624	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**48 979 624**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 920 535	[$]
Debt payments	3 022 691	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 920 535	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67.6693	yr_1	70.7843	yr_{15}
67.8196	yr_2	69.8148	yr_{15}
68.0301	yr_3	70.0062	yr_{16}
68.1907	yr_4	70.2090	yr_{17}
68.4452	yr_5	70.4052	yr_{18}
68.6285	yr_6	70.7652	yr_{19}
68.8776	yr_7	70.3784	yr_{20}
69.0932	yr_8	70.5607	yr_{21}
69.2651	yr_9	70.8306	yr_{22}
69.4927	yr_{10}	71.1149	yr_{23}
69.7293	yr_{11}	71.3767	yr_{25}
70.0108	yr_{12}	69.6873	Mean
70.2358	yr_{13}	1.0827	SD
70.4493	yr_{14}	-0.4490	ϒ (skewness)
$LCOE_{wso}$	**69.6873**	**US$/MWh**	valid !
	0.069687	**US$/kWh**	

Figure I.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.6%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{bos}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{tc}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{MWT}}$	100	[m-h]
$C_{Mhr_{MWT}}$	85.00	[$/m-h]
$N_{m_{MWT}}$	3	[–]
$D_{m_{MWT}}$	2.0	[d]
$C_{md_{MWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{MCT}}$	3.0	[m-h]
$C_{Mhr_{MCT}}$	85.00	[$/m-h]
$N_{m_{MCT}}$	3	[–]
$D_{m_{MCT}}$	2.0	[d]
$C_{md_{MCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70.8203	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
Ψ_{total}	30.00%	[%]
n_{Ψ}	6	[yr]
REP_{CM}	0.00001039	[$/kW$_e$h]
AEP_{avail}/H_{prod}	10 458	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1086	[$/kW$_e$h]
ε_0	0.075000	[$/kW$_e$h]
n_{ε}	15	[yr]
$OREP_{CM}$	21.2289	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	2.4451	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
Ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{Ψ}	15	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	825.2491	[$/tCO$_2$]
$LCER_{CO_2}$	34.2	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	90 108	[MW$_e$h]
n_{Ψ}	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0.00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\,CO_2}}$	0.00003	[tCO$_2$/MW$_e$h]
ε_c	13.0000	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**229.3246**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	90 107 610	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**90 107 610**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048925	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	14 679 146	[$M]
AEP_{avail}	90 107 610	[kWh/yr]
$O\&M_{WFCM}$	**0.147200**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$		Notes
$SC_{O\&M}$	**0.000038**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000138**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000176	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0=no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 869 613	[$]
Debt payments	3 017 547	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 869 613	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.1255	yr_1	78.4712	yr_{15}
73.5187	yr_2	77.6515	yr_{15}
73.7873	yr_3	78.1612	yr_{16}
74.1334	yr_4	78.6268	yr_{17}
74.4746	yr_5	79.1175	yr_{18}
74.9273	yr_6	79.6115	yr_{19}
75.2253	yr_7	77.7347	yr_{20}
75.5275	yr_8	78.2446	yr_{21}
76.0152	yr_9	78.7103	yr_{22}
76.4118	yr_{10}	79.0644	yr_{23}
76.7332	yr_{11}	79.4723	yr_{25}
77.2289	yr_{12}	76.8666	Mean
77.6321	yr_{13}	2.0151	SD
78.0589	yr_{14}	-0.4631	ϒ (skewness)
$LCOE_{wso}$	**76.8666**	**US$/MWh**	valid !
	0.076867	**US$/kWh**	

Figure I.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical $50MW_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)}$. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m^2]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.6%	[%]
Availability	98.2%	[%]
	358	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m^2/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70.8203	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_{ψ}	6	[yr]
REP_{CM}	0.00000052	[$/kW$_e$h]
AEP_{avail}/H_{prod}	24 762	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0128	[$/kW$_e$h]
ε_0	0.009998	[$/kW$_e$h]
n_{ε}	10	[yr]
$OREP_{CM}$	56.8722	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	2.7664	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	10	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	4 500.5522	[$/t$CO_2$]
$LCER_{CO_2}$	80.9	[tCO_2/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	212 943	[MW$_e$h]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0.00041	[tCO_2/MW$_e$h]
$GHG_{EM_{wecs\,CO_2}}$	0.00003	[tCO_2/MW$_e$h]
ε_c	30.0000	[$/t$CO_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**1 157.0612**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 943 465	[kW$_e$h/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m^2]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 943 465**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/$m^2$/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/$m^2$]
Bld_{area}	300.0	[m^2]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041526	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	90	[h]
AAR	29 460 159	[$M]
AEP_{avail}	212 943 465	[kWh/yr]
$O\&M_{WFCM}$	**0.139801**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$		Notes
$SC_{O\&M}$	**0.000024**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000053**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.8	[per yr]
Repair time	2.0	[h]
Hours required	90.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**162.0**	**[h/yr]**
	0.000077	**[$/kWh/yr]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 646 843	[$]
Debt payments	2 995 042	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 646 843	[$]
Discount rate	9.00%	[%/yr]

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February [(*)]	672	641
March	744	737
April	720	713
May	744	737
June [(*)]	720	689
July	744	737
August	744	737
September	720	713
October	744	737
November [(*)]	720	689
December	744	737
Total [h/yr]	**8 760**	**8 600**

[(*)] Period of less hours for production

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Initial Results Summary of $LCOE_{wso}$			Notes
84.3448	yr_1	94.4360	yr_{15}
85.0205	yr_2	94.1138	yr_{15}
85.7100	yr_3	94.9205	yr_{16}
86.1734	yr_4	95.8186	yr_{17}
86.8681	yr_5	96.7191	yr_{18}
87.5940	yr_6	97.4969	yr_{19}
88.1682	yr_7	93.9817	yr_{20}
88.8666	yr_8	94.6831	yr_{21}
89.7788	yr_9	95.7335	yr_{22}
90.3684	yr_{10}	96.5076	yr_{23}
91.1898	yr_{11}	97.5244	yr_{25}
91.9082	yr_{12}	91.7691	Mean
92.6296	yr_{13}	4.1987	SD
93.6712	yr_{14}	-0.3338	ϒ (skewness)
$LCOE_{wso}$	**91.7691**	**US$/MWh**	valid !
	0.091769	**US$/kWh**	

Figure H.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$. Source: Own elaboration

Table I.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	641	850 430	6 803 436	3 673 320	6 803 436	779 598	6 803 436	779 598	779 598	4 727 258	6 803 436	6 803 436	779 598	3 673 320	6 803 436	483 758	483 758	3 300 063	4 727 258	7 716 188	1 577 029	1 577 029	7 716 188	6 803 436	4 727 258	4 727 258
March	4.0	1.1671	737	556 507	7 495 900	5 438 155	8 876 568	978 319	7 495 900	978 319	978 319	6 560 068	7 495 900	7 495 900	978 319	5 438 155	8 876 568	896 836	896 836	1 814 186	4 225 724	1 814 186	1 690 536	1 690 536	7 826 555	8 876 568	3 796 335	6 560 068
April	4.7	1.1667	713	867 380	6 344 604	6 344 604	4 086 931	1 635 011	6 344 604	1 635 011	1 635 011	7 249 700	6 344 604	6 344 604	1 754 600	6 344 604	4 086 931	946 187	946 187	1 635 011	6 344 604	1 635 011	3 671 646	946 187	7 249 700	6 344 604	1 754 600	7 249 700
May	6.0	1.1670	737	1 814 119	5 437 953	7 495 621	5 437 953	1 814 119	5 437 953	1 814 119	1 814 119	7 826 264	5 437 953	5 437 953	1 690 473	7 495 621	6 559 824	1 690 473	1 690 473	978 283	8 876 238	978 283	556 486	896 803	6 559 824	4 225 566	1 690 473	7 826 264
June	7.9	1.1686	689	3 955 677	3 955 677	7 326 396	6 140 844	3 553 729	3 955 677	3 553 729	3 553 729	8 309 307	3 955 677	3 955 677	3 553 729	7 326 396	5 090 627	1 698 250	1 698 250	839 524	7 326 396	839 524	839 524	3 553 729	5 090 627	5 090 627	915 799	8 309 307
July	8.6	1.1698	737	5 450 949	3 805 267	8 897 452	1 694 513	4 235 665	3 805 267	4 235 665	4 235 665	557 816	557 816	3 805 267	5 450 949	8 897 452	1 818 455	3 805 267	3 805 267	557 816	7 513 536	557 816	980 621	4 235 665	4 235 665	1 694 513	898 946	557 816
August	9.6	1.1677	737	7 499 787	1 815 127	1 815 127	1 815 127	8 881 171	1 815 127	5 440 975	5 440 975	897 302	897 302	1 815 127	4 227 915	1 815 127	1 691 413	5 440 975	7 830 614	7 830 614	897 302	4 227 915	7 830 614	5 440 975	1 815 127	1 815 127	556 795	897 302
September	10.1	1.1657	713	8 576 955	1 633 475	1 633 475	3 668 197	7 562 383	1 633 475	6 338 644	6 338 644	945 298	945 298	1 633 475	6 338 644	1 633 475	3 668 197	6 338 644	7 242 889	7 242 889	945 298	5 254 599	8 576 955	6 338 644	1 633 475	3 668 197	6 338 644	945 298
October	9.7	1.1645	737	7 809 082	976 135	976 135	555 264	7 479 165	976 135	7 479 165	7 479 165	1 686 762	1 686 762	976 135	8 856 751	976 135	555 264	7 479 165	6 545 422	6 545 422	1 810 136	6 545 422	4 216 289	7 479 165	976 135	976 135	8 856 751	1 686 762
November	9.2	1.1638	689	6 115 594	836 072	836 072	836 072	6 115 594	836 072	7 296 271	7 296 271	1 691 267	1 691 267	836 072	7 296 271	836 072	836 072	7 296 271	5 069 696	5 069 696	1 575 994	6 988 019	6 115 594	7 296 271	836 072	836 072	7 296 271	1 691 267
December	7.6	1.1651	737	3 790 014	555 580	555 580	976 690	5 429 099	555 580	8 861 786	8 861 786	3 790 014	3 790 014	555 580	7 483 417	555 580	976 690	8 861 786	4 218 687	4 218 687	3 790 014	7 813 521	5 429 099	8 861 786	555 580	555 580	7 483 417	3 790 014
Annual	7.4	1.1666	8 600	48 979 624	48 549 424	48 794 102	48 399 005	49 021 215	48 549 424	48 970 644	48 970 644	48 473 266	48 496 226	48 549 424	48 968 028	48 794 102	48 470 887	49 169 824	49 318 276	48 922 388	48 589 860	48 172 649	48 991 802	48 874 151	48 297 112	48 393 836	48 547 502	48 473 266

Table I.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)}$

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	740	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408
February	11.5	1.2345	648	12 092 721	4 293 137	12 092 721	12 092 721	12 092 721	3 417 096	12 092 721	12 715 785	1 795 784	3 417 096	12 715 785	1 795 784	9 244 173	12 092 721	6 674 015	12 715 785	4 293 137	5 486 290	3 417 096	2 815 600	12 092 721	2 106 703	6 674 015	12 092 721	12 715 785
March	10.5	1.2329	736	10 486 228	3 193 907	13 717 510	13 717 510	13 717 510	6 223 433	13 717 510	13 717 510	2 389 762	3 193 907	13 717 510	2 389 762	13 717 510	13 717 510	6 223 433	13 717 510	3 876 220	7 570 742	4 869 967	13 717 510	14 424 289	2 037 067	10 486 228	14 424 289	3 193 907
April	9.5	1.2317	712	7 316 597	7 316 597	10 458 483	10 458 483	10 458 483	7 316 597	10 458 483	4 706 485	3 086 689	7 316 597	13 257 022	3 086 689	13 257 022	4 706 485	4 706 485	13 257 022	3 086 689	10 134 212	3 086 689	13 940 075	13 257 022	3 086 689	3 086 689	13 257 022	3 746 098
May	8.2	1.2282	736	4 851 676	10 446 845	10 446 845	10 446 845	6 200 059	10 446 845	10 446 845	10 446 845	3 861 662	6 200 059	10 446 845	3 861 662	14 370 115	10 446 845	3 861 662	10 446 845	2 380 787	13 665 991	6 200 059	2 380 787	10 446 845	3 861 662	14 370 115	10 446 845	4 851 676
June	7.1	1.2224	696	2 994 461	12 860 910	7 097 981	7 097 981	7 097 981	10 145 990	4 565 858	12 860 910	4 565 858	10 145 990	7 097 981	4 565 858	7 097 981	2 240 532	2 994 461	7 097 981	1 909 861	12 860 910	7 097 981	1 909 861	7 097 981	4 565 858	12 860 910	7 097 981	5 834 806
July	6.1	1.2154	736	2 008 118	13 522 571	4 800 760	6 134 992	10 337 209	13 522 571	7 463 154	3 148 518	6 134 992	2 008 118	6 134 992	6 134 992	6 134 992	2 008 118	2 355 801	6 134 992	6 134 992	14 219 306	10 337 209	3 821 135	6 134 992	6 134 992	13 522 571	3 821 135	7 463 154
August	6.4	1.2075	736	2 340 496	10 598 668	3 796 310	3 796 310	3 796 310	13 434 719	6 095 134	3 796 310	7 414 668	2 340 496	4 769 571	7 414 668	4 769 571	10 598 668	1 995 072	4 769 571	13 434 719	1 995 072	13 434 719	4 769 571	4 769 571	7 414 668	4 769 571	3 128 063	10 270 051
September	7.6	1.2064	712	3 669 202	1 928 273	5 891 057	4 609 876	4 609 876	4 609 876	1 928 273	5 891 057	9 926 189	9 926 189	3 669 202	9 926 189	3 669 202	5 891 057	9 926 189	3 669 202	12 984 898	2 262 132	12 984 898	5 891 057	3 669 202	9 926 189	3 669 202	2 262 132	1 928 273
October	8.9	1.2126	736	6 121 079	6 121 079	3 141 378	2 003 564	3 141 378	2 003 564	2 350 459	7 446 229	13 491 905	13 491 905	3 141 378	13 491 905	3 141 378	7 446 229	13 491 905	3 141 378	10 643 782	3 141 378	2 003 564	7 446 229	3 141 378	13 491 905	2 350 459	2 003 564	2 350 459
November	10.6	1.2194	696	10 121 586	3 625 425	2 235 143	2 235 143	2 235 143	2 235 143	2 987 258	2 235 143	12 829 976	4 554 876	2 235 143	12 829 976	2 235 143	2 987 258	12 829 976	2 235 143	9 807 761	3 625 425	2 235 143	9 807 761	2 235 143	12 829 976	1 905 267	5 820 771	12 829 976
December	11.5	1.2237	736	13 614 984	2 371 901	2 021 842	3 170 035	2 021 842	3 170 035	3 847 249	2 021 842	14 316 481	13 614 984	2 021 842	14 316 481	2 021 842	3 847 249	14 316 481	2 021 842	7 514 158	4 833 568	14 316 481	13 614 984	2 021 842	14 316 481	6 176 918	4 833 568	13 614 984
Annual	9.1	1.2222	8 616	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577

Table I.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	641	24 319 291	14 509 901	6 932 878	26 305 527	14 509 901	14 509 901	26 305 527	26 305 527	6 932 878	14 509 901	14 509 901	7 772 679	26 305 527	6 932 878	17 428 282	6 932 878	6 932 878	6 932 878	6 932 878	22 528 524	26 305 527	26 305 527	29 044 609	7 772 679	17 402 199
March	12.7	1.2495	737	18 273 052	18 273 052	8 918 969	27 905 823	12 408 183	18 273 052	27 905 823	27 905 823	8 918 969	12 408 183	18 273 052	9 997 395	27 905 823	8 918 969	30 184 982	8 918 969	8 918 969	8 918 969	8 918 969	23 050 141	27 905 823	27 905 823	31 495 010	9 997 395	18 969 625
April	12.4	1.2490	713	16 100 080	19 338 295	9 667 330	24 894 425	9 667 330	19 338 295	24 894 425	24 894 425	9 667 330	9 667 330	19 338 295	9 667 330	24 894 425	9 667 330	26 984 508	9 667 330	29 188 421	9 667 330	9 667 330	22 244 176	20 024 605	24 894 425	24 985 682	9 667 330	18 186 892
May	11.2	1.2425	737	12 338 025	25 598 814	9 940 868	19 885 473	9 940 868	25 598 814	19 885 473	19 885 473	9 940 868	9 940 868	25 598 814	12 338 025	19 885 473	9 940 868	25 598 814	9 940 868	27 748 037	9 940 868	9 940 868	21 042 787	19 885 473	19 885 473	19 137 999	12 338 025	16 209 586
June	10.4	1.2351	689	9 237 631	25 785 086	11 465 208	16 884 369	8 241 161	25 785 086	16 884 369	16 884 369	11 465 208	8 241 161	25 785 086	15 384 455	16 884 369	11 465 208	16 884 369	11 465 208	23 787 904	11 465 208	11 465 208	17 001 691	16 884 369	16 884 369	16 806 455	15 384 455	14 990 327
July	10.0	1.2275	737	8 761 837	29 653 191	16 356 443	16 356 443	7 815 162	29 653 191	16 356 443	16 356 443	16 356 443	7 815 162	29 653 191	17 951 122	16 356 443	16 356 443	7 815 162	16 356 443	19 646 221	16 356 443	16 356 443	15 570 355	16 087 422	16 356 443	16 802 962	17 951 122	8 647 175
August	9.7	1.2216	737	7 777 512	12 130 855	17 864 641	12 130 855	17 864 641	12 130 855	12 130 855	12 130 855	17 864 641	17 864 641	12 130 855	19 551 573	12 130 855	17 864 641	8 719 626	17 864 641	17 864 641	17 864 641	17 864 641	12 936 052	15 417 110	12 130 855	12 621 116	19 551 573	7 130 060
September	10.4	1.2234	713	9 469 157	7 534 977	18 941 875	9 469 157	26 431 347	7 534 977	9 469 157	9 469 157	18 941 875	26 431 347	7 534 977	24 384 108	9 469 157	18 941 875	9 469 157	18 941 875	15 770 041	18 941 875	18 941 875	12 353 594	13 310 548	9 469 157	8 865 389	24 384 108	19 080 004
October	13.1	1.2327	737	19 729 237	8 798 861	29 778 493	9 862 764	25 397 690	8 798 861	9 862 764	9 862 764	29 778 493	25 397 690	8 798 861	27 530 026	9 862 764	25 397 690	9 862 764	25 397 690	12 241 087	29 778 493	25 397 690	12 273 661	8 881 296	9 862 764	8 143 371	27 530 026	21 651 123
November	14.3	1.2429	689	23 939 450	9 296 482	25 949 356	8 293 664	28 068 725	9 296 482	8 293 664	8 293 664	25 949 356	28 068 725	9 296 482	28 068 725	8 293 664	25 949 356	11 538 250	25 949 356	9 296 482	25 949 356	25 949 356	7 443 284	8 293 664	8 293 664	8 895 126	28 068 725	22 011 001
December	15.1	1.2528	737	30 263 395	10 023 366	25 811 256	7 975 983	20 050 501	10 023 366	7 975 983	7 975 983	25 811 256	20 050 501	10 023 366	32 581 568	7 975 983	30 263 395	16 693 026	30 263 395	10 023 366	25 811 256	30 263 395	6 366 601	7 975 983	7 975 983	9 187 032	32 581 568	42 583 526
Annual	12.5	1.2404	8 600	212 943 465	213 677 678	214 362 116	212 699 281	213 130 306	213 677 678	212 699 281	212 699 281	214 362 116	213 130 306	213 677 678	213 240 500	212 699 281	214 433 451	213 913 741	214 433 451	214 152 844	214 362 116	214 433 451	213 565 675	213 706 617	212 699 281	214 004 745	213 240 500	213 962 451

Table I.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table I.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)}$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table I.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table I.7 kWh per H_{prod} with sensitivity analysis of $O\&M_{manag(B)}$

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 696	5 646	5 674	5 628	5 700	5 646	5 695	5 695	5 637	5 639	5 646	5 694	5 674	5 636	5 718	5 735	5 689	5 650	5 602	5 697	5 683	5 616	5 628	5 645	5 637
Corvo Island (Portugal)	10 458	10 535	10 467	10 475	10 468	10 563	10 497	10 429	10 525	10 527	10 454	10 525	10 507	10 500	10 474	10 454	10 510	10 523	10 545	10 560	10 464	10 520	10 532	10 452	10 407
Cape Saint James (Canada)	24 762	24 848	24 927	24 734	24 784	24 848	24 734	24 734	24 927	24 784	24 848	24 797	24 734	24 936	24 875	24 936	24 903	24 927	24 936	24 835	24 851	24 734	24 886	24 797	24 881

Table I.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$

Item	Years: 0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 979 624	48 549 424	48 794 102	48 399 005	49 021 215	48 549 424	48 970 644	48 970 644	48 473 266	48 496 226	48 549 424	48 968 028
(+) AAR ($M/yr)	-	4 308 015	4 376 931	4 508 965	4 584 266	4 759 280	4 831 313	4 995 061	5 119 937	5 194 634	5 327 022	5 466 187	5 651 151
PPAR	-	4 308 015	4 376 931	4 508 965	4 584 266	4 759 280	4 831 313	4 995 061	5 119 937	5 194 634	5 327 022	5 466 187	5 651 151
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	3 958 388	4 021 593	4 142 789	4 211 857	4 372 535	4 459 642	4 610 143	4 724 747	4 793 035	4 914 544	5 042 290	5 212 260
$O\&M_{fixed}$	-	2 661 279	2 703 850	2 785 412	2 831 928	2 940 042	2 984 539	3 085 692	3 162 833	3 208 975	3 290 756	3 376 724	3 490 983
$O\&M_{variable}$	-	1 297 109	1 317 743	1 357 376	1 379 929	1 432 493	1 475 103	1 524 451	1 561 914	1 584 059	1 623 788	1 665 566	1 721 276
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 453 484	2 514 821	2 577 692	2 642 134	2 708 187	2 775 892	2 845 289	2 916 421	2 989 332	3 064 065	3 140 667	3 219 184
(=) Profit before tax	-	3 666 379	3 755 009	3 850 839	3 944 188	4 047 820	4 124 272	4 231 334	4 337 767	4 442 740	4 554 647	4 669 621	4 790 758
(-) Revenue tax	-	1 292 405	1 313 079	1 352 689	1 375 280	1 427 784	1 449 394	1 498 518	1 535 981	1 558 390	1 598 107	1 639 856	1 695 345
(+) REPIM	384 830	2 046	1 989	1 962	1 910	1 899	1 847	1 830	1 798	1 749	1 720	281	290
REI_{CM}	221 313	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 825	1 764	1 730	1 674	1 654	1 599	1 573	1 535	1 482	1 447	-	-
$OREP_{CM}$	163 516	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	221	225	232	235	244	248	256	263	267	274	281	290
(=) Profit after tax w/out interest	-	2 376 021	2 443 919	2 500 111	2 570 818	2 621 934	2 676 725	2 734 645	2 803 583	2 886 099	2 958 260	3 030 046	3 095 703
(-) Debt payments	-	-	3 175 715	3 255 108	3 336 486	3 419 898	3 505 395	3 593 030	3 682 856	3 774 927	3 869 300	3 966 033	4 065 184
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 453 484	2 514 821	2 577 692	2 642 134	2 708 187	2 775 892	2 845 289	2 916 421	2 989 332	3 064 065	3 140 667	3 219 184
(=) Free net cashflow	-59 841 071	7 451 244	4 470 308	4 577 159	4 699 792	4 804 133	4 913 478	5 027 317	5 153 572	5 294 837	5 427 218	5 560 727	5 689 651
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 389 827	-47 919 520	-43 342 361	-38 642 568	-33 838 435	-28 924 957	-23 897 640	-18 744 068	-13 449 230	-8 022 012	-2 461 285	3 228 366
	$LCOE_{wso}$	67.67	67.82	68.03	68.19	68.45	68.63	68.88	69.09	69.27	69.49	69.73	70.01

Item	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	48 794 102	48 470 887	49 169 824	49 318 276	48 922 388	48 589 860	48 172 649	48 991 802	48 874 151	48 297 112	48 393 836	48 547 502	48 473 266
(+) AAR ($M/yr)	5 771 856	5 876 963	6 110 750	6 282 430	6 387 799	6 502 991	6 608 332	6 888 721	4 930 788	4 994 386	5 129 498	5 274 431	5 398 025
PPAR	5 771 856	5 876 963	6 110 750	6 282 430	6 387 799	6 502 991	6 608 332	6 888 721	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 930 788	4 994 386	5 129 498	5 274 431	5 398 025
(-) $O\&M_{WFCM}$	5 322 943	5 419 232	5 634 158	5 791 793	5 888 285	5 993 824	6 090 278	6 348 036	5 856 505	5 931 402	6 091 221	6 262 682	6 408 790
$O\&M_{fixed}$	3 565 547	3 630 475	3 774 895	3 880 948	3 946 038	4 017 195	4 082 268	4 255 476	4 351 387	4 407 510	4 526 744	4 654 645	4 763 714
$O\&M_{variable}$	1 757 396	1 788 757	1 859 263	1 910 846	1 942 247	1 976 628	2 008 010	2 092 560	1 505 118	1 523 892	1 564 477	1 608 038	1 645 077
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 299 663	3 382 155	3 466 709	3 553 376	3 642 211	3 733 266	3 826 598	3 922 263	4 020 319	4 120 827	4 223 848	4 329 444	4 437 680
(=) Profit before tax	4 909 576	5 029 911	5 163 076	4 044 013	4 141 725	4 242 433	4 344 652	4 462 948	3 094 602	3 183 811	3 262 125	3 341 192	3 426 914
(-) Revenue tax	1 731 557	1 763 089	1 833 225	1 884 729	1 916 340	1 950 897	1 982 500	2 066 616	1 479 236	1 498 316	1 538 850	1 582 329	1 619 407
(+) REPIM	296	302	314	323	328	334	339	354	362	366	376	387	396
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	296	302	314	323	328	334	339	354	362	366	376	387	396
(=) Profit after tax w/out interest	3 178 316	3 267 124	3 330 165	2 159 606	2 225 713	2 291 870	2 362 491	2 396 685	1 615 728	1 685 862	1 723 652	1 759 250	1 807 903
(-) Debt payments	4 166 813	4 270 984	4 377 758	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 299 663	3 382 155	3 466 709	3 553 376	3 642 211	3 733 266	3 826 598	3 922 263	4 020 319	4 120 827	4 223 848	4 329 444	4 437 680
(=) Free net cashflow	5 837 113	5 992 391	6 123 564	9 510 042	9 759 910	10 014 421	10 278 107	10 510 191	9 932 071	10 210 114	10 461 010	10 715 042	10 987 590
$\Sigma_{free\ net\ annual\ cashflow}$	9 065 478	15 057 869	21 181 433	30 691 475	40 451 385	50 465 806	60 743 913	71 254 104	81 186 175	91 396 288	101 857 299	112 572 341	123 559 931
$LCOE_{wso}$	70.24	70.45	70.78	69.81	70.01	70.21	70.41	70.77	70.38	70.56	70.83	71.11	71.38

Table I.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)}$

Item	Years 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577
(+) AAR ($M/yr)	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
PPAR	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
(-) $O\&M_{WFCM}$	-	9 414 550	9 720 704	9 900 012	10 154 527	10 401 931	10 758 472	10 957 897	11 159 028	11 543 192	11 833 646	12 046 185	12 430 378	12 719 232	13 028 853	13 321 057	13 628 511	14 043 351	14 411 633	14 802 558	15 194 336	13 212 815	13 615 294	13 970 912	14 212 144	14 504 416
$O\&M_{fixed}$	-	4 895 943	5 055 217	5 148 526	5 280 948	5 409 674	5 595 159	5 698 935	5 803 599	6 003 456	6 154 579	6 265 179	6 465 057	6 615 352	6 776 449	6 928 488	7 088 460	7 304 288	7 495 901	7 699 294	7 903 132	8 027 381	8 271 977	8 488 105	8 634 738	8 812 382
$O\&M_{variable}$	-	4 518 607	4 665 487	4 751 486	4 873 579	4 992 258	5 163 313	5 258 962	5 355 430	5 539 736	5 679 068	5 781 006	5 965 321	6 103 880	6 252 405	6 392 569	6 540 051	6 739 063	6 915 732	7 103 264	7 291 205	5 185 434	5 343 317	5 482 807	5 577 406	5 692 034
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 449 308	2 510 541	2 573 304	2 637 637	2 703 578	2 771 167	2 840 447	2 911 458	2 984 244	3 058 850	3 135 322	3 213 705	3 294 047	3 376 398	3 460 808	3 547 329	3 636 012	3 726 912	3 820 085	3 915 587	4 013 477	4 113 814	4 216 659	4 322 075	4 430 127
(=) Profit before tax	-	8 944 151	9 210 296	9 402 638	9 642 095	9 879 479	10 184 390	10 397 593	10 614 162	10 942 647	11 217 531	11 448 320	11 784 412	12 066 110	12 362 956	12 652 168	11 703 095	12 040 228	12 351 722	12 679 045	13 009 213	8 069 533	8 293 583	8 505 760	8 685 395	8 883 337
(-) Revenue tax	-	4 513 837	4 660 683	4 746 712	4 868 802	4 987 484	5 158 496	5 254 175	5 350 673	5 534 936	5 674 267	5 776 238	5 960 521	6 099 089	6 247 616	6 387 792	6 535 283	6 734 270	6 910 933	7 098 455	7 286 389	5 180 661	5 338 519	5 478 004	5 572 639	5 687 288
(+) REPIM	486 675	1 439	1 420	1 382	1 355	1 327	1 313	1 279	1 247	1 234	1 211	1 180	1 167	1 144	1 123	1 100	165	170	175	179	184	187	193	198	201	205
REI_{CM}	221 313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 325	1 302	1 262	1 232	1 201	1 183	1 147	1 111	1 094	1 068	1 034	1 016	990	965	939	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	265 362	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	114	118	120	123	126	130	133	135	140	143	146	151	154	158	161	165	170	175	179	184	187	193	198	201	205
(=) Profit after tax w/out interest	-	4 431 752	4 551 033	4 657 307	4 774 648	4 893 322	5 027 207	5 144 697	5 264 735	5 408 945	5 544 475	5 673 263	5 825 058	5 968 165	6 116 463	6 265 476	5 167 976	5 306 128	5 440 964	5 580 769	5 723 009	2 889 059	2 955 257	3 027 954	3 112 957	3 196 254
(-) Debt payments	-	-	3 170 310	3 249 568	3 330 807	3 414 077	3 499 429	3 586 915	3 676 588	3 768 503	3 862 715	3 959 283	4 058 265	4 159 722	4 263 715	4 370 308	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 449 308	2 510 541	2 573 304	2 637 637	2 703 578	2 771 167	2 840 447	2 911 458	2 984 244	3 058 850	3 135 322	3 213 705	3 294 047	3 376 398	3 460 808	3 547 329	3 636 012	3 726 912	3 820 085	3 915 587	4 013 477	4 113 814	4 216 659	4 322 075	4 430 127
(=) Free net cashflow	-59 739 225	9 502 799	6 578 546	6 735 508	6 904 804	7 076 732	7 265 202	7 438 642	7 616 029	7 819 021	8 014 803	8 205 349	8 420 446	8 628 438	8 843 243	9 060 425	12 512 365	12 834 126	13 157 162	13 489 872	13 829 839	11 198 560	11 472 495	11 758 123	12 061 381	12 368 389
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 236 426	-43 657 880	-36 922 371	-30 017 567	-22 940 835	-15 675 633	-8 236 990	-620 962	7 198 060	15 212 862	23 418 211	31 838 657	40 467 095	49 310 338	58 370 764	70 883 128	83 717 254	96 874 416	110 364 287	124 194 126	135 392 686	146 865 181	158 623 305	170 684 685	183 053 074
	$LCOE_{wso}$	73.13	73.52	73.79	74.13	74.47	74.93	75.23	75.53	76.02	76.41	76.73	77.23	77.63	78.06	78.47	77.65	78.16	78.63	79.12	79.61	77.73	78.24	78.71	79.06	79.47

Table I.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$

Item	Years 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 943 465	213 677 678	214 362 116	212 699 281	213 130 306	213 677 678	212 699 281	212 699 281	214 362 116	213 130 306	213 677 678	213 240 500	212 699 281	214 433 451	213 913 741	214 433 451	214 152 844	214 362 116	214 433 451	213 565 675	213 706 617	212 699 281	214 004 745	213 240 500	213 962 451
(+) AAR ($M/yr)	-	30 196 663	31 058 298	31 936 726	32 481 214	33 360 711	34 282 550	34 978 715	35 853 182	37 036 811	37 744 583	38 787 558	39 675 905	40 564 585	41 917 697	42 861 506	44 039 781	45 081 704	46 253 902	47 426 027	48 414 954	34 760 655	35 461 726	36 571 360	37 351 777	38 415 192
PPAR	-	30 196 663	31 058 298	31 936 726	32 481 214	33 360 711	34 282 550	34 978 715	35 853 182	37 036 811	37 744 583	38 787 558	39 675 905	40 564 585	41 917 697	42 861 506	44 039 781	45 081 704	46 253 902	47 426 027	48 414 954	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 760 655	35 461 726	36 571 360	37 351 777	38 415 192
(-) $O\&M_{WFCM}$	-	20 633 860	21 222 504	21 822 620	22 194 549	22 795 389	23 425 157	23 900 721	24 498 115	25 306 751	25 790 238	26 502 761	27 109 626	27 716 717	28 641 138	29 285 891	30 090 843	30 802 628	31 603 422	32 404 162	33 079 730	29 459 748	30 053 783	30 994 073	31 655 349	32 556 460
$O\&M_{fixed}$	-	11 570 156	11 900 294	12 236 866	12 445 485	12 782 467	13 135 671	13 402 407	13 737 461	14 190 972	14 462 154	14 861 773	15 202 144	15 542 642	16 061 091	16 422 713	16 874 171	17 273 385	17 722 515	18 171 617	18 550 525	19 026 830	19 410 567	20 017 937	20 445 105	21 027 176
$O\&M_{variable}$	-	9 063 703	9 322 210	9 585 754	9 749 063	10 012 922	10 289 486	10 498 314	10 760 654	11 115 779	11 328 084	11 640 988	11 907 483	12 174 075	12 580 047	12 863 178	13 216 672	13 529 243	13 880 907	14 232 546	14 529 205	10 432 918	10 643 217	10 976 136	11 210 244	11 529 285
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 431 041	2 491 817	2 554 113	2 617 965	2 683 414	2 750 500	2 819 262	2 889 744	2 961 988	3 036 037	3 111 938	3 189 737	3 269 480	3 351 217	3 434 997	3 520 872	3 608 894	3 699 117	3 791 594	3 886 384	3 983 544	4 083 132	4 185 211	4 289 841	4 397 087
(=) Profit before tax	-	12 857 112	13 212 461	13 575 190	13 834 276	14 201 624	14 584 601	14 898 383	15 270 966	15 743 856	16 068 486	16 501 792	16 888 698	17 278 348	17 817 801	18 230 389	17 469 810	17 887 970	18 349 597	18 813 459	19 221 609	9 284 451	9 491 075	9 762 498	9 986 269	10 255 819
(-) Revenue tax	-	9 058 999	9 317 489	9 581 018	9 744 364	10 008 213	10 284 765	10 493 614	10 755 955	11 111 043	11 323 375	11 636 267	11 902 772	12 169 376	12 575 309	12 858 452	13 211 934	13 524 511	13 876 171	14 227 808	14 524 486	10 428 196	10 638 518	10 971 408	11 205 533	11 524 558
(+) REPIM	932 216	778	793	807	814	829	845	855	870	892	903	799	817	836	864	883	907	929	953	977	997	1 023	1 044	1 076	1 099	1 131
REI_{CM}	221 313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	156	153	150	145	142	138	134	131	129	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	710 902	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	622	640	658	669	687	706	721	739	763	778	799	817	836	864	883	907	929	953	977	997	1 023	1 044	1 076	1 099	1 131
(=) Profit after tax w/out interest	-	3 798 892	3 895 764	3 994 980	4 090 726	4 194 239	4 300 681	4 405 624	4 515 882	4 633 705	4 746 014	4 866 323	4 986 744	5 109 808	5 243 355	5 372 820	4 258 783	4 364 388	4 474 379	4 586 628	4 698 120	-1 142 723	-1 146 399	-1 207 834	-1 218 165	-1 267 608
(-) Debt payments	-	-	3 146 666	3 225 332	3 305 966	3 388 615	3 473 330	3 560 163	3 649 168	3 740 397	3 833 907	3 929 754	4 027 998	4 128 698	4 231 916	4 337 713	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 431 041	2 491 817	2 554 113	2 617 965	2 683 414	2 750 500	2 819 262	2 889 744	2 961 988	3 036 037	3 111 938	3 189 737	3 269 480	3 351 217	3 434 997	3 520 872	3 608 894	3 699 117	3 791 594	3 886 384	3 983 544	4 083 132	4 185 211	4 289 841	4 397 087
(=) Free net cashflow	-59 293 685	8 851 672	5 928 198	6 078 224	6 226 051	6 382 948	6 544 108	6 705 136	6 872 881	7 049 630	7 222 337	7 404 555	7 588 431	7 776 537	7 976 753	8 174 552	11 576 715	11 865 268	12 162 781	12 467 240	12 775 748	7 136 846	7 340 158	7 490 887	7 698 025	7 871 486
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 442 013	-44 513 816	-38 435 592	-32 209 540	-25 826 593	-19 282 485	-12 577 349	-5 704 468	1 345 162	8 567 499	15 972 053	23 560 484	31 337 022	39 313 775	47 488 327	59 065 042	70 930 310	83 093 091	95 560 331	108 336 079	115 472 924	122 813 082	130 303 970	138 001 995	145 873 480
	$LCOE_{wso}$	84.34	85.02	85.71	86.17	86.87	87.59	88.17	88.87	89.78	90.37	91.19	91.91	92.63	93.67	94.44	94.11	94.92	95.82	96.72	97.50	93.98	94.68	95.73	96.51	97.52

APPENDIX J

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	42.2302	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	15 030	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7807	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4103	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 207.5681**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{cov}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{rep}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{RC}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 207.5681	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025858	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mh}	72	[h]
n_{th}	113	[h]
AAR	4 192 361	[$M]
AEP_{avail}	48 856 319	[kWh/yr]
$O\&M_{WFCM}$	**0.124133**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000105**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000287**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000392	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
M_{hr}	100	[m-h]
C_{MW}	85.00	[$/m-h]
N_m	3	[–]
D_m	2.0	[d]
C_{md}	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
M_{hr}	3.0	[m-h]
C_{MW}	85.00	[$/m-h]
N_m	3	[–]
D_m	2.0	[d]
C_{md}	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
M_{hr}	3.0	[m-h]
C_{MW}	85.00	[$/m-h]
N_m	3	[–]
D_m	3.0	[d]
C_{md}	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]
	887 464	

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70.9972	[$/kW$_e$]
$LCCCM_{WF}$	1 207.5681	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_ψ	6	[yr]
REP_{CM}	0.00002627	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5 695	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1496	[$/kW$_e$h]
ε_0	0.116883	[$/kW$_e$h]
n_ε	10	[yr]
$OREP_{CM}$	13.0797	[$/kW$_e$]
$LCCCM_{WF_{OREG_{CM}}}$	2.7734	[$/kW]
$LCCCM_{WF}$	1 207.5681	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	10	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	1 596.4321	[$/tCO$_2$]
$LCER_{CO_2}$	18.6	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+\ldots+yr_n}}$	48 856	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0.00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\,CO_2}}$	0.00003	[tCO$_2$/MW$_e$h]
ε_c	46.3820	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**420.1272**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	2 880	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	630	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	48 856 319	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**48 856 319**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 996 522	[$]
Debt payments	3 030 368	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 996 522	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67.8128	yr_1	70.9287	yr_{15}
67.9643	yr_2	69.9602	yr_{15}
68.1735	yr_3	70.1513	yr_{16}
68.3347	yr_4	70.3512	yr_{17}
68.5874	yr_5	70.5480	yr_{18}
68.7766	yr_6	70.9089	yr_{19}
69.0235	yr_7	70.5211	yr_{20}
69.2388	yr_8	70.7039	yr_{21}
69.4112	yr_9	70.9747	yr_{22}
69.6398	yr_{10}	71.2576	yr_{23}
69.8761	yr_{11}	71.5190	yr_{25}
70.1551	yr_{12}	69.8318	Mean
70.3807	yr_{13}	1.0823	SD
70.5948	yr_{14}	-0.4514	ϒ (skewness)
$LCOE_{wso}$	**69.8318**	**US$/MWh**	valid !
	0.069832	**US$/kWh**	

Figure J.1 *I-O representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of L_{wt} *(5D7D)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	42.2302	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	15 030	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW_e]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7807	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4103	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 207.5681**	**[$/kW]**

O&M warranty conditions

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{rec}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 207.5681	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048935	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mh}	72	[h]
n_{th}	113	[h]
AAR	14 605 780	[$M]
AEP_{avail}	89 657 257	[kWh/yr]
$O\&M_{WFCM}$	**0.147210**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000057**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000156**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000214	**[$/kWh/yr]**

Depreciation

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RMCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Revenues

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Renewable Energy Public Incentive Model

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70.9972	[$/kW_e]
$LCCCM_{WF}$	1 207.5681	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_ψ	6	[yr]
REP_{CM}	0.00001039	[$/kW_eh]
AEP_{avail}/H_{prod}	10 451	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1086	[$/kW_eh]
ε_0	0.075000	[$/kW_eh]
n_ε	15	[yr]
$OREP_{CM}$	21.2151	[$/kW_e]
$LCCCM_{WF_{OREGCM}}$	2.4513	[$/kW]
$LCCCM_{WF}$	1 207.5681	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	15	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	821.1245	[$/tCO₂]
$LCER_{CO_2}$	34.1	[tCO₂/MW_eh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	89 657	[MW_eh]
n_ψ	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00041	[tCO₂/MW_eh]
$GHG_{EM_{wecs\ CO_2}}$	0.00003	[tCO₂/MW_eh]
ε_c	13.0000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**228.3342**	**[$/proj]**

Exchange rates

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Farm Life-Cycle Production Model

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW_e/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	2 880	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	630	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	89 657 257	[kW_eh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW_eh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**89 657 257**	**[kW_eh/yr]**

Project Financing

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 945 676	[$]
Debt payments	3 025 231	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 945 676	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$

			Notes
73.2318	yr_1	78.5641	yr_{15}
73.6301	yr_2	77.7428	yr_{15}
73.8961	yr_3	78.2623	yr_{16}
74.2410	yr_4	78.7162	yr_{17}
74.5811	yr_5	79.2229	yr_{18}
75.0412	yr_6	79.7123	yr_{19}
75.3319	yr_7	77.8292	yr_{20}
75.6218	yr_8	78.3423	yr_{21}
76.1219	yr_9	78.8025	yr_{22}
76.5181	yr_{10}	79.1478	yr_{23}
76.8318	yr_{11}	79.5421	yr_{25}
77.3320	yr_{12}	76.9663	Mean
77.7339	yr_{13}	2.0085	SD
78.1605	yr_{14}	-0.4651	Υ (skewness)
$LCOE_{wso}$	**76.9663**	**US$/MWh**	valid !
	0.076966	**US$/kWh**	

Figure J.2 *I-O system representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical $50MW_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of L_{wt} *(5D7D)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	42.2302	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	15 030	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW_e]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7807	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4103	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 207.5681**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inv}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{cm}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 207.5681	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{cm}}$	0.041531	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	29 394 286	[$M]
AEP_{avail}	212 467 325	[kWh/yr]
$O\&M_{WFCM}$	**0.139806**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000024**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000066**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000090	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85.00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2.0	[d]
$C_{md_{RM_{WT}}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2.0	[d]
$C_{md_{RM_{CT}}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	70.9972	[$/kW_e]
$LCCCM_{WF}$	1 207.5681	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_{ψ}	6	[yr]
REP_{CM}	0.00000052	[$/kW_eh]
AEP_{avail}/H_{prod}	24 766	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0128	[$/kW_eh]
ε_0	0.009998	[$/kW_eh]
n_{ε}	10	[yr]
$OREP_{CM}$	56.8814	[$/kW_e]
$LCCCM_{WF_{OREGCM}}$	2.7734	[$/kW]
$LCCCM_{WF}$	1 207.5681	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	10	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	4 490.4890	[$/tCO₂]
$LCER_{CO_2}$	80.7	[tCO₂/MW_eh]
$\sum AEP_{avail\ yr_1+\ldots+yr_n}$	212 467	[MW_eh]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00041	[tCO₂/MW_eh]
$GHG_{EM_{wecs\ CO_2}}$	0.00003	[tCO₂/MW_eh]
ε_c	30.0000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**1 154.5919**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW_e/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	2 880	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	630	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 467 325	[kW_eh/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW_eh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 467 325**	**[kW_eh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 722 762	[$]
Debt payments	3 002 711	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 722 762	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.4521	yr_1	94.5243	yr_{15}
85.1268	yr_2	94.2007	yr_{15}
85.8151	yr_3	95.0057	yr_{16}
86.2772	yr_4	95.9021	yr_{17}
86.9708	yr_5	96.8008	yr_{18}
87.6954	yr_6	97.5797	yr_{19}
88.2682	yr_7	94.0692	yr_{20}
88.9652	yr_8	94.7693	yr_{21}
89.8763	yr_9	95.8157	yr_{22}
90.4645	yr_{10}	96.5815	yr_{23}
91.2843	yr_{11}	97.5952	yr_{25}
91.9934	yr_{12}	91.8606	Mean
92.7210	yr_{13}	4.1890	SD
93.7613	yr_{14}	-0.3343	ϒ (skewness)
$LCOE_{wso}$	**91.8606**	**US$/MWh**	valid !
	0.091861	**US$/kWh**	

Figure J.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical $50MW_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of L_{wt} *(5D7D)*. Source: Own elaboration

Table J.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of L_{wt} (5D7D)

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	639	847 940	6 783 520	3 662 567	6 783 520	777 316	6 783 520	777 316	777 316	4 713 419	6 783 520	6 783 520	777 316	3 662 567	6 783 520	482 342	482 342	3 290 403	4 713 419	7 693 599	1 572 412	1 572 412	7 693 599	6 783 520	4 713 419	4 713 419
March	4.0	1.1671	735	555 090	7 476 817	5 424 310	8 853 970	975 829	7 476 817	975 829	975 829	6 543 367	7 476 817	7 476 817	975 829	5 424 310	8 853 970	894 553	894 553	1 809 568	4 214 966	1 809 568	1 686 232	1 686 232	7 806 630	8 853 970	3 786 671	6 543 367
April	4.7	1.1667	711	865 098	6 327 908	6 327 908	4 076 176	1 630 708	6 327 908	1 630 708	1 630 708	7 230 621	6 327 908	6 327 908	1 749 983	6 327 908	4 076 176	943 697	943 697	1 630 708	6 327 908	1 630 708	3 661 984	943 697	7 230 621	6 327 908	1 749 983	7 230 621
May	6.0	1.1670	735	1 809 500	5 424 109	7 476 539	5 424 109	1 809 500	5 424 109	1 809 500	1 809 500	7 806 340	5 424 109	5 424 109	1 686 169	7 476 539	6 543 124	1 686 169	1 686 169	975 792	8 853 641	975 792	555 069	894 520	6 543 124	4 214 809	1 686 169	7 806 340
June	7.9	1.1686	687	3 944 904	3 944 904	7 306 444	6 124 120	3 544 051	3 944 904	3 544 051	3 544 051	8 286 679	3 944 904	3 944 904	3 544 051	7 306 444	5 076 764	1 693 625	1 693 625	837 237	7 306 444	837 237	837 237	3 544 051	5 076 764	5 076 764	913 305	8 286 679
July	8.6	1.1698	735	5 437 072	3 795 580	8 874 801	1 690 199	4 224 882	3 795 580	4 224 882	4 224 882	556 396	556 396	3 795 580	5 437 072	8 874 801	1 813 825	3 795 580	3 795 580	556 396	7 494 407	556 396	978 125	4 224 882	4 224 882	1 690 199	896 658	556 396
August	9.6	1.1677	735	7 480 694	1 810 506	1 810 506	1 810 506	8 858 561	1 810 506	5 427 123	5 427 123	895 017	895 017	1 810 506	4 217 151	1 810 506	1 687 106	5 427 123	7 810 678	7 810 678	895 017	4 217 151	7 810 678	5 427 123	1 810 506	1 810 506	555 378	895 017
September	10.1	1.1657	711	8 554 384	1 629 176	1 629 176	3 658 543	7 542 482	1 629 176	6 321 963	6 321 963	942 810	942 810	1 629 176	6 321 963	1 629 176	3 658 543	6 321 963	7 223 828	7 223 828	942 810	5 240 771	8 554 384	6 321 963	1 629 176	3 658 543	6 321 963	942 810
October	9.7	1.1645	735	7 789 201	973 650	973 650	553 851	7 460 125	973 650	7 460 125	7 460 125	1 682 467	1 682 467	973 650	8 834 203	973 650	553 851	7 460 125	6 528 759	6 528 759	1 805 528	6 528 759	4 205 556	7 460 125	973 650	973 650	8 834 203	1 682 467
November	9.2	1.1638	687	6 098 939	833 795	833 795	833 795	6 098 939	833 795	7 276 401	7 276 401	1 686 661	1 686 661	833 795	7 276 401	833 795	833 795	7 276 401	5 055 889	5 055 889	1 571 703	6 968 989	6 098 939	7 276 401	833 795	833 795	7 276 401	1 686 661
December	7.6	1.1651	735	3 780 365	554 166	554 166	974 204	5 415 277	554 166	8 839 226	8 839 226	3 780 365	3 780 365	554 166	7 464 366	554 166	974 204	8 839 226	4 207 946	4 207 946	3 780 365	7 793 630	5 415 277	8 839 226	554 166	554 166	7 464 366	3 780 365
Annual	7.4	1.1666	8 579	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354

Table J.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of L_{wt} (5D7D)

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	738	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026
February	11.5	1.2345	639	11 923 902	4 233 203	11 923 902	11 923 902	11 923 902	3 369 392	11 923 902	12 538 268	1 770 714	3 369 392	12 538 268	1 770 714	9 115 121	11 923 902	6 580 843	12 538 268	4 233 203	5 409 699	3 369 392	2 776 293	11 923 902	2 077 293	6 580 843	11 923 902	12 538 268
March	10.5	1.2329	735	10 471 380	3 189 384	13 698 087	13 698 087	13 698 087	6 214 620	13 698 087	13 698 087	2 386 378	3 189 384	13 698 087	2 386 378	13 698 087	13 698 087	6 214 620	13 698 087	3 870 731	7 560 022	4 863 071	13 698 087	14 403 865	2 034 182	10 471 380	14 403 865	3 189 384
April	9.5	1.2317	711	7 305 887	7 305 887	10 443 175	10 443 175	10 443 175	7 305 887	10 443 175	4 699 596	3 082 171	7 305 887	13 237 618	3 082 171	13 237 618	4 699 596	4 699 596	13 237 618	3 082 171	10 119 379	3 082 171	13 919 671	13 237 618	3 082 171	3 082 171	13 237 618	3 740 614
May	8.2	1.2282	735	4 844 807	10 432 053	10 432 053	10 432 053	6 191 280	10 432 053	10 432 053	10 432 053	3 856 194	6 191 280	10 432 053	3 856 194	14 349 768	10 432 053	3 856 194	10 432 053	2 377 416	13 646 640	6 191 280	2 377 416	10 432 053	3 856 194	14 349 768	10 432 053	4 844 807
June	7.1	1.2224	687	2 955 541	12 693 755	7 005 728	7 005 728	7 005 728	10 014 121	4 506 515	12 693 755	4 506 515	10 014 121	7 005 728	4 506 515	7 005 728	2 211 411	2 955 541	7 005 728	1 885 038	12 693 755	7 005 728	1 885 038	7 005 728	4 506 515	12 693 755	7 005 728	5 758 970
July	6.1	1.2154	735	2 005 275	13 503 424	4 793 962	6 126 305	10 322 572	13 503 424	7 452 587	3 144 060	6 126 305	2 005 275	6 126 305	6 126 305	6 126 305	2 005 275	2 352 466	6 126 305	6 126 305	14 199 172	10 322 572	3 815 724	6 126 305	6 126 305	13 503 424	3 815 724	7 452 587
August	6.4	1.2075	735	2 337 182	10 583 661	3 790 935	3 790 935	3 790 935	13 415 696	6 086 504	3 790 935	7 404 169	2 337 182	4 762 817	7 404 169	4 762 817	10 583 661	1 992 247	4 762 817	13 415 696	1 992 247	13 415 696	4 762 817	4 762 817	7 404 169	4 762 817	3 123 634	10 255 509
September	7.6	1.2064	711	3 663 832	1 925 451	5 882 434	4 603 129	4 603 129	4 603 129	1 925 451	5 882 434	9 911 660	9 911 660	3 663 832	9 911 660	3 663 832	5 882 434	9 911 660	3 663 832	12 965 892	2 258 821	12 965 892	5 882 434	3 663 832	9 911 660	3 663 832	2 258 821	1 925 451
October	8.9	1.2126	735	6 112 412	6 112 412	3 136 930	2 000 727	3 136 930	2 000 727	2 347 131	7 435 686	13 472 801	13 472 801	3 136 930	13 472 801	3 136 930	7 435 686	13 472 801	3 136 930	10 628 711	3 136 930	2 000 727	7 435 686	3 136 930	13 472 801	2 347 131	2 000 727	2 347 131
November	10.6	1.2194	687	9 990 034	3 578 305	2 206 092	2 206 092	2 206 092	2 206 092	2 948 433	2 206 092	12 663 223	4 495 676	2 206 092	12 663 223	2 206 092	2 948 433	12 663 223	2 206 092	9 680 288	3 578 305	2 206 092	9 680 288	2 206 092	12 663 223	1 880 504	5 745 118	12 663 223
December	11.5	1.2237	735	13 595 706	2 368 542	2 018 979	3 165 547	2 018 979	3 165 547	3 841 801	2 018 979	14 296 210	13 595 706	2 018 979	14 296 210	2 018 979	3 841 801	14 296 210	2 018 979	7 503 518	4 826 724	14 296 210	13 595 706	2 018 979	14 296 210	6 168 172	4 826 724	13 595 706
Annual	9.1	1.2222	8 579	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675

Table J.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of L_{wt} (5D7D)

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	639	24 248 099	14 467 424	6 912 583	26 228 520	14 467 424	14 467 424	26 228 520	26 228 520	6 912 583	14 467 424	14 467 424	7 749 925	26 228 520	6 912 583	17 377 262	6 912 583	6 912 583	6 912 583	6 912 583	22 462 574	26 228 520	26 228 520	28 959 584	7 749 925	17 351 256
March	12.7	1.2495	735	18 226 532	18 226 532	8 896 263	27 834 779	12 376 594	18 226 532	27 834 779	27 834 779	8 896 263	12 376 594	18 226 532	9 971 944	27 834 779	8 896 263	30 108 137	8 896 263	8 896 263	8 896 263	8 896 263	22 991 460	27 834 779	27 834 779	31 414 830	9 971 944	18 921 332
April	12.4	1.2490	711	16 057 711	19 287 404	9 641 890	24 828 913	9 641 890	19 287 404	24 828 913	24 828 913	9 641 890	9 641 890	19 287 404	9 641 890	24 828 913	9 641 890	26 913 496	9 641 890	29 111 609	9 641 890	9 641 890	22 185 639	19 971 909	24 828 913	24 919 931	9 641 890	18 139 032
May	11.2	1.2425	735	12 306 614	25 533 644	9 915 560	19 834 848	9 915 560	25 533 644	19 834 848	19 834 848	9 915 560	9 915 560	25 533 644	12 306 614	19 834 848	9 915 560	25 533 644	9 915 560	27 677 395	9 915 560	9 915 560	20 989 216	19 834 848	19 834 848	19 089 277	12 306 614	16 168 320
June	10.4	1.2351	687	9 212 474	25 714 865	11 433 985	16 838 388	8 218 718	25 714 865	16 838 388	16 838 388	11 433 985	8 218 718	25 714 865	15 342 558	16 838 388	11 433 985	16 838 388	11 433 985	23 723 122	11 433 985	11 433 985	16 955 390	16 838 388	16 838 388	16 760 685	15 342 558	14 949 503
July	10.0	1.2275	735	8 739 531	29 577 699	16 314 803	16 314 803	7 795 266	29 577 699	16 314 803	16 314 803	16 314 803	7 795 266	29 577 699	17 905 422	16 314 803	16 314 803	7 795 266	16 314 803	19 596 205	16 314 803	16 314 803	15 530 715	16 046 466	16 314 803	16 760 185	17 905 422	8 625 161
August	9.7	1.2216	735	7 757 712	12 099 972	17 819 161	12 099 972	17 819 161	12 099 972	12 099 972	12 099 972	17 819 161	17 819 161	12 099 972	19 501 798	12 099 972	17 819 161	8 697 428	17 819 161	17 819 161	17 819 161	17 819 161	12 903 119	15 377 861	12 099 972	12 588 985	19 501 798	7 111 908
September	10.4	1.2234	711	9 444 238	7 515 148	18 892 028	9 444 238	26 361 791	7 515 148	9 444 238	9 444 238	18 892 028	26 361 791	7 515 148	24 319 940	9 444 238	18 892 028	9 444 238	18 892 028	15 728 541	18 892 028	18 892 028	12 321 085	13 275 521	9 444 238	8 842 059	24 319 940	19 029 793
October	13.1	1.2327	735	19 679 010	8 776 461	29 702 682	9 837 656	25 333 032	8 776 461	9 837 656	9 837 656	29 702 682	25 333 032	8 776 461	27 459 940	9 837 656	25 333 032	9 837 656	25 333 032	12 209 924	29 702 682	25 333 032	12 242 414	8 858 686	9 837 656	8 122 639	27 459 940	21 596 003
November	14.3	1.2429	687	23 874 256	9 271 165	25 878 688	8 271 078	27 992 285	9 271 165	8 271 078	8 271 078	25 878 688	27 992 285	9 271 165	27 992 285	8 271 078	25 878 688	11 506 828	25 878 688	9 271 165	25 878 688	25 878 688	7 423 013	8 271 078	8 271 078	8 870 902	27 992 285	21 951 058
December	15.1	1.2528	735	30 186 350	9 997 848	25 745 545	7 955 677	19 999 456	9 997 848	7 955 677	7 955 677	25 745 545	19 999 456	9 997 848	32 498 621	7 955 677	30 186 350	16 650 529	30 186 350	9 997 848	25 745 545	30 186 350	6 350 393	7 955 677	7 955 677	9 163 644	32 498 621	42 475 115
Annual	12.5	1.2404	8 579	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415

Table J.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of L_{wt} (5D7D)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table J.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of L_{wt} (5D7D)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table J.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of L_{wt} (5D7D)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table J.7 kWh per H_{prod} with sensitivity analysis of L_{wt} (5D7D)

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	*5 695*	*5 647*	*5 674*	*5 629*	*5 699*	*5 647*	*5 694*	*5 694*	*5 637*	*5 641*	*5 647*	*5 693*	*5 674*	*5 637*	*5 718*	*5 737*	*5 690*	*5 649*	*5 602*	*5 698*	*5 682*	*5 616*	*5 628*	*5 645*	*5 637*
Corvo Island (Portugal)	*10 451*	*10 535*	*10 466*	*10 473*	*10 467*	*10 570*	*10 498*	*10 419*	*10 528*	*10 530*	*10 452*	*10 528*	*10 510*	*10 504*	*10 472*	*10 452*	*10 517*	*10 522*	*10 556*	*10 569*	*10 463*	*10 523*	*10 531*	*10 446*	*10 392*
Cape Saint James (Canada)	*24 766*	*24 852*	*24 932*	*24 738*	*24 788*	*24 852*	*24 738*	*24 738*	*24 932*	*24 788*	*24 852*	*24 794*	*24 738*	*24 940*	*24 879*	*24 940*	*24 908*	*24 932*	*24 940*	*24 841*	*24 855*	*24 738*	*24 888*	*24 794*	*24 877*

Table J.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of L_{wt} (5D7D)

Item	Years 0	1	2	3	4	5	6	7	8	9	10	11	12
(-) LCCCM $_{WF}$	60 378 407	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 111 508	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	189 037	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 516	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866
(+) AAR ($M/yr)	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591
PPAR	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) O&M $_{WFCM}$	-	3 949 353	4 013 810	4 133 691	4 203 326	4 362 211	4 455 205	4 603 527	4 717 835	4 786 682	4 909 110	5 036 592	5 204 091
O&M $_{fixed}$	-	2 654 579	2 697 997	2 778 672	2 825 574	2 932 474	2 978 078	3 077 743	3 154 685	3 201 236	3 283 628	3 369 414	3 481 989
O&M $_{variable}$	-	1 294 774	1 315 813	1 355 018	1 377 752	1 429 737	1 477 127	1 525 784	1 563 150	1 585 447	1 625 482	1 667 177	1 722 102
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 459 715	2 521 208	2 584 238	2 648 844	2 715 065	2 782 942	2 852 515	2 923 828	2 996 924	3 071 847	3 148 643	3 227 359
(=) Profit before tax	-	3 670 800	3 759 704	3 855 572	3 949 143	4 052 771	4 125 300	4 232 308	4 338 895	4 444 155	4 556 323	4 671 462	4 792 542
(-) Revenue tax	-	1 289 151	1 310 237	1 349 416	1 372 194	1 424 109	1 446 256	1 494 658	1 532 024	1 554 632	1 594 645	1 636 306	1 690 977
(+) REPIM	385 363	2 045	1 989	1 961	1 910	1 898	1 847	1 829	1 797	1 748	1 720	280	289
REI_{CM}	221 866	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 825	1 765	1 730	1 675	1 654	1 599	1 573	1 535	1 482	1 447	-	-
$OREP_{CM}$	163 497	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	221	224	231	235	244	248	256	262	266	273	280	289
(=) Profit after tax w/out interest	-	2 383 694	2 451 457	2 508 117	2 578 859	2 630 560	2 680 890	2 739 479	2 808 668	2 891 272	2 963 399	3 035 436	3 101 854
(-) Debt payments	-	-	3 183 780	3 263 375	3 344 959	3 428 583	3 514 298	3 602 155	3 692 209	3 784 514	3 879 127	3 976 105	4 075 508
(+) RCM $_{WF}$	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 459 715	2 521 208	2 584 238	2 648 844	2 715 065	2 782 942	2 852 515	2 923 828	2 996 924	3 071 847	3 148 643	3 227 359
(=) Free net cashflow	-59 993 045	7 465 148	4 476 167	4 583 445	4 706 070	4 810 951	4 915 791	5 030 252	5 156 710	5 298 016	5 430 311	5 564 021	5 693 654
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 527 897	-48 051 730	-43 468 285	-38 762 216	-33 951 265	-29 035 474	-24 005 222	-18 848 512	-13 550 496	-8 120 185	-2 556 164	3 137 490
$LCOE_{wso}$		*67.81*	*67.96*	*68.17*	*68.33*	*68.59*	*68.78*	*69.02*	*69.24*	*69.41*	*69.64*	*69.88*	*70.16*

Item	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) LCCCM $_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354
(+) AAR ($M/yr)	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
PPAR	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
(-) O&M $_{WFCM}$	5 315 304	5 412 299	5 626 056	5 784 761	5 880 906	5 983 464	6 080 550	6 339 242	5 846 637	5 922 095	6 082 752	6 252 834	6 398 541
O&M $_{fixed}$	3 556 919	3 622 341	3 765 927	3 872 684	3 937 570	4 006 754	4 072 279	4 246 052	4 340 155	4 396 739	4 516 586	4 643 449	4 752 224
O&M $_{variable}$	1 758 385	1 789 958	1 860 129	1 912 077	1 943 336	1 976 710	2 008 271	2 093 190	1 506 483	1 525 356	1 566 166	1 609 385	1 646 316
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 308 043	3 390 744	3 475 513	3 562 400	3 651 460	3 742 747	3 836 316	3 932 224	4 030 529	4 131 292	4 234 575	4 340 439	4 448 950
(=) Profit before tax	4 911 628	5 032 266	5 165 465	4 046 692	4 144 646	4 245 371	4 347 927	4 466 447	3 101 952	3 191 378	3 269 810	3 349 349	3 435 414
(-) Revenue tax	1 727 367	1 759 139	1 828 870	1 880 716	1 912 227	1 945 827	1 977 648	2 062 040	1 475 418	1 494 654	1 535 396	1 578 523	1 615 502
(+) REPIM	296	301	313	322	327	333	339	353	361	365	375	386	395
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	296	301	313	322	327	333	339	353	361	365	375	386	395
(=) Profit after tax w/out interest	3 184 557	3 273 429	3 336 908	2 166 298	2 232 745	2 299 878	2 370 617	2 404 760	1 626 895	1 697 089	1 734 789	1 771 212	1 820 308
(-) Debt payments	4 177 395	4 281 830	4 388 876	-	-	-	-	-	-	-	-	-	-
(+) RCM $_{WF}$	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 308 043	3 390 744	3 475 513	3 562 400	3 651 460	3 742 747	3 836 316	3 932 224	4 030 529	4 131 292	4 234 575	4 340 439	4 448 950
(=) Free net cashflow	5 841 151	5 996 438	6 127 993	9 525 758	9 776 192	10 031 910	10 295 950	10 528 227	9 953 448	10 231 806	10 482 874	10 737 999	11 011 265
$\Sigma_{free\ net\ annual\ cashflow}$	8 978 642	14 975 080	21 103 073	30 628 832	40 405 023	50 436 934	60 732 884	71 261 111	81 214 559	91 446 366	101 929 240	112 667 239	123 678 504
$LCOE_{wso}$	*70.38*	*70.59*	*70.93*	*69.96*	*70.15*	*70.35*	*70.55*	*70.91*	*70.52*	*70.70*	*70.97*	*71.26*	*71.52*

Table J.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of L_{wt} (5D7D)

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 378 407	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 111 508	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	189 037	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 516	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675
(+) AAR ($M/yr)	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
PPAR	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
(-) $O\&M_{WFCM}$	-	9 368 374	9 679 566	9 856 225	10 109 621	10 355 890	10 719 839	10 911 955	11 100 783	11 497 361	11 787 429	11 992 241	12 380 956	12 668 548	12 977 965	13 261 497	13 567 367	13 991 943	14 348 505	14 755 487	15 142 655	13 154 747	13 560 474	13 910 592	14 143 024	14 421 680
$O\&M_{fixed}$	-	4 871 474	5 033 363	5 125 298	5 257 137	5 385 272	5 574 606	5 674 583	5 772 851	5 979 160	6 130 082	6 236 666	6 438 893	6 588 532	6 749 523	6 897 053	7 056 201	7 277 090	7 462 607	7 674 349	7 875 789	7 991 569	8 238 134	8 450 920	8 592 211	8 761 584
$O\&M_{variable}$	-	4 496 901	4 646 203	4 730 927	4 852 484	4 970 618	5 145 234	5 237 372	5 327 931	5 518 200	5 657 348	5 755 575	5 942 063	6 080 016	6 228 443	6 364 445	6 511 165	6 714 853	6 885 898	7 081 137	7 266 866	5 163 178	5 322 339	5 459 672	5 550 813	5 660 095
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 455 545	2 516 934	2 579 857	2 644 354	2 710 463	2 778 224	2 847 680	2 918 872	2 991 844	3 066 640	3 143 306	3 221 888	3 302 436	3 384 997	3 469 621	3 556 362	3 645 271	3 736 403	3 829 813	3 925 558	4 023 697	4 124 290	4 227 397	4 333 082	4 441 409
(=) Profit before tax	-	8 921 364	9 190 667	9 381 592	9 620 542	9 857 414	10 166 914	10 375 930	10 585 328	10 921 411	11 196 253	11 422 624	11 761 609	12 042 759	12 339 692	12 623 933	11 674 133	12 017 310	12 322 020	12 659 184	12 986 835	8 060 779	8 286 074	8 496 823	8 674 033	8 868 075
(-) Revenue tax	-	4 491 277	4 640 535	4 725 296	4 846 849	4 964 986	5 139 546	5 231 723	5 322 325	5 512 536	5 651 682	5 749 951	5 936 398	6 074 361	6 222 791	6 358 810	6 505 541	6 709 195	6 880 237	7 075 458	7 261 179	5 157 549	5 316 677	5 454 006	5 545 193	5 654 504
(+) REPIM	487 054	1 438	1 420	1 382	1 355	1 327	1 314	1 280	1 245	1 235	1 212	1 180	1 167	1 144	1 123	1 100	164	170	174	179	183	186	192	197	200	204
REI_{CM}	221 866	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 325	1 303	1 263	1 233	1 202	1 184	1 147	1 111	1 095	1 069	1 035	1 017	991	966	939	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	265 188	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	113	117	119	122	125	130	132	134	139	143	145	150	153	157	161	164	170	174	179	183	186	192	197	200	204
(=) Profit after tax w/out interest	-	4 431 525	4 551 552	4 657 677	4 775 048	4 893 755	5 028 682	5 145 486	5 264 248	5 410 110	5 545 783	5 673 853	5 826 378	5 969 541	6 118 025	6 266 223	5 168 756	5 308 285	5 441 957	5 583 906	5 725 839	2 903 417	2 969 589	3 043 015	3 129 041	3 213 775
(-) Debt payments	-	-	3 178 383	3 257 843	3 339 289	3 422 771	3 508 341	3 596 049	3 685 950	3 778 099	3 872 552	3 969 365	4 068 600	4 170 314	4 274 572	4 381 437	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 455 545	2 516 934	2 579 857	2 644 354	2 710 463	2 778 224	2 847 680	2 918 872	2 991 844	3 066 640	3 143 306	3 221 888	3 302 436	3 384 997	3 469 621	3 556 362	3 645 271	3 736 403	3 829 813	3 925 558	4 023 697	4 124 290	4 227 397	4 333 082	4 441 409
(=) Free net cashflow	-59 891 353	9 508 809	6 577 385	6 734 156	6 903 439	7 075 355	7 264 823	7 437 530	7 613 594	7 818 188	8 014 064	8 203 841	8 419 615	8 627 610	8 842 545	9 058 857	12 522 178	12 845 542	13 167 646	13 502 736	13 842 640	11 223 138	11 497 303	11 783 922	12 088 471	12 397 191
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 382 544	-43 805 159	-37 071 003	-30 167 564	-23 092 209	-15 827 386	-8 389 856	-776 262	7 041 926	15 055 990	23 259 831	31 679 446	40 307 056	49 149 600	58 208 457	70 730 635	83 576 177	96 743 823	110 246 559	124 089 199	135 312 337	146 809 640	158 593 562	170 682 033	183 079 224
$LCOE_{wso}$		73.23	73.63	73.90	74.24	74.58	75.04	75.33	75.62	76.12	76.52	76.83	77.33	77.73	78.16	78.56	77.74	78.26	78.72	79.22	79.71	77.83	78.34	78.80	79.15	79.54

Table J.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of L_{wt} (5D7D)

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 378 407	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 111 508	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	189 037	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 516	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415
(+) AAR ($M/yr)	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
PPAR	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
(-) $O\&M_{WFCM}$	-	20 588 652	21 176 288	21 775 288	22 145 849	22 745 587	23 374 048	23 848 205	24 444 264	25 251 713	25 733 771	26 444 814	27 042 406	27 655 669	28 578 722	29 221 648	30 025 220	30 735 352	31 534 457	32 333 423	33 010 055	29 394 776	29 987 510	30 923 747	31 576 700	32 474 766
$O\&M_{fixed}$	-	11 544 286	11 873 857	12 209 801	12 417 657	12 754 020	13 106 489	13 372 439	13 706 743	14 159 585	14 429 969	14 828 756	15 163 927	15 507 888	16 025 566	16 386 164	16 836 847	17 235 135	17 683 317	18 131 423	18 510 930	18 984 265	19 367 164	19 971 913	20 393 708	20 973 809
$O\&M_{variable}$	-	9 044 366	9 302 432	9 565 487	9 728 192	9 991 568	10 267 558	10 475 767	10 737 520	11 092 129	11 303 802	11 616 058	11 878 478	12 147 781	12 553 156	12 835 484	13 188 373	13 500 217	13 851 140	14 202 000	14 499 125	10 410 511	10 620 346	10 951 834	11 182 993	11 500 957
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 437 266	2 498 198	2 560 653	2 624 669	2 690 286	2 757 543	2 826 482	2 897 144	2 969 573	3 043 812	3 119 907	3 197 905	3 277 852	3 359 799	3 443 794	3 529 889	3 618 136	3 708 589	3 801 304	3 896 336	3 993 745	4 093 589	4 195 928	4 300 826	4 408 347
(=) Profit before tax	-	12 841 026	13 196 057	13 558 424	13 817 050	14 184 051	14 566 590	14 879 903	15 252 047	15 724 560	16 048 725	16 481 535	16 864 345	17 257 063	17 796 080	18 208 038	17 447 036	17 864 657	18 325 729	18 789 005	19 197 896	9 281 860	9 488 510	9 759 458	9 982 003	10 251 275
(-) Revenue tax	-	9 038 743	9 296 789	9 559 826	9 722 575	9 985 940	10 261 916	10 470 150	10 731 904	11 086 468	11 298 174	11 610 416	11 872 849	12 142 164	12 547 493	12 829 835	13 182 710	13 494 562	13 845 479	14 196 337	14 493 484	10 404 867	10 614 729	10 946 183	11 177 363	11 495 308
(+) REPIM	932 884	777	791	806	812	827	843	853	868	890	901	797	815	834	862	881	905	927	951	975	995	1 021	1 041	1 074	1 096	1 128
REI_{CM}	221 866	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	156	153	150	145	142	138	134	131	129	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	711 018	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	621	638	656	668	686	705	719	737	761	776	797	815	834	862	881	905	927	951	975	995	1 021	1 041	1 074	1 096	1 128
(=) Profit after tax w/out interest	-	3 803 059	3 900 059	3 999 404	4 095 287	4 198 939	4 305 518	4 410 606	4 521 012	4 638 983	4 751 452	4 871 917	4 992 311	5 115 733	5 249 448	5 379 084	4 265 231	4 371 021	4 481 201	4 593 643	4 705 407	-1 121 987	-1 125 178	-1 185 651	-1 194 263	-1 242 905
(-) Debt payments	-	-	3 154 724	3 233 592	3 314 432	3 397 292	3 482 225	3 569 280	3 658 512	3 749 975	3 843 724	3 939 818	4 038 313	4 139 271	4 242 753	4 348 821	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 437 266	2 498 198	2 560 653	2 624 669	2 690 286	2 757 543	2 826 482	2 897 144	2 969 573	3 043 812	3 119 907	3 197 905	3 277 852	3 359 799	3 443 794	3 529 889	3 618 136	3 708 589	3 801 304	3 896 336	3 993 745	4 093 589	4 195 928	4 300 826	4 408 347
(=) Free net cashflow	-59 445 523	8 862 065	5 930 816	6 080 929	6 228 851	6 385 842	6 547 093	6 708 221	6 876 067	7 052 915	7 225 732	7 408 054	7 591 852	7 780 262	7 980 590	8 178 505	11 592 179	11 881 143	12 179 076	12 483 964	12 792 987	7 167 783	7 371 835	7 523 787	7 732 911	7 907 449
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 583 459	-44 652 643	-38 571 713	-32 342 863	-25 957 021	-19 409 928	-12 701 707	-5 825 640	1 227 275	8 453 007	15 861 060	23 452 912	31 233 174	39 213 764	47 392 269	58 984 448	70 865 591	83 044 667	95 528 631	108 321 618	115 489 401	122 861 236	130 385 023	138 117 935	146 025 383
$LCOE_{wso}$		84.45	85.13	85.82	86.28	86.97	87.70	88.27	88.97	89.88	90.46	91.28	91.99	92.72	93.76	94.52	94.20	95.01	95.90	96.80	97.58	94.07	94.77	95.82	96.58	97.60

APPENDIX K

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	45.2647	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	16 110	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWe]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7903	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$w_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4164	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 210.6183**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 210.6183	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025858	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	4 192 361	[$M]
AEP_{avail}	48 856 319	[kWh/yr]
$O\&M_{WFCM}$	**0.124133**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000105**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000287**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000392	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RMCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WT}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February(*)	672	639
March	744	735
April	720	711
May	744	735
June(*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November(*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*)Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]
	889 675	

Renewable Energy Public Incentive Model		Notes
REI_{CM}	71.1740	[$/kWe]
$LCCCM_{WF}$	1 210.6183	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_ν	6	[yr]
REP_{CM}	0.00002627	[$/kWeh]
AEP_{avail}/H_{prod}	5 695	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1496	[$/kWeh]
ε_0	0.116883	[$/kWeh]
n_ε	10	[yr]
$OREP_{CM}$	13.0797	[$/kWe]
$LCCCM_{WF_{OREP}}$	2.7805	[$/kW]
$LCCCM_{WF}$	1 210.6183	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_ν	10	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	1 596.4321	[$/tCO₂]
$LCER_{CO_2}$	18.6	[tCO₂/MWeh]
$\sum AEP_{avail}$	48 856	[MWeh]
n_ν	25	[yr]
GHG_{EM}	0.00041	[tCO₂/MWeh]
GHG_{EM}	0.00003	[tCO₂/MWeh]
ε_c	46.3820	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**420.1715**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	[1/0]
(%) ccm	80.0%	[%]
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	[1/0]
ξ_2 REP_{CM}	1	[1/0]
ξ_3 $OREP_{CM}$	1	[1/0]
ξ_4 $GHG.R_{CM}$	1	[1/0]
$P\&D_{LM}$		
λ_a	1	[1/0]
$\lambda_{s\&i}$	0	[1/0]
λ_d	1	[1/0]
λ_m	1	[1/0]
p.s.: 1 = yes and 0=no		

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWe/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	3 960	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	810	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	48 856 319	[kWeh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{0}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWeh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**48 856 319**	**[kWeh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	30 072 499	[$]
Debt payments	3 038 043	[$/yr]
Equity ratio	50.0%	[%]
Equity value	30 072 499	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67.9653	yr_1	71.0812	yr_{15}
68.1169	yr_2	70.1127	yr_{15}
68.3260	yr_3	70.3038	yr_{16}
68.4872	yr_4	70.5037	yr_{17}
68.7399	yr_5	70.7005	yr_{18}
68.9291	yr_6	71.0614	yr_{19}
69.1760	yr_7	70.6736	yr_{20}
69.3913	yr_8	70.8564	yr_{21}
69.5637	yr_9	71.1272	yr_{22}
69.7923	yr_{10}	71.4101	yr_{23}
70.0286	yr_{11}	71.6715	yr_{25}
70.3076	yr_{12}	69.9843	Mean
70.5332	yr_{13}	1.0823	SD
70.7473	yr_{14}	-0.4514	Υ^* (skewness)
$LCOE_{wso}$		**69.9843 US$/MWh**	valid !
		0.069984 US$/kWh	

Figure K.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of L_{wt} *(5D10D)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{h_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{h_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RMCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{h_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	71.1740	[$/kWe]
$LCCCM_{WF}$	1 210.6183	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
Ψ_{total}	30.00%	[%]
n_e	6	[yr]
REP_{CM}	0.00001039	[$/kWeh]
AEP_{avail}/H_{prod}	10 451	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1086	[$/kWeh]
ε_0	0.075000	[$/kWeh]
n_e	15	[yr]
$OREP_{CM}$	21.2151	[$/kWe]
$LCCCM_{WF_{OREP_{CM}}}$	2.4575	[$/kW]
$LCCCM_{WF}$	1 210.6183	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
Ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_e	15	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	821.1245	[$/tCO₂]
$LCER_{CO_2}$	34.1	[tCO₂/MWeh]
$\sum AEP_{avail}$	89 657	[MWeh]
n_e	25	[yr]
$GHG_{EM_{T\,CO_2}}$	0.00041	[tCO₂/MWeh]
$GHG_{EM_{wecs\,CO_2}}$	0.00003	[tCO₂/MWeh]
ε_c	13.0000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**228.3784**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWe/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	3 960	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	810	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	89 657 257	[kWeh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWeh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**89 657 257**	**[kWeh/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	45.2647	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	16 110	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWe]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7903	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4164	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 210.6183**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 210.6183	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048935	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	14 605 780	[$M]
AEP_{avail}	89 657 257	[kWh/yr]
$O\&M_{WFCM}$	**0.147210**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000057**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000156**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000214	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February(*)	672	639
March	744	735
April	720	711
May	744	735
June(*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November(*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	[1/0]
(%) ccm	80.0%	[%]
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	[1/0]
ξ_2 REP_{CM}	1	[1/0]
ξ_3 $OREP_{CM}$	1	[1/0]
ξ_4 $GHG.R_{CM}$	1	[1/0]
$P\&D_{LM}$		
λ_a	1	[1/0]
$\lambda_{s\&i}$	0	[1/0]
λ_d	1	[1/0]
λ_m	1	[1/0]

p.s.: 1= yes and 0=no

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	30 021 653	[$]
Debt payments	3 032 907	[$/yr]
Equity ratio	50.0%	[%]
Equity value	30 021 653	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.3843	yr_1	77.7166	yr_{15}
73.7826	yr_2	77.8953	yr_{15}
74.0486	yr_3	78.4148	yr_{16}
74.3935	yr_4	78.8687	yr_{17}
74.7336	yr_5	79.3754	yr_{18}
75.1937	yr_6	79.8648	yr_{19}
75.4844	yr_7	77.9817	yr_{20}
75.7743	yr_8	78.4948	yr_{21}
76.2744	yr_9	78.9550	yr_{22}
76.6706	yr_{10}	79.3003	yr_{23}
76.9843	yr_{11}	79.6946	yr_{25}
77.4845	yr_{12}	77.1188	Mean
77.8864	yr_{13}	2.0085	SD
78.3130	yr_{14}	-0.4651	Υ^* (skewness)
$LCOE_{wso}$	77.1188	US$/MWh	valid !
	0.077119	US$/kWh	

Figure K.2 *I-O system representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of L_{wt} *(5D10D)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	45.2647	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	16 110	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWₑ]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7903	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4164	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 210.6183**	**[$/kW]**

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 210.6183	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041531	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	29 394 286	[$M]
AEP_{avail}	212 467 325	[kWh/yr]
$O\&M_{WFCM}$	**0.139806**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000024**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000066**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000090	**[$/kWh/yr]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85.00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2.0	[d]
$C_{md_{RM_{WT}}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3.0	[m-h]
$C_{Mhr_{RM_{CT}}}$	85.00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2.0	[d]
$C_{md_{RM_{CT}}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Renewable Energy Public Incentive Model		Notes
REI_{CM}	71.1740	[$/kWₑ]
$LCCCM_{WF}$	1 210.6183	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_ψ	6	[yr]
REP_{CM}	0.00000052	[$/kWₑh]
AEP_{avail}/H_{prod}	24 766	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0128	[$/kWₑh]
ε_0	0.009998	[$/kWₑh]
n_ε	10	[yr]
$OREP_{CM}$	56.8814	[$/kWₑ]
$LCCCM_{WF_{OREGCM}}$	2.7805	[$/kW]
$LCCCM_{WF}$	1 210.6183	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	10	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	4 490.4890	[$/tCO₂]
$LCER_{CO_2}$	80.7	[tCO₂/MWₑh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	212 467	[MWₑh]
n_ψ	25	[yr]
$GHG_{EM_{ff\,co_2}}$	0.00041	[tCO₂/MWₑh]
$GHG_{EM_{wecs\,CO_2}}$	0.00003	[tCO₂/MWₑh]
ε_c	30.0000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**1 154.6361**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0 = no	

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWₑ/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	3 960	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	810	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 467 325	[kWₑh/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWₑh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 467 325**	**[kWₑh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 798 739	[$]
Debt payments	3 010 387	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 798 739	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.6046	yr_1	94.6768	yr_{15}
85.2793	yr_2	94.3532	yr_{15}
85.9676	yr_3	95.1583	yr_{16}
86.4297	yr_4	96.0547	yr_{17}
87.1233	yr_5	96.9534	yr_{18}
87.8479	yr_6	97.7322	yr_{19}
88.4207	yr_7	94.2217	yr_{20}
89.1178	yr_8	94.9218	yr_{21}
90.0288	yr_9	95.9682	yr_{22}
90.6170	yr_{10}	96.7340	yr_{23}
91.4368	yr_{11}	97.7477	yr_{25}
92.1460	yr_{12}	92.0131	Mean
92.8735	yr_{13}	4.1890	SD
93.9138	yr_{14}	-0.3343	ϒ (skewness)
$LCOE_{wso}$	**92.0131**	**US$/MWh**	valid !
	0.092013	**US$/kWh**	

Figure K.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MWₑ wind farm in Cape Saint James (Canada) with sensitivity analysis of L_{wt} *(5D10D)*. Source: Own elaboration

Table K.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of L_{wt} (5D10D)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	639	847 940	6 783 520	3 662 567	6 783 520	777 316	6 783 520	777 316	777 316	4 713 419	6 783 520	6 783 520	777 316	3 662 567	6 783 520	482 342	482 342	3 290 403	4 713 419	7 693 599	1 572 412	1 572 412	7 693 599	6 783 520	4 713 419	4 713 419
March	4.0	1.1671	735	555 090	7 476 817	5 424 310	8 853 970	975 829	7 476 817	975 829	975 829	6 543 367	7 476 817	7 476 817	975 829	5 424 310	8 853 970	894 553	894 553	1 809 568	4 214 966	1 809 568	1 686 232	1 686 232	7 806 630	8 853 970	3 786 671	6 543 367
April	4.7	1.1667	711	865 098	6 327 908	6 327 908	4 076 176	1 630 708	6 327 908	1 630 708	1 630 708	7 230 621	6 327 908	6 327 908	1 749 983	6 327 908	4 076 176	943 697	943 697	1 630 708	6 327 908	1 630 708	3 661 984	943 697	7 230 621	6 327 908	1 749 983	7 230 621
May	6.0	1.1670	735	1 809 500	5 424 109	7 476 539	5 424 109	1 809 500	5 424 109	1 809 500	1 809 500	7 806 340	5 424 109	5 424 109	1 686 169	7 476 539	6 543 124	1 686 169	1 686 169	975 792	8 853 641	975 792	555 069	894 520	6 543 124	4 214 809	1 686 169	7 806 340
June	7.9	1.1686	687	3 944 904	3 944 904	7 306 444	6 124 120	3 544 051	3 944 904	3 544 051	3 544 051	8 286 679	3 944 904	3 944 904	3 544 051	7 306 444	5 076 764	1 693 625	1 693 625	837 237	7 306 444	837 237	837 237	3 544 051	5 076 764	5 076 764	913 305	8 286 679
July	8.6	1.1698	735	5 437 072	3 795 580	8 874 801	1 690 199	4 224 882	3 795 580	4 224 882	4 224 882	556 396	556 396	3 795 580	5 437 072	8 874 801	1 813 825	3 795 580	3 795 580	556 396	7 494 407	556 396	978 125	4 224 882	4 224 882	1 690 199	896 658	556 396
August	9.6	1.1677	735	7 480 694	1 810 506	1 810 506	1 810 506	8 858 561	1 810 506	5 427 123	5 427 123	895 017	895 017	1 810 506	4 217 151	1 810 506	1 687 106	5 427 123	7 810 678	7 810 678	895 017	4 217 151	7 810 678	5 427 123	1 810 506	1 810 506	555 378	895 017
September	10.1	1.1657	711	8 554 384	1 629 176	1 629 176	3 658 543	7 542 482	1 629 176	6 321 963	6 321 963	942 810	942 810	1 629 176	6 321 963	1 629 176	3 658 543	6 321 963	7 223 828	7 223 828	942 810	5 240 771	8 554 384	6 321 963	1 629 176	3 658 543	6 321 963	942 810
October	9.7	1.1645	735	7 789 201	973 650	973 650	553 851	7 460 125	973 650	7 460 125	7 460 125	1 682 467	1 682 467	973 650	8 834 203	973 650	553 851	7 460 125	6 528 759	6 528 759	1 805 528	6 528 759	4 205 556	7 460 125	973 650	973 650	8 834 203	1 682 467
November	9.2	1.1638	687	6 098 939	833 795	833 795	833 795	6 098 939	833 795	7 276 401	7 276 401	1 686 661	1 686 661	833 795	7 276 401	833 795	833 795	7 276 401	5 055 889	5 055 889	1 571 703	6 968 989	6 098 939	7 276 401	833 795	833 795	7 276 401	1 686 661
December	7.6	1.1651	735	3 780 365	554 166	554 166	974 204	5 415 277	554 166	8 839 226	8 839 226	3 780 365	3 780 365	554 166	7 464 366	554 166	974 204	8 839 226	4 207 946	4 207 946	3 780 365	7 793 630	5 415 277	8 839 226	554 166	554 166	7 464 366	3 780 365
Annual	7.4	1.1666	8 579	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354

Table K.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of L_{wt} (5D10D)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	738	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026
February	11.5	1.2345	639	11 923 902	4 233 203	11 923 902	11 923 902	11 923 902	3 369 392	11 923 902	12 538 268	1 770 714	3 369 392	12 538 268	1 770 714	9 115 121	11 923 902	6 580 843	12 538 268	4 233 203	5 409 699	3 369 392	2 776 293	11 923 902	2 077 293	6 580 843	11 923 902	12 538 268
March	10.5	1.2329	735	10 471 380	3 189 384	13 698 087	13 698 087	13 698 087	6 214 620	13 698 087	13 698 087	2 386 378	3 189 384	13 698 087	2 386 378	13 698 087	13 698 087	6 214 620	13 698 087	3 870 731	7 560 022	4 863 071	13 698 087	14 403 865	2 034 182	10 471 380	14 403 865	3 189 384
April	9.5	1.2317	711	7 305 887	7 305 887	10 443 175	10 443 175	10 443 175	7 305 887	10 443 175	4 699 596	3 082 171	7 305 887	13 237 618	3 082 171	13 237 618	4 699 596	4 699 596	13 237 618	3 082 171	10 119 379	3 082 171	13 919 671	13 237 618	3 082 171	3 082 171	13 237 618	3 740 614
May	8.2	1.2282	735	4 844 807	10 432 053	10 432 053	10 432 053	6 191 280	10 432 053	10 432 053	10 432 053	3 856 194	6 191 280	10 432 053	3 856 194	14 349 768	10 432 053	3 856 194	10 432 053	2 377 416	13 646 640	6 191 280	2 377 416	10 432 053	3 856 194	14 349 768	10 432 053	4 844 807
June	7.1	1.2224	687	2 955 541	12 693 755	7 005 728	7 005 728	7 005 728	10 014 121	4 506 515	12 693 755	4 506 515	10 014 121	7 005 728	4 506 515	7 005 728	2 211 411	2 955 541	7 005 728	1 885 038	12 693 755	7 005 728	1 885 038	7 005 728	4 506 515	12 693 755	7 005 728	5 758 970
July	6.1	1.2154	735	2 005 275	13 503 424	4 793 962	6 126 305	10 322 572	13 503 424	7 452 587	3 144 060	6 126 305	2 005 275	6 126 305	6 126 305	6 126 305	2 005 275	2 352 466	6 126 305	6 126 305	14 199 172	10 322 572	3 815 724	6 126 305	6 126 305	13 503 424	3 815 724	7 452 587
August	6.4	1.2075	735	2 337 182	10 583 661	3 790 935	3 790 935	3 790 935	13 415 696	6 086 504	3 790 935	7 404 169	2 337 182	4 762 817	7 404 169	4 762 817	10 583 661	1 992 247	4 762 817	13 415 696	1 992 247	13 415 696	4 762 817	4 762 817	7 404 169	4 762 817	3 123 634	10 255 509
September	7.6	1.2064	711	3 663 832	1 925 451	5 882 434	4 603 129	4 603 129	4 603 129	1 925 451	5 882 434	9 911 660	9 911 660	3 663 832	9 911 660	3 663 832	5 882 434	9 911 660	3 663 832	12 965 892	2 258 821	12 965 892	5 882 434	3 663 832	9 911 660	3 663 832	2 258 821	1 925 451
October	8.9	1.2126	735	6 112 412	6 112 412	3 136 930	2 000 727	3 136 930	2 000 727	2 347 131	7 435 686	13 472 801	13 472 801	3 136 930	13 472 801	3 136 930	7 435 686	13 472 801	3 136 930	10 628 711	3 136 930	2 000 727	7 435 686	3 136 930	13 472 801	2 347 131	2 000 727	2 347 131
November	10.6	1.2194	687	9 990 034	3 578 305	2 206 092	2 206 092	2 206 092	2 206 092	2 948 433	2 206 092	12 663 223	4 495 676	2 206 092	12 663 223	2 206 092	2 948 433	12 663 223	2 206 092	9 680 288	3 578 305	2 206 092	9 680 288	2 206 092	12 663 223	1 880 504	5 745 118	12 663 223
December	11.5	1.2237	735	13 595 706	2 368 542	2 018 979	3 165 547	2 018 979	3 165 547	3 841 801	2 018 979	14 296 210	13 595 706	2 018 979	14 296 210	2 018 979	3 841 801	14 296 210	2 018 979	7 503 518	4 826 724	14 296 210	13 595 706	2 018 979	14 296 210	6 168 172	4 826 724	13 595 706
Annual	9.1	1.2222	8 579	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675

Table K.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of L_{wt} (5D10D)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	639	24 248 099	14 467 424	6 912 583	26 228 520	14 467 424	14 467 424	26 228 520	26 228 520	6 912 583	14 467 424	14 467 424	7 749 925	26 228 520	6 912 583	17 377 262	6 912 583	6 912 583	6 912 583	6 912 583	22 462 574	26 228 520	26 228 520	28 959 584	7 749 925	17 351 256
March	12.7	1.2495	735	18 226 532	18 226 532	8 896 263	27 834 779	12 376 594	18 226 532	27 834 779	27 834 779	8 896 263	12 376 594	18 226 532	9 971 944	27 834 779	8 896 263	30 108 137	8 896 263	8 896 263	8 896 263	8 896 263	22 991 460	27 834 779	27 834 779	31 414 830	9 971 944	18 921 332
April	12.4	1.2490	711	16 057 711	19 287 404	9 641 890	24 828 913	9 641 890	19 287 404	24 828 913	24 828 913	9 641 890	9 641 890	19 287 404	9 641 890	24 828 913	9 641 890	26 913 496	9 641 890	29 111 609	9 641 890	9 641 890	22 185 639	19 971 909	24 828 913	24 919 931	9 641 890	18 139 032
May	11.2	1.2425	735	12 306 614	25 533 644	9 915 560	19 834 848	9 915 560	25 533 644	19 834 848	19 834 848	9 915 560	9 915 560	25 533 644	12 306 614	19 834 848	9 915 560	25 533 644	9 915 560	27 677 395	9 915 560	9 915 560	20 989 216	19 834 848	19 834 848	19 089 277	12 306 614	16 168 320
June	10.4	1.2351	687	9 212 474	25 714 865	11 433 985	16 838 388	8 218 718	25 714 865	16 838 388	16 838 388	11 433 985	8 218 718	25 714 865	15 342 558	16 838 388	11 433 985	16 838 388	11 433 985	23 723 122	11 433 985	11 433 985	16 955 390	16 838 388	16 838 388	16 760 685	15 342 558	14 949 503
July	10.0	1.2275	735	8 739 531	29 577 699	16 314 803	16 314 803	7 795 266	29 577 699	16 314 803	16 314 803	16 314 803	7 795 266	29 577 699	17 905 422	16 314 803	16 314 803	7 795 266	16 314 803	19 596 205	16 314 803	16 314 803	15 530 715	16 046 466	16 314 803	16 760 185	17 905 422	8 625 161
August	9.7	1.2216	735	7 757 712	12 099 972	17 819 161	12 099 972	17 819 161	12 099 972	12 099 972	12 099 972	17 819 161	17 819 161	12 099 972	19 501 798	12 099 972	17 819 161	8 697 428	17 819 161	17 819 161	17 819 161	17 819 161	12 903 119	15 377 861	12 099 972	12 588 985	19 501 798	7 111 908
September	10.4	1.2234	711	9 444 238	7 515 148	18 892 028	9 444 238	26 361 791	7 515 148	9 444 238	9 444 238	18 892 028	26 361 791	7 515 148	24 319 940	9 444 238	18 892 028	9 444 238	18 892 028	15 728 541	18 892 028	18 892 028	12 321 085	13 275 521	9 444 238	8 842 059	24 319 940	19 029 793
October	13.1	1.2327	735	19 679 010	8 776 461	29 702 682	9 837 656	25 333 032	8 776 461	9 837 656	9 837 656	29 702 682	25 333 032	8 776 461	27 459 940	9 837 656	25 333 032	9 837 656	25 333 032	12 209 924	29 702 682	25 333 032	12 242 414	8 858 686	9 837 656	8 122 639	27 459 940	21 596 003
November	14.3	1.2429	687	23 874 256	9 271 165	25 878 688	8 271 078	27 992 285	9 271 165	8 271 078	8 271 078	25 878 688	27 992 285	9 271 165	27 992 285	8 271 078	25 878 688	11 506 828	25 878 688	9 271 165	25 878 688	25 878 688	7 423 013	8 271 078	8 271 078	8 870 902	27 992 285	21 951 058
December	15.1	1.2528	735	30 186 350	9 997 848	25 745 545	7 955 677	19 999 456	9 997 848	7 955 677	7 955 677	25 745 545	19 999 456	9 997 848	32 498 621	7 955 677	30 186 350	16 650 529	30 186 350	9 997 848	25 745 545	30 186 350	6 350 393	7 955 677	7 955 677	9 163 644	32 498 621	42 475 115
Annual	12.5	1.2404	8 579	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415

Table K.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of L_{wt} (5D10D)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table K.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of L_{wt} (5D10D)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table K.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of L_{wt} (5D10D)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table K.7 kWh per H_{prod} with sensitivity analysis of L_{wt} (5D10D)

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 695	5 647	5 674	5 629	5 699	5 647	5 694	5 694	5 637	5 641	5 647	5 693	5 674	5 637	5 718	5 737	5 690	5 649	5 602	5 698	5 682	5 616	5 628	5 645	5 637
Corvo Island (Portugal)	10 451	10 535	10 466	10 473	10 467	10 570	10 498	10 419	10 528	10 530	10 452	10 528	10 510	10 504	10 472	10 452	10 517	10 522	10 556	10 569	10 463	10 523	10 531	10 446	10 392
Cape Saint James (Canada)	24 766	24 852	24 932	24 738	24 788	24 852	24 738	24 738	24 932	24 788	24 852	24 794	24 738	24 940	24 879	24 940	24 908	24 932	24 940	24 841	24 855	24 738	24 888	24 794	24 877

Table K.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of L_{wt} (5D10D)

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 530 914	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 263 233	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	189 514	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 820	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354
(+) AAR ($M/yr)	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
PPAR	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
(-) $O\&M_{WFCM}$	-	3 949 353	4 013 810	4 133 691	4 203 326	4 362 211	4 455 206	4 603 527	4 717 835	4 786 683	4 909 110	5 036 592	5 204 091	5 315 304	5 412 299	5 626 056	5 784 761	5 880 906	5 983 464	6 080 550	6 339 242	5 846 638	5 922 095	6 082 753	6 252 834	6 398 541
$O\&M_{fixed}$	-	2 654 579	2 697 997	2 778 672	2 825 574	2 932 475	2 978 078	3 077 743	3 154 685	3 201 236	3 283 628	3 369 414	3 481 989	3 556 919	3 622 341	3 765 928	3 872 685	3 937 570	4 006 755	4 072 279	4 246 052	4 340 155	4 396 739	4 516 587	4 643 449	4 752 225
$O\&M_{variable}$	-	1 294 774	1 315 813	1 355 018	1 377 752	1 429 737	1 477 127	1 525 784	1 563 150	1 585 447	1 625 482	1 667 177	1 722 102	1 758 385	1 789 958	1 860 129	1 912 077	1 943 336	1 976 710	2 008 271	2 093 190	1 506 483	1 525 356	1 566 166	1 609 385	1 646 316
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 465 945	2 527 594	2 590 783	2 655 553	2 721 942	2 789 990	2 859 740	2 931 234	3 004 514	3 079 627	3 156 618	3 235 533	3 316 422	3 399 332	3 484 316	3 571 424	3 660 709	3 752 227	3 846 033	3 942 183	4 040 738	4 141 756	4 245 300	4 351 433	4 460 219
(=) Profit before tax	-	3 677 030	3 766 090	3 862 117	3 955 852	4 059 647	4 132 348	4 239 532	4 346 300	4 451 746	4 564 104	4 679 437	4 800 717	4 920 006	5 040 854	5 174 268	4 055 715	4 153 894	4 254 851	4 357 643	4 476 406	3 112 161	3 201 842	3 280 536	3 360 342	3 446 683
(-) Revenue tax	-	1 289 151	1 310 237	1 349 416	1 372 194	1 424 109	1 446 256	1 494 658	1 532 024	1 554 632	1 594 645	1 636 306	1 690 977	1 727 367	1 759 139	1 828 870	1 880 716	1 912 227	1 945 827	1 977 648	2 062 040	1 475 418	1 494 654	1 535 396	1 578 523	1 615 502
(+) REPIM	385 916	2 045	1 989	1 961	1 910	1 898	1 847	1 829	1 797	1 748	1 720	280	289	296	301	313	322	327	333	339	353	361	365	375	386	395
REI_{CM}	222 419	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 825	1 765	1 730	1 675	1 654	1 599	1 573	1 535	1 482	1 447	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	163 497	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	221	224	231	235	244	248	256	262	266	273	280	289	296	301	313	322	327	333	339	353	361	365	375	386	395
(=) Profit after tax w/out interest	-	2 389 924	2 457 842	2 514 663	2 585 568	2 637 436	2 687 939	2 746 704	2 816 073	2 898 863	2 971 179	3 043 411	3 110 029	3 192 935	3 282 017	3 345 711	2 175 321	2 241 994	2 309 357	2 380 334	2 414 720	1 637 103	1 707 553	1 745 515	1 782 205	1 831 576
(-) Debt payments	-	-	3 191 844	3 271 640	3 353 431	3 437 267	3 523 199	3 611 279	3 701 561	3 794 100	3 888 952	3 986 176	4 085 830	4 187 976	4 292 676	4 399 992	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 465 945	2 527 594	2 590 783	2 655 553	2 721 942	2 789 990	2 859 740	2 931 234	3 004 514	3 079 627	3 156 618	3 235 533	3 316 422	3 399 332	3 484 316	3 571 424	3 660 709	3 752 227	3 846 033	3 942 183	4 040 738	4 141 756	4 245 300	4 351 433	4 460 219
(=) Free net cashflow	-60 144 999	7 477 608	4 480 874	4 588 270	4 711 015	4 816 020	4 920 987	5 035 578	5 162 170	5 303 612	5 436 047	5 569 900	5 699 680	5 847 328	6 002 769	6 134 483	9 543 804	9 794 689	10 050 870	10 315 384	10 548 146	9 973 866	10 252 734	10 504 325	10 759 986	11 033 802
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 667 391	-48 186 517	-43 598 247	-38 887 231	-34 071 211	-29 150 224	-24 114 646	-18 952 476	-13 648 865	-8 212 818	-2 642 918	3 056 763	8 904 091	14 906 860	21 041 343	30 585 147	40 379 836	50 430 706	60 746 090	71 294 236	81 268 102	91 520 836	102 025 162	112 785 148	123 818 950
	$LCOE_{wso}$	67.97	68.12	68.33	68.49	68.74	68.93	69.18	69.39	69.56	69.79	70.03	70.31	70.53	70.75	71.08	70.11	70.30	70.50	70.70	71.06	70.67	70.86	71.13	71.41	71.67

Table K.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of L_{wt} (5D10D)

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 530 914	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 263 233	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	189 514	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 820	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675
(+) AAR ($M/yr)	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
PPAR	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
(-) $O\&M_{WFCM}$	-	9 368 375	9 679 567	9 856 225	10 109 622	10 355 890	10 719 840	10 911 955	11 100 783	11 497 361	11 787 430	11 992 241	12 380 956	12 668 548	12 977 965	13 261 497	13 567 367	13 991 943	14 348 505	14 755 487	15 142 655	13 154 747	13 560 474	13 910 593	14 143 024	14 421 680
$O\&M_{fixed}$	-	4 871 474	5 033 364	5 125 298	5 257 137	5 385 272	5 574 606	5 674 583	5 772 852	5 979 161	6 130 082	6 236 667	6 438 894	6 588 532	6 749 523	6 897 053	7 056 202	7 277 090	7 462 607	7 674 350	7 875 789	7 991 569	8 238 135	8 450 921	8 592 211	8 761 585
$O\&M_{variable}$	-	4 496 901	4 646 203	4 730 927	4 852 484	4 970 618	5 145 234	5 237 372	5 327 931	5 518 200	5 657 348	5 755 575	5 942 063	6 080 016	6 228 443	6 364 445	6 511 165	6 714 853	6 885 898	7 081 137	7 266 866	5 163 178	5 322 339	5 459 672	5 550 813	5 660 095
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 461 776	2 523 320	2 586 403	2 651 063	2 717 340	2 785 273	2 854 905	2 926 278	2 999 435	3 074 420	3 151 281	3 230 063	3 310 814	3 393 585	3 478 424	3 565 385	3 654 520	3 745 883	3 839 530	3 935 518	4 033 906	4 134 754	4 238 122	4 344 075	4 452 677
(=) Profit before tax	-	8 927 594	9 197 052	9 388 137	9 627 250	9 864 290	10 173 963	10 383 155	10 592 734	10 929 002	11 204 033	11 430 598	11 769 783	12 051 137	12 348 280	12 632 736	11 683 156	12 026 558	12 331 500	12 668 901	12 996 794	8 070 987	8 296 538	8 507 549	8 685 027	8 879 343
(-) Revenue tax	-	4 491 277	4 640 535	4 725 296	4 846 849	4 964 986	5 139 546	5 231 723	5 322 325	5 512 536	5 651 682	5 749 951	5 936 398	6 074 361	6 222 791	6 358 810	6 505 541	6 709 195	6 880 237	7 075 458	7 261 179	5 157 549	5 316 677	5 454 006	5 545 193	5 654 504
(+) REPIM	487 607	1 438	1 420	1 382	1 355	1 327	1 314	1 280	1 245	1 235	1 212	1 180	1 167	1 144	1 123	1 100	164	170	174	179	183	186	192	197	200	204
REI_{CM}	222 419	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 325	1 303	1 263	1 233	1 202	1 184	1 147	1 111	1 095	1 069	1 035	1 017	991	966	939	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	265 188	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	113	117	119	122	125	130	132	134	139	143	145	150	153	157	161	164	170	174	179	183	186	192	197	200	204
(=) Profit after tax w/out interest	-	4 437 755	4 557 938	4 664 222	4 781 757	4 900 631	5 035 731	5 152 711	5 271 654	5 417 700	5 553 563	5 681 828	5 834 552	5 977 920	6 126 613	6 275 026	5 177 779	5 317 533	5 451 437	5 593 622	5 735 798	2 913 625	2 980 052	3 053 740	3 140 034	3 225 044
(-) Debt payments	-	-	3 186 448	3 266 109	3 347 761	3 431 455	3 517 242	3 605 173	3 695 302	3 787 685	3 882 377	3 979 436	4 078 922	4 180 895	4 285 418	4 392 553	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 461 776	2 523 320	2 586 403	2 651 063	2 717 340	2 785 273	2 854 905	2 926 278	2 999 435	3 074 420	3 151 281	3 230 063	3 310 814	3 393 585	3 478 424	3 565 385	3 654 520	3 745 883	3 839 530	3 935 518	4 033 906	4 134 754	4 238 122	4 344 075	4 452 677
(=) Free net cashflow	-60 043 307	9 521 269	6 582 092	6 738 981	6 908 384	7 080 425	7 270 019	7 442 856	7 619 053	7 823 784	8 019 799	8 209 720	8 425 641	8 633 786	8 848 876	9 065 346	12 540 224	12 864 039	13 186 605	13 522 170	13 862 559	11 243 555	11 518 231	11 805 373	12 110 458	12 419 728
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 522 038	-43 939 946	-37 200 965	-30 292 580	-23 212 156	-15 942 137	-8 499 281	-880 228	6 943 556	14 963 356	23 173 076	31 598 717	40 232 503	49 081 379	58 146 725	70 686 949	83 550 987	96 737 593	110 259 763	124 122 322	135 365 877	146 884 108	158 689 481	170 799 939	183 219 667
	$LCOE_{wso}$	73.38	73.78	74.05	74.39	74.73	75.19	75.48	75.77	76.27	76.67	76.98	77.48	77.89	78.31	78.72	77.90	78.41	78.87	79.38	79.86	77.98	78.49	78.96	79.30	79.69

Table K.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of L_{wt} (5D10D)

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 530 914	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 263 233	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	189 514	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 820	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415
(+) AAR ($M/yr)	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
PPAR	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
(-) $O\&M_{WFCM}$	-	20 588 653	21 176 289	21 775 289	22 145 849	22 745 588	23 374 048	23 848 206	24 444 264	25 251 714	25 733 772	26 444 815	27 042 406	27 655 670	28 578 723	29 221 649	30 025 221	30 735 353	31 534 457	32 333 424	33 010 055	29 394 777	29 987 510	30 923 748	31 576 701	32 474 767
$O\&M_{fixed}$	-	11 544 287	11 873 857	12 209 802	12 417 658	12 754 020	13 106 490	13 372 439	13 706 744	14 159 585	14 429 969	14 828 756	15 163 928	15 507 889	16 025 567	16 386 165	16 836 848	17 235 136	17 683 317	18 131 424	18 510 931	18 984 266	19 367 164	19 971 914	20 393 708	20 973 810
$O\&M_{variable}$	-	9 044 366	9 302 432	9 565 487	9 728 192	9 991 568	10 267 558	10 475 767	10 737 520	11 092 129	11 303 802	11 616 058	11 878 478	12 147 781	12 553 156	12 835 484	13 188 373	13 500 217	13 851 140	14 202 000	14 499 125	10 410 511	10 620 346	10 951 834	11 182 993	11 500 957
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 443 497	2 504 584	2 567 199	2 631 379	2 697 163	2 764 592	2 833 707	2 904 550	2 977 163	3 051 592	3 127 882	3 206 079	3 286 231	3 368 387	3 452 597	3 538 912	3 627 384	3 718 069	3 811 021	3 906 296	4 003 954	4 104 053	4 206 654	4 311 820	4 419 616
(=) Profit before tax	-	12 847 255	13 202 442	13 564 969	13 823 758	14 190 927	14 573 639	14 887 127	15 259 452	15 732 151	16 056 505	16 489 510	16 872 519	17 265 441	17 804 667	18 216 840	17 456 058	17 873 905	18 335 209	18 798 721	19 207 855	9 292 068	9 498 973	9 770 183	9 992 996	10 262 543
(-) Revenue tax	-	9 038 743	9 296 789	9 559 826	9 722 575	9 985 940	10 261 916	10 470 150	10 731 904	11 086 468	11 298 174	11 610 416	11 872 849	12 142 164	12 547 493	12 829 835	13 182 710	13 494 562	13 845 479	14 196 337	14 493 484	10 404 867	10 614 729	10 946 183	11 177 363	11 495 308
(+) REPIM	933 437	777	791	806	812	827	843	853	868	890	901	797	815	834	862	881	905	927	951	975	995	1 021	1 041	1 074	1 096	1 128
REI_{CM}	222 419	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	156	153	150	145	142	138	134	131	129	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	711 018	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	621	638	656	668	686	705	719	737	761	776	797	815	834	862	881	905	927	951	975	995	1 021	1 041	1 074	1 096	1 128
(=) Profit after tax w/out interest	-	3 809 289	3 906 444	4 005 949	4 101 995	4 205 815	4 312 566	4 417 831	4 528 417	4 646 573	4 759 232	4 879 891	5 000 485	5 124 111	5 258 036	5 387 886	4 274 253	4 380 269	4 490 680	4 603 359	4 715 366	-1 111 779	-1 114 715	-1 174 926	-1 183 270	-1 231 637
(-) Debt payments	-	-	3 162 788	3 241 857	3 322 904	3 405 976	3 491 126	3 578 404	3 667 864	3 759 561	3 853 550	3 949 888	4 048 636	4 149 852	4 253 598	4 359 938	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 443 497	2 504 584	2 567 199	2 631 379	2 697 163	2 764 592	2 833 707	2 904 550	2 977 163	3 051 592	3 127 882	3 206 079	3 286 231	3 368 387	3 452 597	3 538 912	3 627 384	3 718 069	3 811 021	3 906 296	4 003 954	4 104 053	4 206 654	4 311 820	4 419 616
(=) Free net cashflow	-59 597 477	8 874 524	5 935 523	6 085 754	6 233 796	6 390 911	6 552 289	6 713 547	6 881 526	7 058 510	7 231 467	7 413 932	7 597 877	7 786 438	7 986 921	8 184 994	11 610 225	11 899 640	12 198 035	12 503 397	12 812 906	7 188 199	7 392 762	7 545 238	7 754 898	7 929 985
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 722 953	-44 787 430	-38 701 676	-32 467 880	-26 076 969	-19 524 680	-12 811 134	-5 929 608	1 128 902	8 360 369	15 774 301	23 372 179	31 158 617	39 145 537	47 330 531	58 940 756	70 840 395	83 038 430	95 541 827	108 354 733	115 542 933	122 935 695	130 480 933	138 235 831	146 165 817
	$LCOE_{wso}$	84.60	85.28	85.97	86.43	87.12	87.85	88.42	89.12	90.03	90.62	91.44	92.15	92.87	93.91	94.68	94.35	95.16	96.05	96.95	97.73	94.22	94.92	95.97	96.73	97.75

APPENDIX L

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m^2]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	52.3452	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	18 630	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m^2/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m^2]
Bld_{area}	300.0	[m^2]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.8126	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4306	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 217.7353**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 217.7353	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025858	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	4 192 361	[$M]
AEP_{avail}	48 856 319	[kWh/yr]
$O\&M_{WFCM}$	**0.124133**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000105**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000287**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000392	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m^2/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February(*)	672	639
March	744	735
April	720	711
May	744	735
June(*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November(*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]
	894 834	

Renewable Energy Public Incentive Model		Notes
REI_{CM}	71.5867	[$/kW$_e$]
$LCCCM_{WF}$	1 217.7353	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_{ψ}	6	[yr]
REP_{CM}	0.00002627	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5 695	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1496	[$/kW$_e$h]
ε_0	0.116883	[$/kW$_e$h]
n_{ε}	10	[yr]
$OREP_{CM}$	13.0797	[$/kW$_e$]
$LCCCM_{WF_{OREG_{CM}}}$	2.7968	[$/kW]
$LCCCM_{WF}$	1 217.7353	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	10	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	1 596.4321	[$/tCO$_2$]
$LCER_{CO_2}$	18.6	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	48 856	[MW$_e$h]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\,co_2}}$	0.00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\,co_2}}$	0.00003	[tCO$_2$/MW$_e$h]
ε_c	46.3820	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**420.2746**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	4 680	[m]
$L_{x_{col}}$	2 790	[m]
$SD_{x_{row}}$	990	[m]
SD_{xcol}	630	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	48 856 319	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m^2]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**48 856 319**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	30 249 779	[$]
Debt payments	3 055 953	[$/yr]
Equity ratio	50.0%	[%]
Equity value	30 249 779	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
68.3211	yr_1	71.4370	yr_{15}
68.4727	yr_2	70.4686	yr_{15}
68.6819	yr_3	70.6597	yr_{16}
68.8431	yr_4	70.8595	yr_{17}
69.0958	yr_5	71.0563	yr_{18}
69.2849	yr_6	71.4172	yr_{19}
69.5318	yr_7	71.0294	yr_{20}
69.7472	yr_8	71.2123	yr_{21}
69.9196	yr_9	71.4830	yr_{22}
70.1482	yr_{10}	71.7659	yr_{23}
70.3845	yr_{11}	72.0273	yr_{25}
70.6635	yr_{12}	70.3401	Mean
70.8890	yr_{13}	1.0823	SD
71.1032	yr_{14}	-0.4514	Υ (skewness)
$LCOE_{wso}$	**70.3401**	**US$/MWh**	valid !
	0.070340	**US$/kWh**	

Figure L.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of L_{wt} *(6D12D)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	71.5867	[$/kW$_e$]
$LCCCM_{WF}$	1 217.7353	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_{ψ}	6	[yr]
REP_{CM}	0.00001039	[$/kW$_e$h]
AEP_{avail}/H_{prod}	10 451	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1086	[$/kW$_e$h]
ε_0	0.075000	[$/kW$_e$h]
n_{ε}	15	[yr]
$OREP_{CM}$	21.2151	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	2.4720	[$/kW]
$LCCCM_{WF}$	1 217.7353	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	15	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	821.1245	[$/tCO$_2$]
$LCER_{CO_2}$	34.1	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail\ yr_1+\ldots+yr_n}$	89 657	[MW$_e$h]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\,co_2}}$	0.00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\,co_2}}$	0.00003	[tCO$_2$/MW$_e$h]
ε_c	13.0000	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**228.4816**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	4 680	[m]
$L_{x_{col}}$	2 790	[m]
$SD_{x_{row}}$	990	[m]
SD_{xcol}	630	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	89 657 257	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**89 657 257**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	52.3452	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	18 630	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.8126	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4306	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 217.7353**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 217.7353	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048935	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	14 605 780	[$M]
AEP_{avail}	89 657 257	[kWh/yr]
$O\&M_{WFCM}$	**0.147210**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000057**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000156**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000214	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	30 198 933	[$]
Debt payments	3 050 816	[$/yr]
Equity ratio	50.0%	[%]
Equity value	30 198 933	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.7401	yr_1	79.0725	yr_{15}
74.1385	yr_2	78.2512	yr_{15}
74.4044	yr_3	78.7707	yr_{16}
74.7494	yr_4	79.2246	yr_{17}
75.0894	yr_5	79.7313	yr_{18}
75.5496	yr_6	80.2207	yr_{19}
75.8403	yr_7	78.3375	yr_{20}
76.1301	yr_8	78.8507	yr_{21}
76.6303	yr_9	79.3109	yr_{22}
77.0265	yr_{10}	79.6561	yr_{23}
77.3401	yr_{11}	80.0505	yr_{25}
77.8404	yr_{12}	77.4747	Mean
78.2423	yr_{13}	2.0085	SD
78.6689	yr_{14}	-0.4651	Υ (skewness)
$LCOE_{wso}$	**77.4747**	**US$/MWh**	valid !
	0.077475	**US$/kWh**	

Figure L.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of L_{wt} *(6D12D)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	52.3452	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	18 630	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.8126	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4306	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 217.7353**	**[$/kW]**

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 217.7353	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041531	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	29 394 286	[$M]
AEP_{avail}	212 467 325	[kWh/yr]
$O\&M_{WFCM}$	**0.139806**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000024**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000066**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000090	**[$/kWh/yr]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Renewable Energy Public Incentive Model		Notes
REI_{CM}	71.5867	[$/kW$_e$]
$LCCCM_{WF}$	1 217.7353	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	30.00%	[%]
n_ψ	6	[yr]
REP_{CM}	0.00000052	[$/kW$_e$h]
AEP_{avail}/H_{prod}	24 766	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0128	[$/kW$_e$h]
ε_0	0.009998	[$/kW$_e$h]
n_ε	10	[yr]
$OREP_{CM}$	56.8814	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	2.7968	[$/kW]
$LCCCM_{WF}$	1 217.7353	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	30.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	10	[yr]
CR_f	80.0%	[%]
$GHG.R_{CM}$	4 490.4890	[$/tCO$_2$]
$LCER_{CO_2}$	80.7	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	212 467	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\,co_2}}$	0.00041	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\,co_2}}$	0.00003	[tCO$_2$/MW$_e$h]
ε_c	30.0000	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	25.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	25.0%	[%]
REPIM	**1 154.7393**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	4 680	[m]
$L_{x_{col}}$	2 790	[m]
$SD_{x_{row}}$	990	[m]
SD_{xcol}	630	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 467 325	[kW$_e$h/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 467 325**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 976 018	[$]
Debt payments	3 028 296	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 976 018	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.9604	yr_1	95.0326	yr_{15}
85.6352	yr_2	94.7090	yr_{15}
86.3235	yr_3	95.5141	yr_{16}
86.7856	yr_4	96.4105	yr_{17}
87.4791	yr_5	97.3092	yr_{18}
88.2038	yr_6	98.0881	yr_{19}
88.7765	yr_7	94.5776	yr_{20}
89.4736	yr_8	95.2777	yr_{21}
90.3846	yr_9	96.3240	yr_{22}
90.9728	yr_{10}	97.0898	yr_{23}
91.7927	yr_{11}	98.1035	yr_{25}
92.5018	yr_{12}	92.3690	Mean
93.2294	yr_{13}	4.1890	SD
94.2696	yr_{14}	-0.3343	Υ (skewness)
$LCOE_{wso}$	**92.3690**	**US$/MWh**	valid !
	0.092369	**US$/kWh**	

Figure L.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of L_{wt} *(6D12D)*. Source: Own elaboration

Table L.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of L_{wt} (6D12D)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	639	847 940	6 783 520	3 662 567	6 783 520	777 316	6 783 520	777 316	777 316	4 713 419	6 783 520	6 783 520	777 316	3 662 567	6 783 520	482 342	482 342	3 290 403	4 713 419	7 693 599	1 572 412	1 572 412	7 693 599	6 783 520	4 713 419	4 713 419
March	4.0	1.1671	735	555 090	7 476 817	5 424 310	8 853 970	975 829	7 476 817	975 829	975 829	6 543 367	7 476 817	7 476 817	975 829	5 424 310	8 853 970	894 553	894 553	1 809 568	4 214 966	1 809 568	1 686 232	1 686 232	7 806 630	8 853 970	3 786 671	6 543 367
April	4.7	1.1667	711	865 098	6 327 908	6 327 908	4 076 176	1 630 708	6 327 908	1 630 708	1 630 708	7 230 621	6 327 908	6 327 908	1 749 983	6 327 908	4 076 176	943 697	943 697	1 630 708	6 327 908	1 630 708	3 661 984	943 697	7 230 621	6 327 908	1 749 983	7 230 621
May	6.0	1.1670	735	1 809 500	5 424 109	7 476 539	5 424 109	1 809 500	5 424 109	1 809 500	1 809 500	7 806 340	5 424 109	5 424 109	1 686 169	7 476 539	6 543 124	1 686 169	1 686 169	975 792	8 853 641	975 792	555 069	894 520	6 543 124	4 214 809	1 686 169	7 806 340
June	7.9	1.1686	687	3 944 904	3 944 904	7 306 444	6 124 120	3 544 051	3 944 904	3 544 051	3 544 051	8 286 679	3 944 904	3 944 904	3 544 051	7 306 444	5 076 764	1 693 625	1 693 625	837 237	7 306 444	837 237	837 237	3 544 051	5 076 764	5 076 764	913 305	8 286 679
July	8.6	1.1698	735	5 437 072	3 795 580	8 874 801	1 690 199	4 224 882	3 795 580	4 224 882	4 224 882	556 396	556 396	3 795 580	5 437 072	8 874 801	1 813 825	3 795 580	3 795 580	556 396	7 494 407	556 396	978 125	4 224 882	4 224 882	1 690 199	896 658	556 396
August	9.6	1.1677	735	7 480 694	1 810 506	1 810 506	1 810 506	8 858 561	1 810 506	5 427 123	5 427 123	895 017	895 017	1 810 506	4 217 151	1 810 506	1 687 106	5 427 123	7 810 678	7 810 678	895 017	4 217 151	7 810 678	5 427 123	1 810 506	1 810 506	555 378	895 017
September	10.1	1.1657	711	8 554 384	1 629 176	1 629 176	3 658 543	7 542 482	1 629 176	6 321 963	6 321 963	942 810	942 810	1 629 176	6 321 963	1 629 176	3 658 543	6 321 963	7 223 828	7 223 828	942 810	5 240 771	8 554 384	6 321 963	1 629 176	3 658 543	6 321 963	942 810
October	9.7	1.1645	735	7 789 201	973 650	973 650	553 851	7 460 125	973 650	7 460 125	7 460 125	1 682 467	1 682 467	973 650	8 834 203	973 650	553 851	7 460 125	6 528 759	6 528 759	1 805 528	6 528 759	4 205 556	7 460 125	973 650	973 650	8 834 203	1 682 467
November	9.2	1.1638	687	6 098 939	833 795	833 795	833 795	6 098 939	833 795	7 276 401	7 276 401	1 686 661	1 686 661	833 795	7 276 401	833 795	833 795	7 276 401	5 055 889	5 055 889	1 571 703	6 968 989	6 098 939	7 276 401	833 795	833 795	7 276 401	1 686 661
December	7.6	1.1651	735	3 780 365	554 166	554 166	974 204	5 415 277	554 166	8 839 226	8 839 226	3 780 365	3 780 365	554 166	7 464 366	554 166	974 204	8 839 226	4 207 946	4 207 946	3 780 365	7 793 630	5 415 277	8 839 226	554 166	554 166	7 464 366	3 780 365
Annual	7.4	1.1666	8 579	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354

Table L.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of L_{wt} (6D12D)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	738	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026
February	11.5	1.2345	639	11 923 902	4 233 203	11 923 902	11 923 902	11 923 902	3 369 392	11 923 902	12 538 268	1 770 714	3 369 392	12 538 268	1 770 714	9 115 121	11 923 902	6 580 843	12 538 268	4 233 203	5 409 699	3 369 392	2 776 293	11 923 902	2 077 293	6 580 843	11 923 902	12 538 268
March	10.5	1.2329	735	10 471 380	3 189 384	13 698 087	13 698 087	13 698 087	6 214 620	13 698 087	13 698 087	2 386 378	3 189 384	13 698 087	2 386 378	13 698 087	13 698 087	6 214 620	13 698 087	3 870 731	7 560 022	4 863 071	13 698 087	14 403 865	2 034 182	10 471 380	14 403 865	3 189 384
April	9.5	1.2317	711	7 305 887	7 305 887	10 443 175	10 443 175	10 443 175	7 305 887	10 443 175	4 699 596	3 082 171	7 305 887	13 237 618	3 082 171	13 237 618	4 699 596	4 699 596	13 237 618	3 082 171	10 119 379	3 082 171	13 919 671	13 237 618	3 082 171	3 082 171	13 237 618	3 740 614
May	8.2	1.2282	735	4 844 807	10 432 053	10 432 053	10 432 053	6 191 280	10 432 053	10 432 053	10 432 053	3 856 194	6 191 280	10 432 053	3 856 194	14 349 768	10 432 053	3 856 194	10 432 053	2 377 416	13 646 640	6 191 280	2 377 416	10 432 053	3 856 194	14 349 768	10 432 053	4 844 807
June	7.1	1.2224	687	2 955 541	12 693 755	7 005 728	7 005 728	7 005 728	10 014 121	4 506 515	12 693 755	4 506 515	10 014 121	7 005 728	4 506 515	7 005 728	2 211 411	2 955 541	7 005 728	1 885 038	12 693 755	7 005 728	1 885 038	7 005 728	4 506 515	12 693 755	7 005 728	5 758 970
July	6.1	1.2154	735	2 005 275	13 503 424	4 793 962	6 126 305	10 322 572	13 503 424	7 452 587	3 144 060	6 126 305	2 005 275	6 126 305	6 126 305	6 126 305	2 005 275	2 352 466	6 126 305	6 126 305	14 199 172	10 322 572	3 815 724	6 126 305	6 126 305	13 503 424	3 815 724	7 452 587
August	6.4	1.2075	735	2 337 182	10 583 661	3 790 935	3 790 935	3 790 935	13 415 696	6 086 504	3 790 935	7 404 169	2 337 182	4 762 817	7 404 169	4 762 817	10 583 661	1 992 247	4 762 817	13 415 696	1 992 247	13 415 696	4 762 817	4 762 817	7 404 169	4 762 817	3 123 634	10 255 509
September	7.6	1.2064	711	3 663 832	1 925 451	5 882 434	4 603 129	4 603 129	4 603 129	1 925 451	5 882 434	9 911 660	9 911 660	3 663 832	9 911 660	3 663 832	5 882 434	9 911 660	3 663 832	12 965 892	2 258 821	12 965 892	5 882 434	3 663 832	9 911 660	3 663 832	2 258 821	1 925 451
October	8.9	1.2126	735	6 112 412	6 112 412	3 136 930	2 000 727	3 136 930	2 000 727	2 347 131	7 435 686	13 472 801	13 472 801	3 136 930	13 472 801	3 136 930	7 435 686	13 472 801	3 136 930	10 628 711	3 136 930	2 000 727	7 435 686	3 136 930	13 472 801	2 347 131	2 000 727	2 347 131
November	10.6	1.2194	687	9 990 034	3 578 305	2 206 092	2 206 092	2 206 092	2 206 092	2 948 433	2 206 092	12 663 223	4 495 676	2 206 092	12 663 223	2 206 092	2 948 433	12 663 223	2 206 092	9 680 288	3 578 305	2 206 092	9 680 288	2 206 092	12 663 223	1 880 504	5 745 118	12 663 223
December	11.5	1.2237	735	13 595 706	2 368 542	2 018 979	3 165 547	2 018 979	3 165 547	3 841 801	2 018 979	14 296 210	13 595 706	2 018 979	14 296 210	2 018 979	3 841 801	14 296 210	2 018 979	7 503 518	4 826 724	14 296 210	13 595 706	2 018 979	14 296 210	6 168 172	4 826 724	13 595 706
Annual	9.1	1.2222	8 579	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675

Table L.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of L_{wt} (6D12D)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	639	24 248 099	14 467 424	6 912 583	26 228 520	14 467 424	14 467 424	26 228 520	26 228 520	6 912 583	14 467 424	14 467 424	7 749 925	26 228 520	6 912 583	17 377 262	6 912 583	6 912 583	6 912 583	6 912 583	22 462 574	26 228 520	26 228 520	28 959 584	7 749 925	17 351 256
March	12.7	1.2495	735	18 226 532	18 226 532	8 896 263	27 834 779	12 376 594	18 226 532	27 834 779	27 834 779	8 896 263	12 376 594	18 226 532	9 971 944	27 834 779	8 896 263	30 108 137	8 896 263	8 896 263	8 896 263	8 896 263	22 991 460	27 834 779	27 834 779	31 414 830	9 971 944	18 921 332
April	12.4	1.2490	711	16 057 711	19 287 404	9 641 890	24 828 913	9 641 890	19 287 404	24 828 913	24 828 913	9 641 890	9 641 890	19 287 404	9 641 890	24 828 913	9 641 890	26 913 496	9 641 890	29 111 609	9 641 890	9 641 890	22 185 639	19 971 909	24 828 913	24 919 931	9 641 890	18 139 032
May	11.2	1.2425	735	12 306 614	25 533 644	9 915 560	19 834 848	9 915 560	25 533 644	19 834 848	19 834 848	9 915 560	9 915 560	25 533 644	12 306 614	19 834 848	9 915 560	25 533 644	9 915 560	27 677 395	9 915 560	9 915 560	20 989 216	19 834 848	19 834 848	19 089 277	12 306 614	16 168 320
June	10.4	1.2351	687	9 212 474	25 714 865	11 433 985	16 838 388	8 218 718	25 714 865	16 838 388	16 838 388	11 433 985	8 218 718	25 714 865	15 342 558	16 838 388	11 433 985	16 838 388	11 433 985	23 723 122	11 433 985	11 433 985	16 955 390	16 838 388	16 838 388	16 760 685	15 342 558	14 949 503
July	10.0	1.2275	735	8 739 531	29 577 699	16 314 803	16 314 803	7 795 266	29 577 699	16 314 803	16 314 803	16 314 803	7 795 266	29 577 699	17 905 422	16 314 803	16 314 803	7 795 266	16 314 803	19 596 205	16 314 803	16 314 803	15 530 715	16 046 466	16 314 803	16 760 185	17 905 422	8 625 161
August	9.7	1.2216	735	7 757 712	12 099 972	17 819 161	12 099 972	17 819 161	12 099 972	12 099 972	12 099 972	17 819 161	17 819 161	12 099 972	19 501 798	12 099 972	17 819 161	8 697 428	17 819 161	17 819 161	17 819 161	17 819 161	12 903 119	15 377 861	12 099 972	12 588 985	19 501 798	7 111 908
September	10.4	1.2234	711	9 444 238	7 515 148	18 892 028	9 444 238	26 361 791	7 515 148	9 444 238	9 444 238	18 892 028	26 361 791	7 515 148	24 319 940	9 444 238	18 892 028	9 444 238	18 892 028	15 728 541	18 892 028	18 892 028	12 321 085	13 275 521	9 444 238	8 842 059	24 319 940	19 029 793
October	13.1	1.2327	735	19 679 010	8 776 461	29 702 682	9 837 656	25 333 032	8 776 461	9 837 656	9 837 656	29 702 682	25 333 032	8 776 461	27 459 940	9 837 656	25 333 032	9 837 656	25 333 032	12 209 924	29 702 682	25 333 032	12 242 414	8 858 686	9 837 656	8 122 639	27 459 940	21 596 003
November	14.3	1.2429	687	23 874 256	9 271 165	25 878 688	8 271 078	27 992 285	9 271 165	8 271 078	8 271 078	25 878 688	27 992 285	9 271 165	27 992 285	8 271 078	25 878 688	11 506 828	25 878 688	9 271 165	25 878 688	25 878 688	7 423 013	8 271 078	8 271 078	8 870 902	27 992 285	21 951 058
December	15.1	1.2528	735	30 186 350	9 997 848	25 745 545	7 955 677	19 999 456	9 997 848	7 955 677	7 955 677	25 745 545	19 999 456	9 997 848	32 498 621	7 955 677	30 186 350	16 650 529	30 186 350	9 997 848	25 745 545	30 186 350	6 350 393	7 955 677	7 955 677	9 163 644	32 498 621	42 475 115
Annual	12.5	1.2404	8 579	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415

Table L.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of L_{wt} (6D12D)

Months	v_{wc}	*Wind speed data series for simulations (m/s)*																								
	(m/s)	yr_{1}	yr_{2}	yr_{3}	yr_{4}	yr_{5}	yr_{6}	yr_{7}	yr_{8}	yr_{9}	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table L.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of L_{wt} (6D12D)

Months	v_{wc}	*Wind speed data series for simulations (m/s)*																								
	(m/s)	yr_{1}	yr_{2}	yr_{3}	yr_{4}	yr_{5}	yr_{6}	yr_{7}	yr_{8}	yr_{9}	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table L.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of L_{wt} (6D12D)

Months	v_{wc}	*Wind speed data series for simulations (m/s)*																								
	(m/s)	yr_{1}	yr_{2}	yr_{3}	yr_{4}	yr_{5}	yr_{6}	yr_{7}	yr_{8}	yr_{9}	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table L.7 kWh per H_{prod} with sensitivity analysis of L_{wt} (6D12D)

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 695	5 647	5 674	5 629	5 699	5 647	5 694	5 694	5 637	5 641	5 647	5 693	5 674	5 637	5 718	5 737	5 690	5 649	5 602	5 698	5 682	5 616	5 628	5 645	5 637
Corvo Island (Portugal)	10 451	10 535	10 466	10 473	10 467	10 570	10 498	10 419	10 528	10 530	10 452	10 528	10 510	10 504	10 472	10 452	10 517	10 522	10 556	10 569	10 463	10 523	10 531	10 446	10 392
Cape Saint James (Canada)	24 766	24 852	24 932	24 738	24 788	24 852	24 738	24 738	24 932	24 788	24 852	24 794	24 738	24 940	24 879	24 940	24 908	24 932	24 940	24 841	24 855	24 738	24 888	24 794	24 877

Table L.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of L_{wt} (6D12D)

Item	Years												
	0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 886 763	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 617 258	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	190 628	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	121 530	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866
(+) AAR ($M/yr)	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591
PPAR	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	3 949 354	4 013 810	4 133 691	4 203 326	4 362 211	4 455 206	4 603 527	4 717 836	4 786 683	4 909 110	5 036 592	5 204 091
$O\&M_{fixed}$	-	2 654 580	2 697 998	2 778 673	2 825 574	2 932 475	2 978 079	3 077 743	3 154 685	3 201 236	3 283 628	3 369 415	3 481 990
$O\&M_{variable}$	-	1 294 774	1 315 813	1 355 018	1 377 752	1 429 737	1 477 127	1 525 784	1 563 150	1 585 447	1 625 482	1 667 177	1 722 102
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 480 482	2 542 494	2 606 056	2 671 208	2 737 988	2 806 438	2 876 599	2 948 513	3 022 226	3 097 782	3 175 227	3 254 607
(=) Profit before tax	-	3 691 566	3 780 990	3 877 390	3 971 506	4 075 693	4 148 795	4 256 390	4 363 580	4 469 457	4 582 258	4 698 045	4 819 790
(-) Revenue tax	-	1 289 151	1 310 237	1 349 416	1 372 194	1 424 109	1 446 256	1 494 658	1 532 024	1 554 632	1 594 645	1 636 306	1 690 977
(+) REPIM	387 205	2 045	1 989	1 961	1 910	1 898	1 847	1 829	1 797	1 748	1 720	280	289
REI_{CM}	223 708	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 825	1 765	1 730	1 675	1 654	1 599	1 573	1 535	1 482	1 447	-	-
$OREP_{CM}$	163 497	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	221	224	231	235	244	248	256	262	266	273	280	289
(=) Profit after tax w/out interest	-	2 404 461	2 472 742	2 529 935	2 601 222	2 653 482	2 704 385	2 763 562	2 833 353	2 916 574	2 989 333	3 062 019	3 129 102
(-) Debt payments	-	-	3 210 660	3 290 927	3 373 200	3 457 530	3 543 968	3 632 568	3 723 382	3 816 466	3 911 878	4 009 675	4 109 917
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 480 482	2 542 494	2 606 056	2 671 208	2 737 988	2 806 438	2 876 599	2 948 513	3 022 226	3 097 782	3 175 227	3 254 607
(=) Free net cashflow	-60 499 558	7 506 681	4 491 858	4 599 529	4 722 556	4 827 849	4 933 112	5 048 006	5 174 908	5 316 668	5 449 430	5 583 618	5 713 741
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 992 877	-48 501 019	-43 901 490	-39 178 934	-34 351 085	-29 417 973	-24 369 967	-19 195 059	-13 878 391	-8 428 961	-2 845 343	2 868 398
	$LCOE_{wso}$	*68.32*	*68.47*	*68.68*	*68.84*	*69.10*	*69.28*	*69.53*	*69.75*	*69.92*	*70.15*	*70.38*	*70.66*

Item	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354
(+) AAR ($M/yr)	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
PPAR	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
(-) $O\&M_{WFCM}$	5 315 305	5 412 299	5 626 057	5 784 762	5 880 907	5 983 465	6 080 550	6 339 243	5 846 638	5 922 096	6 082 753	6 252 835	6 398 541
$O\&M_{fixed}$	3 556 919	3 622 342	3 765 928	3 872 685	3 937 571	4 006 755	4 072 279	4 246 052	4 340 155	4 396 740	4 516 587	4 643 449	4 752 225
$O\&M_{variable}$	1 758 385	1 789 958	1 860 129	1 912 077	1 943 336	1 976 710	2 008 271	2 093 190	1 506 483	1 525 356	1 566 166	1 609 385	1 646 316
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 335 972	3 419 372	3 504 856	3 592 477	3 682 289	3 774 347	3 868 705	3 965 423	4 064 558	4 166 172	4 270 327	4 377 085	4 486 512
(=) Profit before tax	4 939 556	5 060 893	5 194 808	4 076 768	4 175 474	4 276 970	4 380 316	4 499 645	3 135 981	3 226 257	3 305 562	3 385 994	3 472 976
(-) Revenue tax	1 727 367	1 759 139	1 828 870	1 880 716	1 912 227	1 945 827	1 977 648	2 062 040	1 475 418	1 494 654	1 535 396	1 578 523	1 615 502
(+) REPIM	296	301	313	322	327	333	339	353	361	365	375	386	395
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	296	301	313	322	327	333	339	353	361	365	375	386	395
(=) Profit after tax w/out interest	3 212 486	3 302 056	3 366 251	2 196 374	2 263 574	2 331 477	2 403 006	2 437 959	1 660 923	1 731 969	1 770 541	1 807 857	1 857 869
(-) Debt payments	4 212 665	4 317 981	4 425 931	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 335 972	3 419 372	3 504 856	3 592 477	3 682 289	3 774 347	3 868 705	3 965 423	4 064 558	4 166 172	4 270 327	4 377 085	4 486 512
(=) Free net cashflow	5 861 740	6 017 542	6 149 625	9 585 911	9 837 849	10 095 109	10 360 729	10 594 625	10 021 506	10 301 566	10 554 378	10 811 290	11 086 388
$\Sigma_{free\ net\ annual\ cashflow}$	8 730 139	14 747 681	20 897 306	30 483 217	40 321 066	50 416 175	60 776 904	71 371 529	81 393 035	91 694 601	102 248 979	113 060 269	124 146 657
$LCOE_{wso}$	*70.89*	*71.10*	*71.44*	*70.47*	*70.66*	*70.86*	*71.06*	*71.42*	*71.03*	*71.21*	*71.48*	*71.77*	*72.03*

Table L.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of L_{wt} (6D12D)

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 886 763	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 617 258	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	190 628	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	121 530	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675
(+) AAR ($M/yr)	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
PPAR	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
(-) $O\&M_{WFCM}$	-	9 368 375	9 679 567	9 856 226	10 109 622	10 355 891	10 719 840	10 911 956	11 100 784	11 497 362	11 787 430	11 992 242	12 380 957	12 668 549	12 977 966	13 261 498	13 567 367	13 991 944	14 348 506	14 755 488	15 142 656	13 154 748	13 560 475	13 910 593	14 143 025	14 421 680
$O\&M_{fixed}$	-	4 871 475	5 033 364	5 125 299	5 257 138	5 385 273	5 574 607	5 674 584	5 772 852	5 979 161	6 130 083	6 236 667	6 438 894	6 588 533	6 749 523	6 897 054	7 056 202	7 277 091	7 462 608	7 674 350	7 875 790	7 991 569	8 238 135	8 450 921	8 592 212	8 761 585
$O\&M_{variable}$	-	4 496 901	4 646 203	4 730 927	4 852 484	4 970 618	5 145 234	5 237 372	5 327 931	5 518 200	5 657 348	5 755 575	5 942 063	6 080 016	6 228 443	6 364 445	6 511 165	6 714 853	6 885 898	7 081 137	7 266 866	5 163 178	5 322 339	5 459 672	5 550 813	5 660 095
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 476 313	2 538 220	2 601 676	2 666 718	2 733 386	2 801 720	2 871 763	2 943 557	3 017 146	3 092 575	3 169 889	3 249 137	3 330 365	3 413 624	3 498 965	3 586 439	3 676 100	3 768 002	3 862 202	3 958 757	4 057 726	4 159 170	4 263 149	4 369 728	4 478 971
(=) Profit before tax	-	8 942 130	9 211 952	9 403 409	9 642 905	9 880 336	10 190 410	10 400 013	10 610 013	10 946 713	11 222 187	11 449 206	11 788 856	12 070 687	12 368 319	12 653 276	11 704 209	12 048 138	12 353 619	12 691 573	13 020 033	8 094 807	8 320 953	8 532 574	8 710 678	8 905 636
(-) Revenue tax	-	4 491 277	4 640 535	4 725 296	4 846 849	4 964 986	5 139 546	5 231 723	5 322 325	5 512 536	5 651 682	5 749 951	5 936 398	6 074 361	6 222 791	6 358 810	6 505 541	6 709 195	6 880 237	7 075 458	7 261 179	5 157 549	5 316 677	5 454 006	5 545 193	5 654 504
(+) REPIM	488 897	1 438	1 420	1 382	1 355	1 327	1 314	1 280	1 245	1 235	1 212	1 180	1 167	1 144	1 123	1 100	164	170	174	179	183	186	192	197	200	204
REI_{CM}	223 708	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 325	1 303	1 263	1 233	1 202	1 184	1 147	1 111	1 095	1 069	1 035	1 017	991	966	939	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	265 188	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	113	117	119	122	125	130	132	134	139	143	145	150	153	157	161	164	170	174	179	183	186	192	197	200	204
(=) Profit after tax w/out interest	-	4 452 291	4 572 837	4 679 495	4 797 411	4 916 677	5 052 177	5 169 569	5 288 933	5 435 411	5 571 717	5 700 436	5 853 625	5 997 470	6 146 651	6 295 566	5 198 832	5 339 113	5 473 556	5 616 294	5 759 037	2 937 445	3 004 468	3 078 766	3 165 686	3 251 336
(-) Debt payments	-	-	3 205 264	3 285 395	3 367 530	3 451 718	3 538 011	3 626 462	3 717 123	3 810 051	3 905 303	4 002 935	4 103 008	4 205 584	4 310 723	4 418 491	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 476 313	2 538 220	2 601 676	2 666 718	2 733 386	2 801 720	2 871 763	2 943 557	3 017 146	3 092 575	3 169 889	3 249 137	3 330 365	3 413 624	3 498 965	3 586 439	3 676 100	3 768 002	3 862 202	3 958 757	4 057 726	4 159 170	4 263 149	4 369 728	4 478 971
(=) Free net cashflow	-60 397 866	9 550 342	6 593 076	6 750 240	6 919 924	7 092 253	7 282 143	7 455 284	7 631 791	7 836 841	8 033 182	8 223 437	8 439 702	8 648 198	8 863 648	9 080 488	12 582 331	12 907 199	13 230 844	13 567 515	13 909 038	11 291 196	11 567 062	11 855 425	12 161 761	12 472 314
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 847 524	-44 254 448	-37 504 208	-30 584 284	-23 492 031	-16 209 888	-8 754 604	-1 122 813	6 714 027	14 747 210	22 970 647	31 410 349	40 058 547	48 922 195	58 002 683	70 585 014	83 492 212	96 723 056	110 290 571	124 199 609	135 490 804	147 057 866	158 913 291	171 075 053	183 547 367
	$LCOE_{wso}$	73.74	74.14	74.40	74.75	75.09	75.55	75.84	76.13	76.63	77.03	77.34	77.84	78.24	78.67	79.07	78.25	78.77	79.22	79.73	80.22	78.34	78.85	79.31	79.66	80.05

Table L.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of L_{wt} (6D12D)

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 886 763	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	2 617 258	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	190 628	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	121 530	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415
(+) AAR ($M/yr)	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
PPAR	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
(-) $O\&M_{WFCM}$	-	20 588 655	21 176 291	21 775 291	22 145 851	22 745 589	23 374 050	23 848 208	24 444 266	25 251 716	25 733 773	26 444 816	27 042 408	27 655 671	28 578 724	29 221 650	30 025 222	30 735 354	31 534 459	32 333 425	33 010 057	29 394 778	29 987 512	30 923 749	31 576 703	32 474 768
$O\&M_{fixed}$	-	11 544 288	11 873 859	12 209 803	12 417 659	12 754 022	13 106 491	13 372 441	13 706 746	14 159 587	14 429 971	14 828 758	15 163 929	15 507 890	16 025 568	16 386 166	16 836 849	17 235 137	17 683 319	18 131 425	18 510 932	18 984 267	19 367 166	19 971 915	20 393 710	20 973 811
$O\&M_{variable}$	-	9 044 366	9 302 432	9 565 487	9 728 192	9 991 568	10 267 558	10 475 767	10 737 520	11 092 129	11 303 802	11 616 058	11 878 478	12 147 781	12 553 156	12 835 484	13 188 373	13 500 217	13 851 140	14 202 000	14 499 125	10 410 511	10 620 346	10 951 834	11 182 993	11 500 957
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 458 034	2 519 484	2 582 471	2 647 033	2 713 209	2 781 039	2 850 565	2 921 829	2 994 875	3 069 747	3 146 491	3 225 153	3 305 782	3 388 426	3 473 137	3 559 965	3 648 965	3 740 189	3 833 693	3 929 536	4 027 774	4 128 468	4 231 680	4 337 472	4 445 909
(=) Profit before tax	-	12 861 791	13 217 341	13 580 240	13 839 411	14 206 972	14 590 084	14 903 984	15 276 730	15 749 861	16 074 658	16 508 117	16 891 591	17 284 990	17 824 705	18 237 379	17 477 111	17 895 483	18 357 327	18 821 392	19 231 093	9 315 887	9 523 387	9 795 208	10 018 647	10 288 835
(-) Revenue tax	-	9 038 743	9 296 789	9 559 826	9 722 575	9 985 940	10 261 916	10 470 150	10 731 904	11 086 468	11 298 174	11 610 416	11 872 849	12 142 164	12 547 493	12 829 835	13 182 710	13 494 562	13 845 479	14 196 337	14 493 484	10 404 867	10 614 729	10 946 183	11 177 363	11 495 308
(+) REPIM	934 726	777	791	806	812	827	843	853	868	890	901	797	815	834	862	881	905	927	951	975	995	1 021	1 041	1 074	1 096	1 128
REI_{CM}	223 708	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	156	153	150	145	142	138	134	131	129	125	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	711 018	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	621	638	656	668	686	705	719	737	761	776	797	815	834	862	881	905	927	951	975	995	1 021	1 041	1 074	1 096	1 128
(=) Profit after tax w/out interest	-	3 823 824	3 921 343	4 021 220	4 117 649	4 221 859	4 329 012	4 434 687	4 545 695	4 664 283	4 777 385	4 898 498	5 019 557	5 143 660	5 278 073	5 408 425	4 295 306	4 401 848	4 512 798	4 626 030	4 738 604	-1 087 960	-1 090 301	-1 149 902	-1 157 620	-1 205 346
(-) Debt payments	-	-	3 181 604	3 261 144	3 342 673	3 426 239	3 511 895	3 599 693	3 689 685	3 781 927	3 876 475	3 973 387	4 072 722	4 174 540	4 278 904	4 385 876	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 458 034	2 519 484	2 582 471	2 647 033	2 713 209	2 781 039	2 850 565	2 921 829	2 994 875	3 069 747	3 146 491	3 225 153	3 305 782	3 388 426	3 473 137	3 559 965	3 648 965	3 740 189	3 833 693	3 929 536	4 027 774	4 128 468	4 231 680	4 337 472	4 445 909
(=) Free net cashflow	-59 952 037	8 903 597	5 946 506	6 097 012	6 245 335	6 402 738	6 564 412	6 725 973	6 894 263	7 071 566	7 244 849	7 427 649	7 611 937	7 800 849	8 001 692	8 200 134	11 652 331	11 942 799	12 242 273	12 548 741	12 859 383	7 235 839	7 441 593	7 595 289	7 806 201	7 982 571
$\Sigma_{free\ net\ annual\ cashflow}$	-	-51 048 440	-45 101 934	-39 004 923	-32 759 587	-26 356 849	-19 792 437	-13 066 463	-6 172 201	899 365	8 144 214	15 571 863	23 183 800	30 984 649	38 986 342	47 186 476	58 838 807	70 781 605	83 023 878	95 572 619	108 432 002	115 667 841	123 109 434	130 704 723	138 510 924	146 493 495
	$LCOE_{wso}$	84.96	85.64	86.32	86.79	87.48	88.20	88.78	89.47	90.38	90.97	91.79	92.50	93.23	94.27	95.03	94.71	95.51	96.41	97.31	98.09	94.58	95.28	96.32	97.09	98.10

APPENDIX M

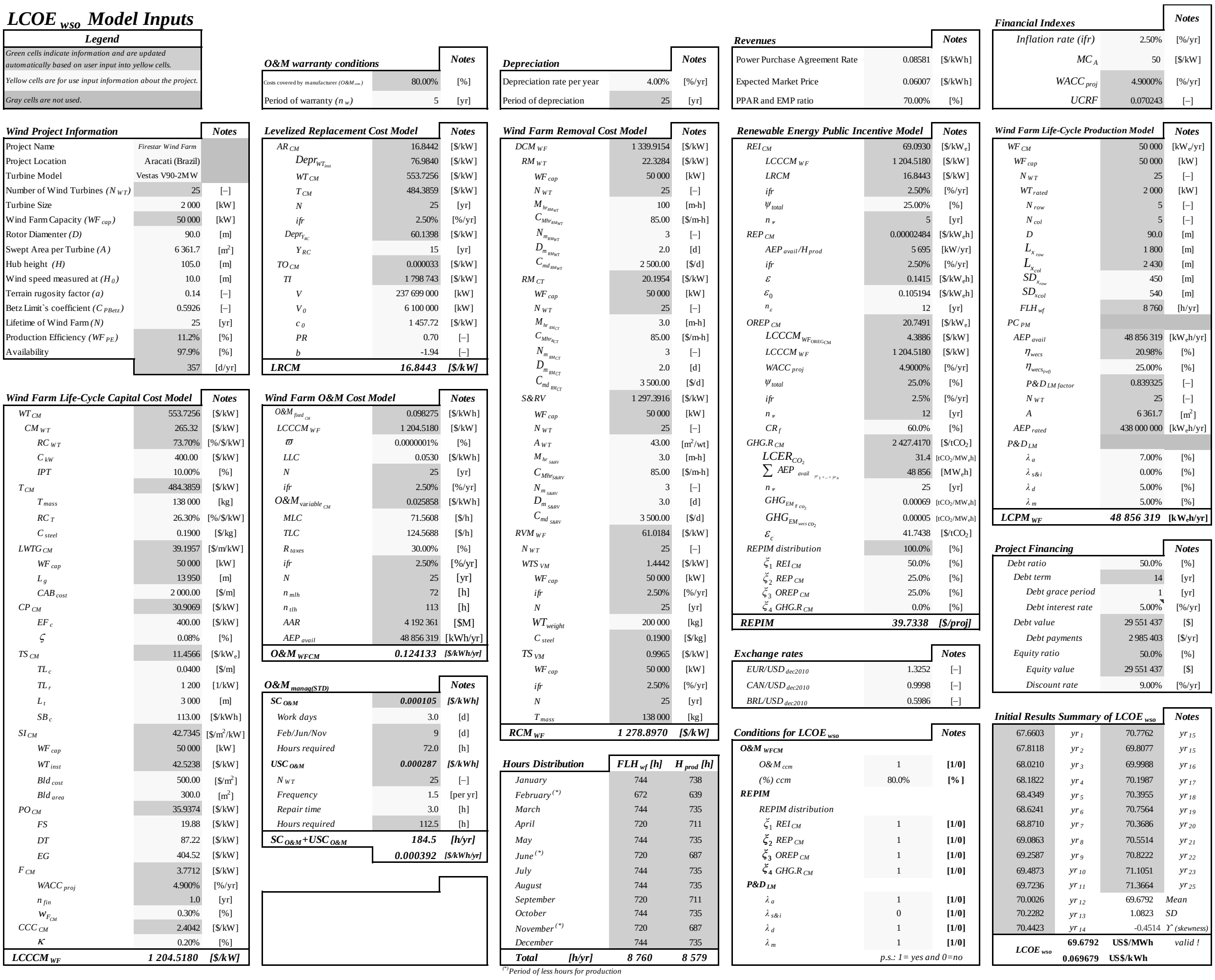

Figure M.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of E_{pi} *(Case $_1$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m^2]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{rec}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{rc}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85.00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2.0	[d]
$C_{md_{RM_{WT}}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2.0	[d]
$C_{md_{RM_{CT}}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m^2/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_{ψ}	5	[yr]
REP_{CM}	0.00000983	[$/kW$_e$h]
AEP_{avail}/H_{prod}	10 451	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1027	[$/kW$_e$h]
ε_0	0.067500	[$/kW$_e$h]
n_{ε}	17	[yr]
$OREP_{CM}$	33.6547	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	3.8789	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	17	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	1 248.5415	[$/tCO$_2$]
$LCER_{CO_2}$	57.6	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	89 657	[MW$_e$h]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00069	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ CO_2}}$	0.00005	[tCO$_2$/MW$_e$h]
ε_c	11.7000	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**42.9602**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	89 657 257	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m^2]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**89 657 257**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m^2/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m^2]
Bld_{area}	300.0	[m^2]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{cm}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{cm}}$	0.048935	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	14 605 780	[$M]
AEP_{avail}	89 657 257	[kWh/yr]
$O\&M_{WFCM}$	**0.147210**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000057**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000156**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000214	**[$/kWh/yr]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 470 778	[$]
Debt payments	2 977 255	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 470 778	[$]
Discount rate	9.00%	[%/yr]

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0 = no	

Initial Results Summary of $LCOE_{wso}$			Notes
73.0793	yr_1	78.4116	yr_{15}
73.4776	yr_2	77.5903	yr_{15}
73.7436	yr_3	78.1098	yr_{16}
74.0885	yr_4	78.5637	yr_{17}
74.4286	yr_5	79.0704	yr_{18}
74.8887	yr_6	79.5598	yr_{19}
75.1794	yr_7	77.6767	yr_{20}
75.4693	yr_8	78.1898	yr_{21}
75.9694	yr_9	78.6500	yr_{22}
76.3656	yr_{10}	78.9953	yr_{23}
76.6792	yr_{11}	79.3896	yr_{25}
77.1795	yr_{12}	76.8138	Mean
77.5814	yr_{13}	2.0085	SD
78.0080	yr_{14}	-0.4651	Υ (skewness)
$LCOE_{wso}$	**76.8138**	**US$/MWh**	valid !
	0.076814	**US$/kWh**	

Figure M.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of E_{pi} *(Case $_1$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RMCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kW_e]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_ψ	5	[yr]
REP_{CM}	0.00000049	[$/kW_eh]
AEP_{avail}/H_{prod}	24 766	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0121	[$/kW_eh]
ε_0	0.008998	[$/kW_eh]
n_ε	12	[yr]
$OREP_{CM}$	90.2343	[$/kW_e]
$LCCCM_{WF_{OREGCM}}$	4.3886	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	12	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	6 827.9067	[$/tCO_2]
$LCER_{CO_2}$	136.4	[tCO_2/MW_eh]
$\sum AEP_{avail\ yr_1+\ldots+yr_n}$	212 467	[MW_eh]
n_ψ	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00069	[tCO_2/MW_eh]
$GHG_{EM_{wecs\ CO_2}}$	0.00005	[tCO_2/MW_eh]
ε_c	27.0000	[$/tCO_2]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**57.1051**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW_e/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 467 325	[kW_eh/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW_eh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 467 325**	**[kW_eh/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW_e]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041531	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	29 394 286	[$M]
AEP_{avail}	212 467 325	[kWh/yr]
$O\&M_{WFCM}$	**0.139806**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	0.000024	[$/kWh]
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	0.000066	[$/kWh]
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000090	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February(*)	672	639
March	744	735
April	720	711
May	744	735
June(*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November(*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 117 155	[$]
Debt payments	2 941 531	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 117 155	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.2996	yr_1	94.3718	yr_{15}
84.9743	yr_2	94.0482	yr_{15}
85.6626	yr_3	94.8532	yr_{16}
86.1247	yr_4	95.7496	yr_{17}
86.8183	yr_5	96.6483	yr_{18}
87.5429	yr_6	97.4272	yr_{19}
88.1156	yr_7	93.9167	yr_{20}
88.8127	yr_8	94.6168	yr_{21}
89.7238	yr_9	95.6632	yr_{22}
90.3120	yr_{10}	96.4289	yr_{23}
91.1318	yr_{11}	97.4427	yr_{25}
91.8409	yr_{12}	91.7081	Mean
92.5685	yr_{13}	4.1890	SD
93.6087	yr_{14}	-0.3343	Υ (skewness)
$LCOE_{wso}$	**91.7081**	**US$/MWh**	valid !
	0.091708	**US$/kWh**	

Figure M.3 *I-O system representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical $50MW_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of E_{pi} *(Case $_1$)*. Source: Own elaboration

Table M.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of E_{pi} $(Case_1)$

Months	v_{wc} (m/s)	ρ (kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	639	847 940	6 783 520	3 662 567	6 783 520	777 316	6 783 520	777 316	777 316	4 713 419	6 783 520	6 783 520	777 316	3 662 567	6 783 520	482 342	482 342	3 290 403	4 713 419	7 693 599	1 572 412	1 572 412	7 693 599	6 783 520	4 713 419	4 713 419
March	4.0	1.1671	735	555 090	7 476 817	5 424 310	8 853 970	975 829	7 476 817	975 829	975 829	6 543 367	7 476 817	7 476 817	975 829	5 424 310	8 853 970	894 553	894 553	1 809 568	4 214 966	1 809 568	1 686 232	1 686 232	7 806 630	8 853 970	3 786 671	6 543 367
April	4.7	1.1667	711	865 098	6 327 908	6 327 908	4 076 176	1 630 708	6 327 908	1 630 708	1 630 708	7 230 621	6 327 908	6 327 908	1 749 983	6 327 908	4 076 176	943 697	943 697	1 630 708	6 327 908	1 630 708	3 661 984	943 697	7 230 621	6 327 908	1 749 983	7 230 621
May	6.0	1.1670	735	1 809 500	5 424 109	7 476 539	5 424 109	1 809 500	5 424 109	1 809 500	1 809 500	7 806 340	5 424 109	5 424 109	1 686 169	7 476 539	6 543 124	1 686 169	1 686 169	975 792	8 853 641	975 792	555 069	894 520	6 543 124	4 214 809	1 686 169	7 806 340
June	7.9	1.1686	687	3 944 904	3 944 904	7 306 444	6 124 120	3 544 051	3 944 904	3 544 051	3 544 051	8 286 679	3 944 904	3 944 904	3 544 051	7 306 444	5 076 764	1 693 625	1 693 625	837 237	7 306 444	837 237	837 237	3 544 051	5 076 764	5 076 764	913 305	8 286 679
July	8.6	1.1698	735	5 437 072	3 795 580	8 874 801	1 690 199	4 224 882	3 795 580	4 224 882	4 224 882	556 396	556 396	3 795 580	5 437 072	8 874 801	1 813 825	3 795 580	3 795 580	556 396	7 494 407	556 396	978 125	4 224 882	4 224 882	1 690 199	896 658	556 396
August	9.6	1.1677	735	7 480 694	1 810 506	1 810 506	1 810 506	8 858 561	1 810 506	5 427 123	5 427 123	895 017	895 017	1 810 506	4 217 151	1 810 506	1 687 106	5 427 123	7 810 678	7 810 678	895 017	4 217 151	7 810 678	5 427 123	1 810 506	1 810 506	555 378	895 017
September	10.1	1.1657	711	8 554 384	1 629 176	1 629 176	3 658 543	7 542 482	1 629 176	6 321 963	6 321 963	942 810	942 810	1 629 176	6 321 963	1 629 176	3 658 543	6 321 963	7 223 828	7 223 828	942 810	5 240 771	8 554 384	6 321 963	1 629 176	3 658 543	6 321 963	942 810
October	9.7	1.1645	735	7 789 201	973 650	973 650	553 851	7 460 125	973 650	7 460 125	7 460 125	1 682 467	1 682 467	973 650	8 834 203	973 650	553 851	7 460 125	6 528 759	6 528 759	1 805 528	6 528 759	4 205 556	7 460 125	973 650	973 650	8 834 203	1 682 467
November	9.2	1.1638	687	6 098 939	833 795	833 795	833 795	6 098 939	833 795	7 276 401	7 276 401	1 686 661	1 686 661	833 795	7 276 401	833 795	833 795	7 276 401	5 055 889	5 055 889	1 571 703	6 968 989	6 098 939	7 276 401	833 795	833 795	7 276 401	1 686 661
December	7.6	1.1651	735	3 780 365	554 166	554 166	974 204	5 415 277	554 166	8 839 226	8 839 226	3 780 365	3 780 365	554 166	7 464 366	554 166	974 204	8 839 226	4 207 946	4 207 946	3 780 365	7 793 630	5 415 277	8 839 226	554 166	554 166	7 464 366	3 780 365
Annual	7.4	1.1666	8 579	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354

Table M.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of E_{pi} $(Case_1)$

Months	v_{wc} (m/s)	ρ (kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	639	24 248 099	14 467 424	6 912 583	26 228 520	14 467 424	14 467 424	26 228 520	26 228 520	6 912 583	14 467 424	14 467 424	7 749 925	26 228 520	6 912 583	17 377 262	6 912 583	6 912 583	6 912 583	6 912 583	22 462 574	26 228 520	26 228 520	28 959 584	7 749 925	17 351 256
March	12.7	1.2495	735	18 226 532	18 226 532	8 896 263	27 834 779	12 376 594	18 226 532	27 834 779	27 834 779	8 896 263	12 376 594	18 226 532	9 971 944	27 834 779	8 896 263	30 108 137	8 896 263	8 896 263	8 896 263	8 896 263	22 991 460	27 834 779	27 834 779	31 414 830	9 971 944	18 921 332
April	12.4	1.2490	711	16 057 711	19 287 404	9 641 890	24 828 913	9 641 890	19 287 404	24 828 913	24 828 913	9 641 890	9 641 890	19 287 404	9 641 890	24 828 913	9 641 890	26 913 496	9 641 890	29 111 609	9 641 890	9 641 890	22 185 639	19 971 909	24 828 913	24 919 931	9 641 890	18 139 032
May	11.2	1.2425	735	12 306 614	25 533 644	9 915 560	19 834 848	9 915 560	25 533 644	19 834 848	19 834 848	9 915 560	9 915 560	25 533 644	12 306 614	19 834 848	9 915 560	25 533 644	9 915 560	27 677 395	9 915 560	9 915 560	20 989 216	19 834 848	19 834 848	19 089 277	12 306 614	16 168 320
June	10.4	1.2351	687	9 212 474	25 714 865	11 433 985	16 838 388	8 218 718	25 714 865	16 838 388	16 838 388	11 433 985	8 218 718	25 714 865	15 342 558	16 838 388	11 433 985	16 838 388	11 433 985	23 723 122	11 433 985	11 433 985	16 955 390	16 838 388	16 838 388	16 760 685	15 342 558	14 949 503
July	10.0	1.2275	735	8 739 531	29 577 699	16 314 803	16 314 803	7 795 266	29 577 699	16 314 803	16 314 803	16 314 803	7 795 266	29 577 699	17 905 422	16 314 803	16 314 803	7 795 266	16 314 803	19 596 205	16 314 803	16 314 803	15 530 715	16 046 466	16 314 803	16 760 185	17 905 422	8 625 161
August	9.7	1.2216	735	7 757 712	12 099 972	17 819 161	12 099 972	17 819 161	12 099 972	12 099 972	12 099 972	17 819 161	17 819 161	12 099 972	19 501 798	12 099 972	17 819 161	8 697 428	17 819 161	17 819 161	17 819 161	17 819 161	12 903 119	15 377 861	12 099 972	12 588 985	19 501 798	7 111 908
September	10.4	1.2234	711	9 444 238	7 515 148	18 892 028	9 444 238	26 361 791	7 515 148	9 444 238	9 444 238	18 892 028	26 361 791	7 515 148	24 319 940	9 444 238	18 892 028	9 444 238	18 892 028	15 728 541	18 892 028	18 892 028	12 321 085	13 275 521	9 444 238	8 842 059	24 319 940	19 029 793
October	13.1	1.2327	735	19 679 010	8 776 461	29 702 682	9 837 656	25 333 032	8 776 461	9 837 656	9 837 656	29 702 682	25 333 032	8 776 461	27 459 940	9 837 656	25 333 032	9 837 656	25 333 032	12 209 924	29 702 682	25 333 032	12 242 414	8 858 686	9 837 656	8 122 639	27 459 940	21 596 003
November	14.3	1.2429	687	23 874 256	9 271 165	25 878 688	8 271 078	27 992 285	9 271 165	8 271 078	8 271 078	25 878 688	27 992 285	9 271 165	27 992 285	8 271 078	25 878 688	11 506 828	25 878 688	9 271 165	25 878 688	25 878 688	7 423 013	8 271 078	8 271 078	8 870 902	27 992 285	21 951 058
December	15.1	1.2528	735	30 186 350	9 997 848	25 745 545	7 955 677	19 999 456	9 997 848	7 955 677	7 955 677	25 745 545	19 999 456	9 997 848	32 498 621	7 955 677	30 186 350	16 650 529	30 186 350	9 997 848	25 745 545	30 186 350	6 350 393	7 955 677	7 955 677	9 163 644	32 498 621	42 475 115
Annual	12.5	1.2404	8 579	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415

Table M.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of E_{pi} $(Case_1)$

Months	v_{wc} (m/s)	ρ (kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	738	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026
February	11.5	1.2345	639	11 923 902	4 233 203	11 923 902	11 923 902	11 923 902	3 369 392	11 923 902	12 538 268	1 770 714	3 369 392	12 538 268	1 770 714	9 115 121	11 923 902	6 580 843	12 538 268	4 233 203	5 409 699	3 369 392	2 776 293	11 923 902	2 077 293	6 580 843	11 923 902	12 538 268
March	10.5	1.2329	735	10 471 380	3 189 384	13 698 087	13 698 087	13 698 087	6 214 620	13 698 087	13 698 087	2 386 378	3 189 384	13 698 087	2 386 378	13 698 087	13 698 087	6 214 620	13 698 087	3 870 731	7 560 022	4 863 071	13 698 087	14 403 865	2 034 182	10 471 380	14 403 865	3 189 384
April	9.5	1.2317	711	7 305 887	7 305 887	10 443 175	10 443 175	10 443 175	7 305 887	10 443 175	4 699 596	3 082 171	7 305 887	13 237 618	3 082 171	13 237 618	4 699 596	4 699 596	13 237 618	3 082 171	10 119 379	3 082 171	13 919 671	13 237 618	3 082 171	3 082 171	13 237 618	3 740 614
May	8.2	1.2282	735	4 844 807	10 432 053	10 432 053	10 432 053	6 191 280	10 432 053	10 432 053	10 432 053	3 856 194	6 191 280	10 432 053	3 856 194	14 349 768	10 432 053	3 856 194	10 432 053	2 377 416	13 646 640	6 191 280	2 377 416	10 432 053	3 856 194	14 349 768	10 432 053	4 844 807
June	7.1	1.2224	687	2 955 541	12 693 755	7 005 728	7 005 728	7 005 728	10 014 121	4 506 515	12 693 755	4 506 515	10 014 121	7 005 728	4 506 515	7 005 728	2 211 411	2 955 541	7 005 728	1 885 038	12 693 755	7 005 728	1 885 038	7 005 728	4 506 515	12 693 755	7 005 728	5 758 970
July	6.1	1.2154	735	2 005 275	13 503 424	4 793 962	6 126 305	10 322 572	13 503 424	7 452 587	3 144 060	6 126 305	2 005 275	6 126 305	6 126 305	6 126 305	2 005 275	2 352 466	6 126 305	6 126 305	14 199 172	10 322 572	3 815 724	6 126 305	6 126 305	13 503 424	3 815 724	7 452 587
August	6.4	1.2075	735	2 337 182	10 583 661	3 790 935	3 790 935	3 790 935	13 415 696	6 086 504	3 790 935	7 404 169	2 337 182	4 762 817	7 404 169	4 762 817	10 583 661	1 992 247	4 762 817	13 415 696	1 992 247	13 415 696	4 762 817	4 762 817	7 404 169	4 762 817	3 123 634	10 255 509
September	7.6	1.2064	711	3 663 832	1 925 451	5 882 434	4 603 129	4 603 129	4 603 129	1 925 451	5 882 434	9 911 660	9 911 660	3 663 832	9 911 660	3 663 832	5 882 434	9 911 660	3 663 832	12 965 892	2 258 821	12 965 892	5 882 434	3 663 832	9 911 660	3 663 832	2 258 821	1 925 451
October	8.9	1.2126	735	6 112 412	6 112 412	3 136 930	2 000 727	3 136 930	2 000 727	2 347 131	7 435 686	13 472 801	13 472 801	3 136 930	13 472 801	3 136 930	7 435 686	13 472 801	3 136 930	10 628 711	3 136 930	2 000 727	7 435 686	3 136 930	13 472 801	2 347 131	2 000 727	2 347 131
November	10.6	1.2194	687	9 990 034	3 578 305	2 206 092	2 206 092	2 206 092	2 206 092	2 948 433	2 206 092	12 663 223	4 495 676	2 206 092	12 663 223	2 206 092	2 948 433	12 663 223	2 206 092	9 680 288	3 578 305	2 206 092	9 680 288	2 206 092	12 663 223	1 880 504	5 745 118	12 663 223
December	11.5	1.2237	735	13 595 706	2 368 542	2 018 979	3 165 547	2 018 979	3 165 547	3 841 801	2 018 979	14 296 210	13 595 706	2 018 979	14 296 210	2 018 979	3 841 801	14 296 210	2 018 979	7 503 518	4 826 724	14 296 210	13 595 706	2 018 979	14 296 210	6 168 172	4 826 724	13 595 706
Annual	9.1	1.2222	8 579	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675

Table M.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of E_{pi} ($Case_{1}$)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_{1}	yr_{2}	yr_{3}	yr_{4}	yr_{5}	yr_{6}	yr_{7}	yr_{8}	yr_{9}	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	*5.8*	*5.8*	*10.1*	*7.6*	*9.6*	*4.0*	*10.1*	*4.0*	*4.0*	*7.9*	*10.1*	*10.1*	*4.0*	*7.6*	*9.6*	*7.9*	*10.1*	*10.1*	*4.0*	*7.6*	*9.6*	*4.0*	*7.6*	*9.6*	*7.9*	*7.9*
February	*4.9*	*4.9*	*9.7*	*7.9*	*9.7*	*4.7*	*9.7*	*4.7*	*4.7*	*8.6*	*9.7*	*9.7*	*4.7*	*7.9*	*9.7*	*4.0*	*4.0*	*7.6*	*8.6*	*10.1*	*6.0*	*6.0*	*10.1*	*9.7*	*8.6*	*8.6*
March	*4.0*	*4.0*	*9.6*	*8.6*	*10.1*	*4.9*	*9.6*	*4.9*	*4.9*	*9.2*	*9.6*	*9.6*	*4.9*	*8.6*	*10.1*	*4.7*	*4.7*	*6.0*	*7.9*	*6.0*	*5.8*	*5.8*	*9.7*	*10.1*	*7.6*	*9.2*
April	*4.7*	*4.7*	*9.2*	*9.2*	*7.9*	*5.8*	*9.2*	*5.8*	*5.8*	*9.6*	*9.2*	*9.2*	*6.0*	*9.2*	*7.9*	*4.9*	*4.9*	*5.8*	*9.2*	*5.8*	*7.6*	*4.9*	*9.6*	*9.2*	*6.0*	*9.6*
May	*6.0*	*6.0*	*8.6*	*9.6*	*8.6*	*6.0*	*8.6*	*6.0*	*6.0*	*9.7*	*8.6*	*8.6*	*5.8*	*9.6*	*9.2*	*5.8*	*5.8*	*4.9*	*10.1*	*4.9*	*4.0*	*4.7*	*9.2*	*7.9*	*5.8*	*9.7*
June	*7.9*	*7.9*	*7.9*	*9.7*	*9.2*	*7.6*	*7.9*	*7.6*	*7.6*	*10.1*	*7.9*	*7.9*	*7.6*	*9.7*	*8.6*	*6.0*	*6.0*	*4.7*	*9.7*	*4.7*	*4.7*	*7.6*	*8.6*	*8.6*	*4.9*	*10.1*
July	*8.6*	*8.6*	*7.6*	*10.1*	*5.8*	*7.9*	*7.6*	*7.9*	*7.9*	*4.0*	*4.0*	*7.6*	*8.6*	*10.1*	*6.0*	*7.6*	*7.6*	*4.0*	*9.6*	*4.0*	*4.9*	*7.9*	*7.9*	*5.8*	*4.7*	*4.0*
August	*9.6*	*9.6*	*6.0*	*6.0*	*6.0*	*10.1*	*6.0*	*8.6*	*8.6*	*4.7*	*4.7*	*6.0*	*7.9*	*6.0*	*5.8*	*8.6*	*9.7*	*9.7*	*4.7*	*7.9*	*9.7*	*8.6*	*6.0*	*6.0*	*4.0*	*4.7*
September	*10.1*	*10.1*	*5.8*	*5.8*	*7.6*	*9.7*	*5.8*	*9.2*	*9.2*	*4.9*	*4.9*	*5.8*	*9.2*	*5.8*	*7.6*	*9.2*	*9.6*	*9.6*	*4.9*	*8.6*	*10.1*	*9.2*	*5.8*	*7.6*	*9.2*	*4.9*
October	*9.7*	*9.7*	*4.9*	*4.9*	*4.0*	*9.6*	*4.9*	*9.6*	*9.6*	*5.8*	*5.8*	*4.9*	*10.1*	*4.9*	*4.0*	*9.6*	*9.2*	*9.2*	*6.0*	*9.2*	*7.9*	*9.6*	*4.9*	*4.9*	*10.1*	*5.8*
November	*9.2*	*9.2*	*4.7*	*4.7*	*4.7*	*9.2*	*4.7*	*9.7*	*9.7*	*6.0*	*6.0*	*4.7*	*9.7*	*4.7*	*4.7*	*9.7*	*8.6*	*8.6*	*5.8*	*9.6*	*9.2*	*9.7*	*4.7*	*4.7*	*9.7*	*6.0*
December	*7.6*	*7.6*	*4.0*	*4.0*	*4.9*	*8.6*	*4.0*	*10.1*	*10.1*	*7.6*	*7.6*	*4.0*	*9.6*	*4.0*	*4.9*	*10.1*	*7.9*	*7.9*	*7.6*	*9.7*	*8.6*	*10.1*	*4.0*	*4.0*	*9.6*	*7.6*
Annual	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*	*7.4*

Table M.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of E_{pi} ($Case_{1}$)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_{1}	yr_{2}	yr_{3}	yr_{4}	yr_{5}	yr_{6}	yr_{7}	yr_{8}	yr_{9}	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	*11.7*	*11.7*	*11.7*	*11.7*	*11.7*	*11.7*	*11.7*	*11.7*	*10.6*	*10.6*	*11.7*	*10.6*	*10.6*	*10.6*	*11.7*	*10.6*	*10.6*	*11.7*	*10.6*	*10.6*	*10.6*	*10.6*	*10.6*	*10.6*	*10.6*	*10.6*
February	*11.5*	*11.5*	*8.2*	*11.5*	*11.5*	*11.5*	*7.6*	*11.5*	*11.7*	*6.1*	*7.6*	*11.7*	*6.1*	*10.5*	*11.5*	*9.5*	*11.7*	*8.2*	*8.9*	*7.6*	*7.1*	*11.5*	*6.4*	*9.5*	*11.5*	*11.7*
March	*10.5*	*10.5*	*7.1*	*11.5*	*11.5*	*11.5*	*8.9*	*11.5*	*11.5*	*6.4*	*7.1*	*11.5*	*6.4*	*11.5*	*11.5*	*8.9*	*11.5*	*7.6*	*9.5*	*8.2*	*11.5*	*11.7*	*6.1*	*10.5*	*11.7*	*7.1*
April	*9.5*	*9.5*	*9.5*	*10.6*	*10.6*	*10.6*	*9.5*	*10.6*	*8.2*	*7.1*	*9.5*	*11.5*	*7.1*	*11.5*	*8.2*	*8.2*	*11.5*	*7.1*	*10.5*	*7.1*	*11.7*	*11.5*	*7.1*	*7.1*	*11.5*	*7.6*
May	*8.2*	*8.2*	*10.5*	*10.5*	*10.5*	*8.9*	*10.5*	*10.5*	*10.5*	*7.6*	*8.9*	*10.5*	*7.6*	*11.7*	*10.5*	*7.6*	*10.5*	*6.4*	*11.5*	*8.9*	*6.4*	*10.5*	*7.6*	*11.7*	*10.5*	*8.2*
June	*7.1*	*7.1*	*11.5*	*9.5*	*9.5*	*9.5*	*10.6*	*8.2*	*11.5*	*8.2*	*10.6*	*9.5*	*8.2*	*9.5*	*6.4*	*7.1*	*9.5*	*6.1*	*11.5*	*9.5*	*6.1*	*9.5*	*8.2*	*11.5*	*9.5*	*8.9*
July	*6.1*	*6.1*	*11.5*	*8.2*	*8.9*	*10.5*	*11.5*	*9.5*	*7.1*	*8.9*	*6.1*	*8.9*	*8.9*	*8.9*	*6.1*	*6.4*	*8.9*	*8.9*	*11.7*	*10.5*	*7.6*	*8.9*	*8.9*	*11.5*	*7.6*	*9.5*
August	*6.4*	*6.4*	*10.6*	*7.6*	*7.6*	*7.6*	*11.5*	*8.9*	*7.6*	*9.5*	*6.4*	*8.2*	*9.5*	*8.2*	*10.6*	*6.1*	*8.2*	*11.5*	*6.1*	*11.5*	*8.2*	*8.2*	*9.5*	*8.2*	*7.1*	*10.5*
September	*7.6*	*7.6*	*6.1*	*8.9*	*8.2*	*8.2*	*8.2*	*6.1*	*8.9*	*10.5*	*10.5*	*7.6*	*10.5*	*7.6*	*8.9*	*10.5*	*7.6*	*11.5*	*6.4*	*11.5*	*8.9*	*7.6*	*10.5*	*7.6*	*6.4*	*6.1*
October	*8.9*	*8.9*	*8.9*	*7.1*	*6.1*	*7.1*	*6.1*	*6.4*	*9.5*	*11.5*	*11.5*	*7.1*	*11.5*	*7.1*	*9.5*	*11.5*	*7.1*	*10.6*	*7.1*	*6.1*	*9.5*	*7.1*	*11.5*	*6.4*	*6.1*	*6.4*
November	*10.6*	*10.6*	*7.6*	*6.4*	*6.4*	*6.4*	*6.4*	*7.1*	*6.4*	*11.5*	*8.2*	*6.4*	*11.5*	*6.4*	*7.1*	*11.5*	*6.4*	*10.5*	*7.6*	*6.4*	*10.5*	*6.4*	*11.5*	*6.1*	*8.9*	*11.5*
December	*11.5*	*11.5*	*6.4*	*6.1*	*7.1*	*6.1*	*7.1*	*7.6*	*6.1*	*11.7*	*11.5*	*6.1*	*11.7*	*6.1*	*7.6*	*11.7*	*6.1*	*9.5*	*8.2*	*11.7*	*11.5*	*6.1*	*11.7*	*8.9*	*8.2*	*11.5*
Annual	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*	*9.1*

Table M.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of E_{pi} ($Case_{1}$)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_{1}	yr_{2}	yr_{3}	yr_{4}	yr_{5}	yr_{6}	yr_{7}	yr_{8}	yr_{9}	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*9.7*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*15.4*	*16.6*	*15.4*	*15.4*	*14.7*	*9.7*	*9.3*
February	*14.7*	*14.7*	*12.4*	*9.7*	*15.1*	*12.4*	*12.4*	*15.1*	*15.1*	*9.7*	*12.4*	*12.4*	*10.0*	*15.1*	*9.7*	*13.1*	*9.7*	*9.7*	*9.7*	*9.7*	*14.3*	*15.1*	*15.1*	*15.6*	*10.0*	*13.1*
March	*12.7*	*12.7*	*12.7*	*10.0*	*14.7*	*11.2*	*12.7*	*14.7*	*14.7*	*10.0*	*11.2*	*12.7*	*10.4*	*14.7*	*10.0*	*15.1*	*10.0*	*10.0*	*10.0*	*10.0*	*13.8*	*14.7*	*14.7*	*15.3*	*10.4*	*12.9*
April	*12.4*	*12.4*	*13.1*	*10.4*	*14.3*	*10.4*	*13.1*	*14.3*	*14.3*	*10.4*	*10.4*	*13.1*	*10.4*	*14.3*	*10.4*	*14.7*	*10.4*	*15.1*	*10.4*	*10.4*	*13.8*	*13.3*	*14.3*	*14.3*	*10.4*	*12.9*
May	*11.2*	*11.2*	*14.3*	*10.4*	*13.1*	*10.4*	*14.3*	*13.1*	*13.1*	*10.4*	*10.4*	*14.3*	*11.2*	*13.1*	*10.4*	*14.3*	*10.4*	*14.7*	*10.4*	*10.4*	*13.4*	*13.1*	*13.1*	*13.0*	*11.2*	*12.3*
June	*10.4*	*10.4*	*14.7*	*11.2*	*12.7*	*10.0*	*14.7*	*12.7*	*12.7*	*11.2*	*10.0*	*14.7*	*12.4*	*12.7*	*11.2*	*12.7*	*11.2*	*14.3*	*11.2*	*11.2*	*12.8*	*12.7*	*12.7*	*12.7*	*12.4*	*12.2*
July	*10.0*	*10.0*	*15.1*	*12.4*	*12.4*	*9.7*	*15.1*	*12.4*	*12.4*	*12.4*	*9.7*	*15.1*	*12.7*	*12.4*	*12.4*	*9.7*	*12.4*	*13.1*	*12.4*	*12.4*	*12.2*	*12.3*	*12.4*	*12.5*	*12.7*	*10.0*
August	*9.7*	*9.7*	*11.2*	*12.7*	*11.2*	*12.7*	*11.2*	*11.2*	*11.2*	*12.7*	*12.7*	*11.2*	*13.1*	*11.2*	*12.7*	*10.0*	*12.7*	*12.7*	*12.7*	*12.7*	*11.4*	*12.1*	*11.2*	*11.4*	*13.1*	*9.4*
September	*10.4*	*10.4*	*9.7*	*13.1*	*10.4*	*14.7*	*9.7*	*10.4*	*10.4*	*13.1*	*14.7*	*9.7*	*14.3*	*10.4*	*13.1*	*10.4*	*13.1*	*12.4*	*13.1*	*13.1*	*11.4*	*11.7*	*10.4*	*10.2*	*14.3*	*13.2*
October	*13.1*	*13.1*	*10.0*	*15.1*	*10.4*	*14.3*	*10.0*	*10.4*	*10.4*	*15.1*	*14.3*	*10.0*	*14.7*	*10.4*	*14.3*	*10.4*	*14.3*	*11.2*	*15.1*	*14.3*	*11.2*	*10.1*	*10.4*	*9.8*	*14.7*	*13.5*
November	*14.3*	*14.3*	*10.4*	*14.7*	*10.0*	*15.1*	*10.4*	*10.0*	*10.0*	*14.7*	*15.1*	*10.4*	*15.1*	*10.0*	*14.7*	*11.2*	*14.7*	*10.4*	*14.7*	*14.7*	*9.7*	*10.0*	*10.0*	*10.3*	*15.1*	*13.9*
December	*15.1*	*15.1*	*10.4*	*14.3*	*9.7*	*13.1*	*10.4*	*9.7*	*9.7*	*14.3*	*13.1*	*10.4*	*15.4*	*9.7*	*15.1*	*12.4*	*15.1*	*10.4*	*14.3*	*15.1*	*9.0*	*9.7*	*9.7*	*10.1*	*15.4*	*16.9*
Annual	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*	*12.5*

Table M.7 kWh per H_{prod} with sensitivity analysis of E_{pi} $(Case_1)$

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	*5 695*	*5 647*	*5 674*	*5 629*	*5 699*	*5 647*	*5 694*	*5 694*	*5 637*	*5 641*	*5 647*	*5 693*	*5 674*	*5 637*	*5 718*	*5 737*	*5 690*	*5 649*	*5 602*	*5 698*	*5 682*	*5 616*	*5 628*	*5 645*	*5 637*
Corvo Island (Portugal)	*10 451*	*10 535*	*10 466*	*10 473*	*10 467*	*10 570*	*10 498*	*10 419*	*10 528*	*10 530*	*10 452*	*10 528*	*10 510*	*10 504*	*10 472*	*10 452*	*10 517*	*10 522*	*10 556*	*10 569*	*10 463*	*10 523*	*10 531*	*10 446*	*10 392*
Cape Saint James (Canada)	*24 766*	*24 852*	*24 932*	*24 738*	*24 788*	*24 852*	*24 738*	*24 738*	*24 932*	*24 788*	*24 852*	*24 794*	*24 738*	*24 940*	*24 879*	*24 940*	*24 908*	*24 932*	*24 940*	*24 841*	*24 855*	*24 738*	*24 888*	*24 794*	*24 877*

Table M.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of E_{pi} $(Case_1)$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354
(+) AAR ($M/yr)	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
PPAR	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
(-) $O\&M_{WFCM}$	-	3 949 353	4 013 810	4 133 691	4 203 326	4 362 211	4 455 205	4 603 526	4 717 835	4 786 682	4 909 110	5 036 591	5 204 091	5 315 304	5 412 299	5 626 056	5 784 761	5 880 906	5 983 464	6 080 550	6 339 242	5 846 637	5 922 095	6 082 752	6 252 834	6 398 541
$O\&M_{fixed}$	-	2 654 579	2 697 997	2 778 672	2 825 574	2 932 474	2 978 078	3 077 743	3 154 685	3 201 236	3 283 628	3 369 414	3 481 989	3 556 919	3 622 341	3 765 927	3 872 684	3 937 570	4 006 754	4 072 279	4 246 052	4 340 155	4 396 739	4 516 586	4 643 449	4 752 224
$O\&M_{variable}$	-	1 294 774	1 315 813	1 355 018	1 377 752	1 429 737	1 477 127	1 525 784	1 563 150	1 585 447	1 625 482	1 667 177	1 722 102	1 758 385	1 789 958	1 860 129	1 912 077	1 943 336	1 976 710	2 008 271	2 093 190	1 506 483	1 525 356	1 566 166	1 609 385	1 646 316
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 423 218	2 483 798	2 545 893	2 609 541	2 674 779	2 741 649	2 810 190	2 880 445	2 952 456	3 026 267	3 101 924	3 179 472	3 258 959	3 340 433	3 423 943	3 509 542	3 597 281	3 687 213	3 779 393	3 873 878	3 970 725	4 069 993	4 171 743	4 276 036	4 382 937
(=) Profit before tax	-	3 634 303	3 722 295	3 817 228	3 909 840	4 012 485	4 084 007	4 189 982	4 295 512	4 399 687	4 510 744	4 624 743	4 744 655	4 862 543	4 981 955	5 113 896	3 993 834	4 090 466	4 189 837	4 291 004	4 408 101	3 042 148	3 130 078	3 206 978	3 284 946	3 369 401
(-) Revenue tax	-	1 289 151	1 310 237	1 349 416	1 372 194	1 424 109	1 446 256	1 494 658	1 532 024	1 554 632	1 594 645	1 636 306	1 690 977	1 727 367	1 759 139	1 828 870	1 880 716	1 912 227	1 945 827	1 977 648	2 062 040	1 475 418	1 494 654	1 535 396	1 578 523	1 615 502
(+) REPIM	1 123 026	1 725	1 669	1 636	1 584	1 564	1 512	1 487	1 451	1 402	1 368	1 336	1 315	-	-	-	-	-	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 725	1 669	1 636	1 584	1 564	1 512	1 487	1 451	1 402	1 368	1 336	1 315	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	259 364	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	2 346 877	2 413 727	2 469 448	2 539 230	2 589 940	2 639 262	2 696 812	2 764 939	2 846 457	2 917 467	2 989 773	3 054 992	3 135 177	3 222 816	3 285 026	2 113 118	2 178 238	2 244 010	2 313 356	2 346 061	1 566 730	1 635 424	1 671 582	1 706 423	1 753 900
(-) Debt payments	-	-	3 136 540	3 214 953	3 295 327	3 377 710	3 462 153	3 548 707	3 637 424	3 728 360	3 821 569	3 917 108	4 015 036	4 115 412	4 218 297	4 323 754	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 423 218	2 483 798	2 545 893	2 609 541	2 674 779	2 741 649	2 810 190	2 880 445	2 952 456	3 026 267	3 101 924	3 179 472	3 258 959	3 340 433	3 423 943	3 509 542	3 597 281	3 687 213	3 779 393	3 873 878	3 970 725	4 069 993	4 171 743	4 276 036	4 382 937
(=) Free net cashflow	-59 102 874	7 391 834	4 448 268	4 554 852	4 676 769	4 780 918	4 885 015	4 998 708	5 124 382	5 264 887	5 396 358	5 530 636	5 659 377	5 804 671	5 959 048	6 089 664	9 419 719	9 667 505	9 920 509	10 181 766	10 411 182	9 833 479	10 108 842	10 356 835	10 608 807	10 878 844
$\Sigma_{free\ net\ annual\ cashflow}$	-	-51 711 040	-47 262 772	-42 707 920	-38 031 151	-33 250 232	-28 365 217	-23 366 509	-18 242 126	-12 977 239	-7 580 881	-2 050 245	3 609 132	9 413 803	15 372 851	21 462 514	30 882 234	40 549 739	50 470 247	60 652 014	71 063 196	80 896 674	91 005 516	101 362 351	111 971 158	122 850 002
	$LCOE_{wso}$	*67.66*	*67.81*	*68.02*	*68.18*	*68.43*	*68.62*	*68.87*	*69.09*	*69.26*	*69.49*	*69.72*	*70.00*	*70.23*	*70.44*	*70.78*	*69.81*	*70.00*	*70.20*	*70.40*	*70.76*	*70.37*	*70.55*	*70.82*	*71.11*	*71.37*

Table M.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of E_{pi} $(Case_{1})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675
(+) AAR ($M/yr)	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
PPAR	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
(-) $O\&M_{WFCM}$	-	9 368 374	9 679 566	9 856 225	10 109 621	10 355 890	10 719 839	10 911 955	11 100 782	11 497 361	11 787 429	11 992 241	12 380 956	12 668 548	12 977 965	13 261 497	13 567 366	13 991 943	14 348 504	14 755 487	15 142 655	13 154 746	13 560 473	13 910 592	14 143 024	14 421 679
$O\&M_{fixed}$	-	4 871 474	5 033 363	5 125 297	5 257 137	5 385 272	5 574 606	5 674 583	5 772 851	5 979 160	6 130 081	6 236 666	6 438 893	6 588 532	6 749 522	6 897 052	7 056 201	7 277 090	7 462 607	7 674 349	7 875 789	7 991 568	8 238 134	8 450 920	8 592 210	8 761 584
$O\&M_{variable}$	-	4 496 901	4 646 203	4 730 927	4 852 484	4 970 618	5 145 234	5 237 372	5 327 931	5 518 200	5 657 348	5 755 575	5 942 063	6 080 016	6 228 443	6 364 445	6 511 165	6 714 853	6 885 898	7 081 137	7 266 866	5 163 178	5 322 339	5 459 672	5 550 813	5 660 095
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 416 604	2 477 019	2 538 944	2 602 418	2 667 478	2 734 165	2 802 519	2 872 582	2 944 397	3 018 007	3 093 457	3 170 794	3 250 063	3 331 315	3 414 598	3 499 963	3 587 462	3 677 148	3 769 077	3 863 304	3 959 887	4 058 884	4 160 356	4 264 365	4 370 974
(=) Profit before tax	-	8 882 422	9 150 752	9 340 679	9 578 606	9 814 430	10 122 856	10 330 770	10 539 039	10 873 965	11 147 620	11 372 775	11 710 514	11 990 387	12 286 011	12 568 910	11 617 734	11 959 501	12 262 766	12 598 449	12 924 581	7 996 969	8 220 669	8 429 783	8 605 316	8 797 640
(-) Revenue tax	-	4 491 277	4 640 535	4 725 296	4 846 849	4 964 986	5 139 546	5 231 723	5 322 325	5 512 536	5 651 682	5 749 951	5 936 398	6 074 361	6 222 791	6 358 810	6 505 541	6 709 195	6 880 237	7 075 458	7 261 179	5 157 549	5 316 677	5 454 006	5 545 193	5 654 504
(+) REPIM	1 284 346	1 253	1 232	1 194	1 166	1 136	1 120	1 085	1 050	1 036	1 011	979	962	937	913	888	865	849	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 253	1 232	1 194	1 166	1 136	1 120	1 085	1 050	1 036	1 011	979	962	937	913	888	865	849	-	-	-	-	-	-	-	-
$OREP_{CM}$	420 684	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	4 392 398	4 511 449	4 616 576	4 732 922	4 850 580	4 984 429	5 100 131	5 217 764	5 362 464	5 496 949	5 623 803	5 775 078	5 916 962	6 064 133	6 210 988	5 113 058	5 251 155	5 382 529	5 522 991	5 663 401	2 839 420	2 903 991	2 975 777	3 060 124	3 143 137
(-) Debt payments	-	-	3 127 978	3 206 178	3 286 332	3 368 491	3 452 703	3 539 021	3 627 496	3 718 183	3 811 138	3 906 416	4 004 077	4 104 179	4 206 783	4 311 953	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 416 604	2 477 019	2 538 944	2 602 418	2 667 478	2 734 165	2 802 519	2 872 582	2 944 397	3 018 007	3 093 457	3 170 794	3 250 063	3 331 315	3 414 598	3 499 963	3 587 462	3 677 148	3 769 077	3 863 304	3 959 887	4 058 884	4 160 356	4 264 365	4 370 974
(=) Free net cashflow	-58 941 555	9 430 740	6 547 771	6 703 807	6 872 334	7 043 477	7 232 149	7 404 043	7 579 274	7 783 012	7 978 011	8 166 891	8 381 743	8 588 794	8 802 761	9 018 082	12 410 080	12 730 603	13 048 963	13 381 086	13 717 949	11 095 331	11 366 300	11 649 644	11 950 837	12 256 118
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 510 815	-42 963 043	-36 259 236	-29 386 902	-22 343 426	-15 111 277	-7 707 234	-127 959	7 655 053	15 633 064	23 799 955	32 181 698	40 770 491	49 573 252	58 591 334	71 001 414	83 732 018	96 780 981	110 162 067	123 880 016	134 975 347	146 341 647	157 991 290	169 942 128	182 198 245
	$LCOE_{wso}$	73.08	73.48	73.74	74.09	74.43	74.89	75.18	75.47	75.97	76.37	76.68	77.18	77.58	78.01	78.41	77.59	78.11	78.56	79.07	79.56	77.68	78.19	78.65	79.00	79.39

Table M.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of E_{pi} $(Case_{1})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415
(+) AAR ($M/yr)	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
PPAR	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
(-) $O\&M_{WFCM}$	-	20 588 652	21 176 288	21 775 288	22 145 848	22 745 587	23 374 047	23 848 205	24 444 263	25 251 713	25 733 770	26 444 813	27 042 405	27 655 668	28 578 721	29 221 647	30 025 220	30 735 351	31 534 456	32 333 422	33 010 054	29 394 775	29 987 509	30 923 746	31 576 700	32 474 765
$O\&M_{fixed}$	-	11 544 286	11 873 856	12 209 801	12 417 656	12 754 019	13 106 489	13 372 438	13 706 743	14 159 584	14 429 968	14 828 755	15 163 927	15 507 888	16 025 565	16 386 164	16 836 847	17 235 134	17 683 316	18 131 422	18 510 929	18 984 265	19 367 163	19 971 913	20 393 707	20 973 809
$O\&M_{variable}$	-	9 044 366	9 302 432	9 565 487	9 728 192	9 991 568	10 267 558	10 475 767	10 737 520	11 092 129	11 303 802	11 616 058	11 878 478	12 147 781	12 553 156	12 835 484	13 188 373	13 500 217	13 851 140	14 202 000	14 499 125	10 410 511	10 620 346	10 951 834	11 182 993	11 500 957
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 387 607	2 447 297	2 508 479	2 571 191	2 635 471	2 701 358	2 768 892	2 838 114	2 909 067	2 981 794	3 056 338	3 132 747	3 211 066	3 291 342	3 373 626	3 457 966	3 544 416	3 633 026	3 723 852	3 816 948	3 912 372	4 010 181	4 110 435	4 213 196	4 318 526
(=) Profit before tax	-	12 791 367	13 145 157	13 506 251	13 763 572	14 129 237	14 510 406	14 822 313	15 193 018	15 664 056	15 986 708	16 417 967	16 799 188	17 190 277	17 727 624	18 137 871	17 375 115	17 790 937	18 250 167	18 711 553	19 118 508	9 200 487	9 405 103	9 673 966	9 894 374	10 161 455
(-) Revenue tax	-	9 038 743	9 296 789	9 559 826	9 722 575	9 985 940	10 261 916	10 470 150	10 731 904	11 086 468	11 298 174	11 610 416	11 872 849	12 142 164	12 547 493	12 829 835	13 182 710	13 494 562	13 845 479	14 196 337	14 493 484	10 404 867	10 614 729	10 946 183	11 177 363	11 495 308
(+) REPIM	1 991 590	148	144	141	137	134	131	127	124	122	118	116	113	-	-	-	-	-	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	148	144	141	137	134	131	127	124	122	118	116	113	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	1 127 928	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	3 752 771	3 848 512	3 946 566	4 041 134	4 143 431	4 248 621	4 352 291	4 461 238	4 577 710	4 688 652	4 807 667	4 926 451	5 048 113	5 180 130	5 308 036	4 192 404	4 296 375	4 404 688	4 515 216	4 625 024	-1 204 380	-1 209 627	-1 272 217	-1 282 989	-1 333 853
(-) Debt payments	-	-	3 090 446	3 167 707	3 246 899	3 328 072	3 411 274	3 496 556	3 583 969	3 673 569	3 765 408	3 859 543	3 956 032	4 054 932	4 156 306	4 260 213	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 387 607	2 447 297	2 508 479	2 571 191	2 635 471	2 701 358	2 768 892	2 838 114	2 909 067	2 981 794	3 056 338	3 132 747	3 211 066	3 291 342	3 373 626	3 457 966	3 544 416	3 633 026	3 723 852	3 816 948	3 912 372	4 010 181	4 110 435	4 213 196	4 318 526
(=) Free net cashflow	-58 234 310	8 762 117	5 892 645	6 041 803	6 188 752	6 344 739	6 504 962	6 665 040	6 831 807	7 007 542	7 179 230	7 360 510	7 543 115	7 730 193	7 929 263	8 125 897	11 447 430	11 732 777	12 026 999	12 328 086	12 633 215	7 004 016	7 203 979	7 351 729	7 556 555	7 726 680
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 472 193	-43 579 548	-37 537 745	-31 348 993	-25 004 254	-18 499 292	-11 834 252	-5 002 446	2 005 097	9 184 327	16 544 837	24 087 952	31 818 145	39 747 408	47 873 305	59 320 735	71 053 512	83 080 511	95 408 597	108 041 812	115 045 828	122 249 807	129 601 536	137 158 092	144 884 772
	$LCOE_{wso}$	84.30	84.97	85.66	86.12	86.82	87.54	88.12	88.81	89.72	90.31	91.13	91.84	92.57	93.61	94.37	94.05	94.85	95.75	96.65	97.43	93.92	94.62	95.66	96.43	97.44

APPENDIX N

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]
	337 039	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (α)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	67.4078	[$/kWₑ]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	20.00%	[%]
n_ψ	4	[yr]
REP_{CM}	0.00002465	[$/kWₑh]
AEP_{avail}/H_{prod}	5 695	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1404	[$/kWₑh]
ε_0	0.099350	[$/kWₑh]
n_ε	14	[yr]
$OREP_{CM}$	23.6992	[$/kWₑ]
$LCCCM_{WF_{OREGCM}}$	5.0125	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	20.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	14	[yr]
CR_f	40.0%	[%]
$GHG.R_{CM}$	2 910.3377	[$/tCO₂]
$LCER_{CO_2}$	39.8	[tCO₂/MWₑh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	48 856	[MWₑh]
n_ψ	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0.00089	[tCO₂/MWₑh]
$GHG_{EM_{wecs\,CO_2}}$	0.00008	[tCO₂/MWₑh]
ε_c	39.4247	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	10.0%	[%]
ξ_2 REP_{CM}	50.0%	[%]
ξ_3 $OREP_{CM}$	20.0%	[%]
ξ_4 $GHG.R_{CM}$	20.0%	[%]
REPIM	**593.5482**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWₑ/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	48 856 319	[kWₑh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWₑh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**48 856 319**	**[kWₑh/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWₑ]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025858	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	4 192 361	[$M]
AEP_{avail}	48 856 319	[kWh/yr]
$O\&M_{WFCM}$	**0.124133**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000105**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000287**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000392	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 977 602	[$]
Debt payments	3 028 456	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 977 602	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67.6603	yr_1	70.7762	yr_{15}
67.8118	yr_2	69.8077	yr_{15}
68.0210	yr_3	69.9988	yr_{16}
68.1822	yr_4	70.1987	yr_{17}
68.4349	yr_5	70.3955	yr_{18}
68.6241	yr_6	70.7564	yr_{19}
68.8710	yr_7	70.3686	yr_{20}
69.0863	yr_8	70.5514	yr_{21}
69.2587	yr_9	70.8222	yr_{22}
69.4873	yr_{10}	71.1051	yr_{23}
69.7236	yr_{11}	71.3664	yr_{25}
70.0026	yr_{12}	69.6792	Mean
70.2282	yr_{13}	1.0823	SD
70.4423	yr_{14}	-0.4514	ϒ (skewness)
$LCOE_{wso}$	**69.6792**	**US$/MWh**	valid !
	0.069679	**US$/kWh**	

Figure N.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of E_{pi} *(Case* $_2$*)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer (O&M $_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit´s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWₑ]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048935	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	14 605 780	[$M]
AEP_{avail}	89 657 257	[kWh/yr]
$O\&M_{WFCM}$	**0.147210**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000057**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000156**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000214	**[$/kWh/yr]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Renewable Energy Public Incentive Model		Notes
REI_{CM}	67.4078	[$/kWₑ]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	20.00%	[%]
n_ψ	4	[yr]
REP_{CM}	0.00000951	[$/kWₑh]
AEP_{avail}/H_{prod}	10 451	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0994	[$/kWₑh]
ε_0	0.063750	[$/kWₑh]
n_ε	18	[yr]
$OREP_{CM}$	39.4006	[$/kWₑ]
$LCCCM_{WF_{OREGCM}}$	4.5411	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	20.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	18	[yr]
CR_f	40.0%	[%]
$GHG.R_{CM}$	1 496.9316	[$/tCO₂]
$LCER_{CO_2}$	73.1	[tCO₂/MWₑh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	89 657	[MWₑh]
n_ψ	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00089	[tCO₂/MWₑh]
$GHG_{EM_{wecs\ CO_2}}$	0.00008	[tCO₂/MWₑh]
ε_c	11.0500	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	10.0%	[%]
ξ_2 REP_{CM}	50.0%	[%]
ξ_3 $OREP_{CM}$	20.0%	[%]
ξ_4 $GHG.R_{CM}$	20.0%	[%]
REPIM	**314.0072**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWₑ/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	89 657 257	[kWₑh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWₑh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**89 657 257**	**[kWₑh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 899 095	[$]
Debt payments	3 020 525	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 899 095	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.0793	yr_1	78.4116	yr_{15}
73.4776	yr_2	77.5903	yr_{15}
73.7436	yr_3	78.1098	yr_{16}
74.0885	yr_4	78.5637	yr_{17}
74.4286	yr_5	79.0704	yr_{18}
74.8887	yr_6	79.5598	yr_{19}
75.1794	yr_7	77.6767	yr_{20}
75.4693	yr_8	78.1898	yr_{21}
75.9694	yr_9	78.6500	yr_{22}
76.3656	yr_{10}	78.9953	yr_{23}
76.6792	yr_{11}	79.3896	yr_{25}
77.1795	yr_{12}	76.8138	Mean
77.5814	yr_{13}	2.0085	SD
78.0080	yr_{14}	-0.4651	Υ (skewness)
$LCOE_{wso}$	**76.8138**	**US$/MWh**	valid !
	0.076814	**US$/kWh**	

Figure N.2 *I-O system representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical 50MWₑ wind farm in Corvo Island (Portugal) with sensitivity analysis of *E_{pi} (Case $_2$)*. Source: Own elaboration

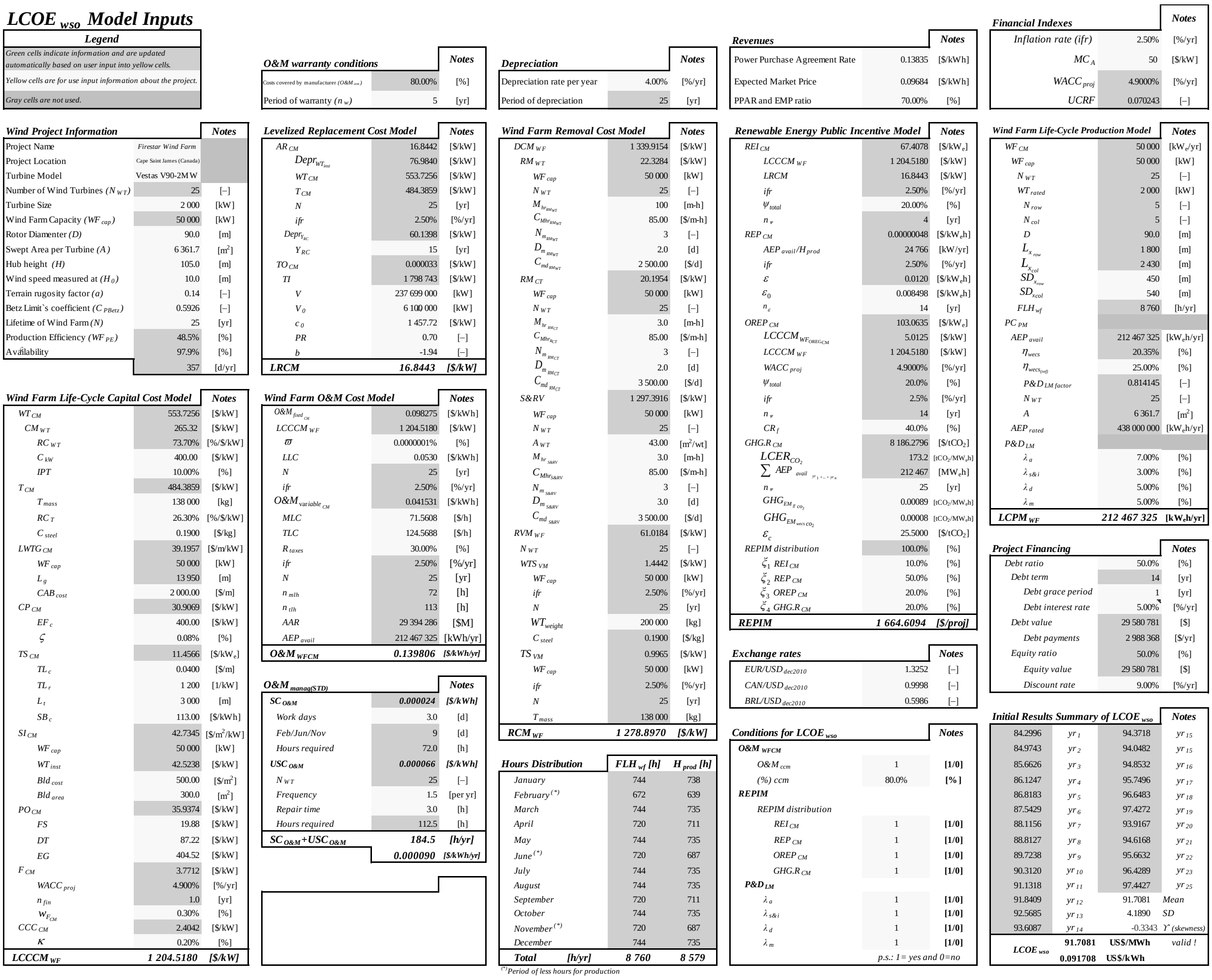

Figure N.3 *I-O system representation* of *LCOE$_{wso}$ algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of E_{pi} *(Case $_2$)*. Source: Own elaboration

Table N.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of E_{pi} ($Case_2$)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	639	847 940	6 783 520	3 662 567	6 783 520	777 316	6 783 520	777 316	777 316	4 713 419	6 783 520	6 783 520	777 316	3 662 567	6 783 520	482 342	482 342	3 290 403	4 713 419	7 693 599	1 572 412	1 572 412	7 693 599	6 783 520	4 713 419	4 713 419
March	4.0	1.1671	735	555 090	7 476 817	5 424 310	8 853 970	975 829	7 476 817	975 829	975 829	6 543 367	7 476 817	7 476 817	975 829	5 424 310	8 853 970	894 553	894 553	1 809 568	4 214 966	1 809 568	1 686 232	1 686 232	7 806 630	8 853 970	3 786 671	6 543 367
April	4.7	1.1667	711	865 098	6 327 908	6 327 908	4 076 176	1 630 708	6 327 908	1 630 708	1 630 708	7 230 621	6 327 908	6 327 908	1 749 983	6 327 908	4 076 176	943 697	943 697	1 630 708	6 327 908	1 630 708	3 661 984	943 697	7 230 621	6 327 908	1 749 983	7 230 621
May	6.0	1.1670	735	1 809 500	5 424 109	7 476 539	5 424 109	1 809 500	5 424 109	1 809 500	1 809 500	7 806 340	5 424 109	5 424 109	1 686 169	7 476 539	6 543 124	1 686 169	1 686 169	975 792	8 853 641	975 792	555 069	894 520	6 543 124	4 214 809	1 686 169	7 806 340
June	7.9	1.1686	687	3 944 904	3 944 904	7 306 444	6 124 120	3 544 051	3 944 904	3 544 051	3 544 051	8 286 679	3 944 904	3 944 904	3 544 051	7 306 444	5 076 764	1 693 625	1 693 625	837 237	7 306 444	837 237	837 237	3 544 051	5 076 764	5 076 764	913 305	8 286 679
July	8.6	1.1698	735	5 437 072	3 795 580	8 874 801	1 690 199	4 224 882	3 795 580	4 224 882	4 224 882	556 396	556 396	3 795 580	5 437 072	8 874 801	1 813 825	3 795 580	3 795 580	556 396	7 494 407	556 396	978 125	4 224 882	4 224 882	1 690 199	896 658	556 396
August	9.6	1.1677	735	7 480 694	1 810 506	1 810 506	1 810 506	8 858 561	1 810 506	5 427 123	5 427 123	895 017	895 017	1 810 506	4 217 151	1 810 506	1 687 106	5 427 123	7 810 678	7 810 678	895 017	4 217 151	7 810 678	5 427 123	1 810 506	1 810 506	555 378	895 017
September	10.1	1.1657	711	8 554 384	1 629 176	1 629 176	3 658 543	7 542 482	1 629 176	6 321 963	6 321 963	942 810	942 810	1 629 176	6 321 963	1 629 176	3 658 543	6 321 963	7 223 828	7 223 828	942 810	5 240 771	8 554 384	6 321 963	1 629 176	3 658 543	6 321 963	942 810
October	9.7	1.1645	735	7 789 201	973 650	973 650	553 851	7 460 125	973 650	7 460 125	7 460 125	1 682 467	1 682 467	973 650	8 834 203	973 650	553 851	7 460 125	6 528 759	6 528 759	1 805 528	6 528 759	4 205 556	7 460 125	973 650	973 650	8 834 203	1 682 467
November	9.2	1.1638	687	6 098 939	833 795	833 795	833 795	6 098 939	833 795	7 276 401	7 276 401	1 686 661	1 686 661	833 795	7 276 401	833 795	833 795	7 276 401	5 055 889	5 055 889	1 571 703	6 968 989	6 098 939	7 276 401	833 795	833 795	7 276 401	1 686 661
December	7.6	1.1651	735	3 780 365	554 166	554 166	974 204	5 415 277	554 166	8 839 226	8 839 226	3 780 365	3 780 365	554 166	7 464 366	554 166	974 204	8 839 226	4 207 946	4 207 946	3 780 365	7 793 630	5 415 277	8 839 226	554 166	554 166	7 464 366	3 780 365
Annual	7.4	1.1666	8 579	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354

Table N.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of E_{pi} ($Case_2$)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	738	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026
February	11.5	1.2345	639	11 923 902	4 233 203	11 923 902	11 923 902	11 923 902	3 369 392	11 923 902	12 538 268	1 770 714	3 369 392	12 538 268	1 770 714	9 115 121	11 923 902	6 580 843	12 538 268	4 233 203	5 409 699	3 369 392	2 776 293	11 923 902	2 077 293	6 580 843	11 923 902	12 538 268
March	10.5	1.2329	735	10 471 380	3 189 384	13 698 087	13 698 087	13 698 087	6 214 620	13 698 087	13 698 087	2 386 378	3 189 384	13 698 087	2 386 378	13 698 087	13 698 087	6 214 620	13 698 087	3 870 731	7 560 022	4 863 071	13 698 087	14 403 865	2 034 182	10 471 380	14 403 865	3 189 384
April	9.5	1.2317	711	7 305 887	7 305 887	10 443 175	10 443 175	10 443 175	7 305 887	10 443 175	4 699 596	3 082 171	7 305 887	13 237 618	3 082 171	13 237 618	4 699 596	4 699 596	13 237 618	3 082 171	10 119 379	3 082 171	13 919 671	13 237 618	3 082 171	3 082 171	13 237 618	3 740 614
May	8.2	1.2282	735	4 844 807	10 432 053	10 432 053	10 432 053	6 191 280	10 432 053	10 432 053	10 432 053	3 856 194	6 191 280	10 432 053	3 856 194	14 349 768	10 432 053	3 856 194	10 432 053	2 377 416	13 646 640	6 191 280	2 377 416	10 432 053	3 856 194	14 349 768	10 432 053	4 844 807
June	7.1	1.2224	687	2 955 541	12 693 755	7 005 728	7 005 728	7 005 728	10 014 121	4 506 515	12 693 755	4 506 515	10 014 121	7 005 728	4 506 515	7 005 728	2 211 411	2 955 541	7 005 728	1 885 038	12 693 755	7 005 728	1 885 038	7 005 728	4 506 515	12 693 755	7 005 728	5 758 970
July	6.1	1.2154	735	2 005 275	13 503 424	4 793 962	6 126 305	10 322 572	13 503 424	7 452 587	3 144 060	6 126 305	2 005 275	6 126 305	6 126 305	6 126 305	2 005 275	2 352 466	6 126 305	6 126 305	14 199 172	10 322 572	3 815 724	6 126 305	6 126 305	13 503 424	3 815 724	7 452 587
August	6.4	1.2075	735	2 337 182	10 583 661	3 790 935	3 790 935	3 790 935	13 415 696	6 086 504	3 790 935	7 404 169	2 337 182	4 762 817	7 404 169	4 762 817	10 583 661	1 992 247	4 762 817	13 415 696	1 992 247	13 415 696	4 762 817	4 762 817	7 404 169	4 762 817	3 123 634	10 255 509
September	7.6	1.2064	711	3 663 832	1 925 451	5 882 434	4 603 129	4 603 129	4 603 129	1 925 451	5 882 434	9 911 660	9 911 660	3 663 832	9 911 660	3 663 832	5 882 434	9 911 660	3 663 832	12 965 892	2 258 821	12 965 892	5 882 434	3 663 832	9 911 660	3 663 832	2 258 821	1 925 451
October	8.9	1.2126	735	6 112 412	6 112 412	3 136 930	2 000 727	3 136 930	2 000 727	2 347 131	7 435 686	13 472 801	13 472 801	3 136 930	13 472 801	3 136 930	7 435 686	13 472 801	3 136 930	10 628 711	3 136 930	2 000 727	7 435 686	3 136 930	13 472 801	2 347 131	2 000 727	2 347 131
November	10.6	1.2194	687	9 990 034	3 578 305	2 206 092	2 206 092	2 206 092	2 206 092	2 948 433	2 206 092	12 663 223	4 495 676	2 206 092	12 663 223	2 206 092	2 948 433	12 663 223	2 206 092	9 680 288	3 578 305	2 206 092	9 680 288	2 206 092	12 663 223	1 880 504	5 745 118	12 663 223
December	11.5	1.2237	735	13 595 706	2 368 542	2 018 979	3 165 547	2 018 979	3 165 547	3 841 801	2 018 979	14 296 210	13 595 706	2 018 979	14 296 210	2 018 979	3 841 801	14 296 210	2 018 979	7 503 518	4 826 724	14 296 210	13 595 706	2 018 979	14 296 210	6 168 172	4 826 724	13 595 706
Annual	9.1	1.2222	8 579	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675

Table N.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of E_{pi} ($Case_2$)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	639	24 248 099	14 467 424	6 912 583	26 228 520	14 467 424	14 467 424	26 228 520	26 228 520	6 912 583	14 467 424	14 467 424	7 749 925	26 228 520	6 912 583	17 377 262	6 912 583	6 912 583	6 912 583	6 912 583	22 462 574	26 228 520	26 228 520	28 959 584	7 749 925	17 351 256
March	12.7	1.2495	735	18 226 532	18 226 532	8 896 263	27 834 779	12 376 594	18 226 532	27 834 779	27 834 779	8 896 263	12 376 594	18 226 532	9 971 944	27 834 779	8 896 263	30 108 137	8 896 263	8 896 263	8 896 263	8 896 263	22 991 460	27 834 779	27 834 779	31 414 830	9 971 944	18 921 332
April	12.4	1.2490	711	16 057 711	19 287 404	9 641 890	24 828 913	9 641 890	19 287 404	24 828 913	24 828 913	9 641 890	9 641 890	19 287 404	9 641 890	24 828 913	9 641 890	26 913 496	9 641 890	29 111 609	9 641 890	9 641 890	22 185 639	19 971 909	24 828 913	24 919 931	9 641 890	18 139 032
May	11.2	1.2425	735	12 306 614	25 533 644	9 915 560	19 834 848	9 915 560	25 533 644	19 834 848	19 834 848	9 915 560	9 915 560	25 533 644	12 306 614	19 834 848	9 915 560	25 533 644	9 915 560	27 677 395	9 915 560	9 915 560	20 989 216	19 834 848	19 834 848	19 089 277	12 306 614	16 168 320
June	10.4	1.2351	687	9 212 474	25 714 865	11 433 985	16 838 388	8 218 718	25 714 865	16 838 388	16 838 388	11 433 985	8 218 718	25 714 865	15 342 558	16 838 388	11 433 985	16 838 388	11 433 985	23 723 122	11 433 985	11 433 985	16 955 390	16 838 388	16 838 388	16 760 685	15 342 558	14 949 503
July	10.0	1.2275	735	8 739 531	29 577 699	16 314 803	16 314 803	7 795 266	29 577 699	16 314 803	16 314 803	16 314 803	7 795 266	29 577 699	17 905 422	16 314 803	16 314 803	7 795 266	16 314 803	19 596 205	16 314 803	16 314 803	15 530 715	16 046 466	16 314 803	16 760 185	17 905 422	8 625 161
August	9.7	1.2216	735	7 757 712	12 099 972	17 819 161	12 099 972	17 819 161	12 099 972	12 099 972	12 099 972	17 819 161	17 819 161	12 099 972	19 501 798	12 099 972	17 819 161	8 697 428	17 819 161	17 819 161	17 819 161	17 819 161	12 903 119	15 377 861	12 099 972	12 588 985	19 501 798	7 111 908
September	10.4	1.2234	711	9 444 238	7 515 148	18 892 028	9 444 238	26 361 791	7 515 148	9 444 238	9 444 238	18 892 028	26 361 791	7 515 148	24 319 940	9 444 238	18 892 028	9 444 238	18 892 028	15 728 541	18 892 028	18 892 028	12 321 085	13 275 521	9 444 238	8 842 059	24 319 940	19 029 793
October	13.1	1.2327	735	19 679 010	8 776 461	29 702 682	9 837 656	25 333 032	8 776 461	9 837 656	9 837 656	29 702 682	25 333 032	8 776 461	27 459 940	9 837 656	25 333 032	9 837 656	25 333 032	12 209 924	29 702 682	25 333 032	12 242 414	8 858 686	9 837 656	8 122 639	27 459 940	21 596 003
November	14.3	1.2429	687	23 874 256	9 271 165	25 878 688	8 271 078	27 992 285	9 271 165	8 271 078	8 271 078	25 878 688	27 992 285	9 271 165	27 992 285	8 271 078	25 878 688	11 506 828	25 878 688	9 271 165	25 878 688	25 878 688	7 423 013	8 271 078	8 271 078	8 870 902	27 992 285	21 951 058
December	15.1	1.2528	735	30 186 350	9 997 848	25 745 545	7 955 677	19 999 456	9 997 848	7 955 677	7 955 677	25 745 545	19 999 456	9 997 848	32 498 621	7 955 677	30 186 350	16 650 529	30 186 350	9 997 848	25 745 545	30 186 350	6 350 393	7 955 677	7 955 677	9 163 644	32 498 621	42 475 115
Annual	12.5	1.2404	8 579	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415

Table N.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of E_{pi} (*Case* $_2$)

Months	v_{wc} (m/s)	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table N.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of E_{pi} (*Case* $_2$)

Months	v_{wc} (m/s)	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table N.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of E_{pi} (*Case* $_2$)

Months	v_{wc} (m/s)	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table N.7 kWh per H_{prod} with sensitivity analysis of E_{pi} $(Case_{\ 2})$

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	*5 695*	*5 647*	*5 674*	*5 629*	*5 699*	*5 647*	*5 694*	*5 694*	*5 637*	*5 641*	*5 647*	*5 693*	*5 674*	*5 637*	*5 718*	*5 737*	*5 690*	*5 649*	*5 602*	*5 698*	*5 682*	*5 616*	*5 628*	*5 645*	*5 637*
Corvo Island (Portugal)	*10 451*	*10 535*	*10 466*	*10 473*	*10 467*	*10 570*	*10 498*	*10 419*	*10 528*	*10 530*	*10 452*	*10 528*	*10 510*	*10 504*	*10 472*	*10 452*	*10 517*	*10 522*	*10 556*	*10 569*	*10 463*	*10 523*	*10 531*	*10 446*	*10 392*
Cape Saint James (Canada)	*24 766*	*24 852*	*24 932*	*24 738*	*24 788*	*24 852*	*24 738*	*24 738*	*24 932*	*24 788*	*24 852*	*24 794*	*24 738*	*24 940*	*24 879*	*24 940*	*24 908*	*24 932*	*24 940*	*24 841*	*24 855*	*24 738*	*24 888*	*24 794*	*24 877*

Table N.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of E_{pi} $(Case_{\ 2})$

Item	Years												
	0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866
(+) AAR ($M/yr)	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591
PPAR	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	3 949 353	4 013 810	4 133 691	4 203 326	4 362 211	4 455 205	4 603 526	4 717 835	4 786 682	4 909 110	5 036 591	5 204 091
$O\&M_{fixed}$	-	2 654 579	2 697 997	2 778 672	2 825 574	2 932 474	2 978 078	3 077 743	3 154 685	3 201 236	3 283 628	3 369 414	3 481 989
$O\&M_{variable}$	-	1 294 774	1 315 813	1 355 018	1 377 752	1 429 737	1 477 127	1 525 784	1 563 150	1 585 447	1 625 482	1 667 177	1 722 102
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 458 163	2 519 617	2 582 608	2 647 173	2 713 352	2 781 186	2 850 716	2 921 984	2 995 033	3 069 909	3 146 657	3 225 323
(=) Profit before tax	-	3 669 248	3 758 114	3 853 942	3 947 472	4 051 058	4 123 544	4 230 509	4 337 051	4 442 265	4 554 386	4 669 476	4 790 507
(-) Revenue tax	-	1 289 151	1 310 237	1 349 416	1 372 194	1 424 109	1 446 256	1 494 658	1 532 024	1 554 632	1 594 645	1 636 306	1 690 977
(+) REPIM	270 696	3 746	3 639	3 584	3 485	3 460	3 362	3 325	3 262	3 169	3 114	3 061	3 031
REI_{CM}	33 704	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	3 424	3 312	3 247	3 143	3 104	3 001	2 952	2 880	2 781	2 716	2 652	2 609
$OREP_{CM}$	236 992	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	322	327	337	343	356	361	373	382	388	398	408	422
(=) Profit after tax w/out interest	-	2 383 843	2 451 517	2 508 110	2 578 764	2 630 409	2 680 650	2 739 176	2 808 289	2 890 803	2 962 855	3 036 231	3 102 560
(-) Debt payments	-	-	3 181 772	3 261 316	3 342 849	3 426 420	3 512 081	3 599 883	3 689 880	3 782 127	3 876 680	3 973 597	4 072 937
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 458 163	2 519 617	2 582 608	2 647 173	2 713 352	2 781 186	2 850 716	2 921 984	2 995 033	3 069 909	3 146 657	3 225 323
(=) Free net cashflow	-59 955 205	7 463 745	4 476 644	4 583 866	4 706 414	4 811 250	4 916 012	5 030 422	5 156 816	5 298 044	5 430 276	5 565 338	5 694 895
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 491 459	-48 014 815	-43 430 949	-38 724 536	-33 913 285	-28 997 273	-23 966 852	-18 810 035	-13 511 992	-8 081 715	-2 516 378	3 178 518
$LCOE_{wso}$		*67.66*	*67.81*	*68.02*	*68.18*	*68.43*	*68.62*	*68.87*	*69.09*	*69.26*	*69.49*	*69.72*	*70.00*

Item	Years												
	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354
(+) AAR ($M/yr)	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
PPAR	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
(-) $O\&M_{WFCM}$	5 315 304	5 412 299	5 626 056	5 784 761	5 880 906	5 983 464	6 080 550	6 339 242	5 846 637	5 922 095	6 082 752	6 252 834	6 398 541
$O\&M_{fixed}$	3 556 919	3 622 341	3 765 927	3 872 684	3 937 570	4 006 754	4 072 279	4 246 052	4 340 155	4 396 739	4 516 586	4 643 449	4 752 224
$O\&M_{variable}$	1 758 385	1 789 958	1 860 129	1 912 077	1 943 336	1 976 710	2 008 271	2 093 190	1 506 483	1 525 356	1 566 166	1 609 385	1 646 316
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 305 956	3 388 605	3 473 321	3 560 154	3 649 157	3 740 386	3 833 896	3 929 743	4 027 987	4 128 687	4 231 904	4 337 701	4 446 144
(=) Profit before tax	4 909 541	5 030 128	5 163 273	4 044 445	4 142 343	4 243 011	4 345 507	4 463 967	3 099 410	3 188 772	3 267 139	3 346 611	3 432 608
(-) Revenue tax	1 727 367	1 759 139	1 828 870	1 880 716	1 912 227	1 945 827	1 977 648	2 062 040	1 475 418	1 494 654	1 535 396	1 578 523	1 615 502
(+) REPIM	2 968	2 898	457	469	477	486	494	515	526	533	548	563	576
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	2 536	2 459	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	431	439	457	469	477	486	494	515	526	533	548	563	576
(=) Profit after tax w/out interest	3 185 142	3 273 887	3 334 860	2 164 199	2 230 593	2 297 670	2 368 353	2 402 442	1 624 518	1 694 651	1 732 291	1 768 651	1 817 683
(-) Debt payments	4 174 761	4 279 130	4 386 108	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 305 956	3 388 605	3 473 321	3 560 154	3 649 157	3 740 386	3 833 896	3 929 743	4 027 987	4 128 687	4 231 904	4 337 701	4 446 144
(=) Free net cashflow	5 842 285	5 997 458	6 126 521	9 521 412	9 771 736	10 027 342	10 291 266	10 523 428	9 948 529	10 226 763	10 477 705	10 732 701	11 005 834
$\Sigma_{free\ net\ annual\ cashflow}$	9 020 803	15 018 261	21 144 782	30 666 194	40 437 930	50 465 272	60 756 539	71 279 967	81 228 496	91 455 259	101 932 964	112 665 664	123 671 498
$LCOE_{wso}$	*70.23*	*70.44*	*70.78*	*69.81*	*70.00*	*70.20*	*70.40*	*70.76*	*70.37*	*70.55*	*70.82*	*71.11*	*71.37*

Table N.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of E_{pi} $(Case_{2})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675
(+) AAR ($M/yr)	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
PPAR	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
(-) $O\&M_{WFCM}$	-	9 368 374	9 679 566	9 856 225	10 109 621	10 355 890	10 719 839	10 911 955	11 100 782	11 497 361	11 787 429	11 992 241	12 380 956	12 668 548	12 977 965	13 261 497	13 567 366	13 991 943	14 348 504	14 755 487	15 142 655	13 154 746	13 560 473	13 910 592	14 143 024	14 421 679
$O\&M_{fixed}$	-	4 871 474	5 033 363	5 125 297	5 257 137	5 385 272	5 574 606	5 674 583	5 772 851	5 979 160	6 130 081	6 236 666	6 438 893	6 588 532	6 749 522	6 897 052	7 056 201	7 277 090	7 462 607	7 674 349	7 875 789	7 991 568	8 238 134	8 450 920	8 592 210	8 761 584
$O\&M_{variable}$	-	4 496 901	4 646 203	4 730 927	4 852 484	4 970 618	5 145 234	5 237 372	5 327 931	5 518 200	5 657 348	5 755 575	5 942 063	6 080 016	6 228 443	6 364 445	6 511 165	6 714 853	6 885 898	7 081 137	7 266 866	5 163 178	5 322 339	5 459 672	5 550 813	5 660 095
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 451 726	2 513 019	2 575 844	2 640 241	2 706 247	2 773 903	2 843 250	2 914 332	2 987 190	3 061 870	3 138 416	3 216 877	3 297 299	3 379 731	3 464 224	3 550 830	3 639 601	3 730 591	3 823 856	3 919 452	4 017 438	4 117 874	4 220 821	4 326 342	4 434 500
(=) Profit before tax	-	8 917 545	9 186 752	9 377 579	9 616 429	9 853 198	10 162 593	10 371 501	10 580 788	10 916 757	11 191 483	11 417 734	11 756 598	12 037 622	12 334 427	12 618 537	11 668 602	12 011 640	12 316 208	12 653 227	12 980 729	8 054 520	8 279 659	8 490 248	8 667 293	8 861 166
(-) Revenue tax	-	4 491 277	4 640 535	4 725 296	4 846 849	4 964 986	5 139 546	5 231 723	5 322 325	5 512 536	5 651 682	5 749 951	5 936 398	6 074 361	6 222 791	6 358 810	6 505 541	6 709 195	6 880 237	7 075 458	7 261 179	5 157 549	5 316 677	5 454 006	5 545 193	5 654 504
(+) REPIM	427 710	2 591	2 556	2 486	2 435	2 383	2 357	2 293	2 230	2 208	2 165	2 107	2 081	2 037	1 997	1 954	1 914	1 891	1 858	261	268	272	280	287	292	298
REI_{CM}	33 704	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	2 425	2 385	2 311	2 257	2 200	2 168	2 100	2 034	2 005	1 957	1 895	1 862	1 813	1 768	1 720	1 675	1 644	1 605	-	-	-	-	-	-	-
$OREP_{CM}$	394 006	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	166	171	174	179	183	189	193	196	203	208	212	219	224	229	234	240	247	254	261	268	272	280	287	292	298
(=) Profit after tax w/out interest	-	4 428 858	4 548 773	4 654 768	4 772 015	4 890 595	5 025 404	5 142 070	5 260 693	5 406 430	5 541 966	5 669 890	5 822 280	5 965 298	6 113 634	6 261 681	5 164 975	5 304 336	5 437 830	5 578 031	5 719 817	2 897 243	2 963 261	3 036 529	3 122 393	3 206 960
(-) Debt payments	-	-	3 173 439	3 252 775	3 334 095	3 417 447	3 502 883	3 590 455	3 680 217	3 772 222	3 866 528	3 963 191	4 062 271	4 163 827	4 267 923	4 374 621	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 451 726	2 513 019	2 575 844	2 640 241	2 706 247	2 773 903	2 843 250	2 914 332	2 987 190	3 061 870	3 138 416	3 216 877	3 297 299	3 379 731	3 464 224	3 550 830	3 639 601	3 730 591	3 823 856	3 919 452	4 017 438	4 117 874	4 220 821	4 326 342	4 434 500
(=) Free net cashflow	-59 798 191	9 502 322	6 575 635	6 732 301	6 901 487	7 073 303	7 262 681	7 435 279	7 611 231	7 815 732	8 011 501	8 201 163	8 416 835	8 624 716	8 839 538	9 055 732	12 512 864	12 835 923	13 157 706	13 490 904	13 830 512	11 210 706	11 484 561	11 770 861	12 075 083	12 383 468
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 295 868	-43 720 233	-36 987 932	-30 086 445	-23 013 142	-15 750 461	-8 315 183	-703 951	7 111 780	15 123 281	23 324 444	31 741 279	40 365 995	49 205 532	58 261 265	70 774 129	83 610 052	96 767 758	110 258 662	124 089 174	135 299 880	146 784 441	158 555 301	170 630 384	183 013 852
	$LCOE_{wso}$	73.08	73.48	73.74	74.09	74.43	74.89	75.18	75.47	75.97	76.37	76.68	77.18	77.58	78.01	78.41	77.59	78.11	78.56	79.07	79.56	77.68	78.19	78.65	79.00	79.39

Table N.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of E_{pi} $(Case_{2})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415
(+) AAR ($M/yr)	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
PPAR	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
(-) $O\&M_{WFCM}$	-	20 588 652	21 176 288	21 775 288	22 145 848	22 745 587	23 374 047	23 848 205	24 444 263	25 251 713	25 733 770	26 444 813	27 042 405	27 655 668	28 578 721	29 221 647	30 025 220	30 735 351	31 534 456	32 333 422	33 010 054	29 394 775	29 987 509	30 923 746	31 576 700	32 474 765
$O\&M_{fixed}$	-	11 544 286	11 873 856	12 209 801	12 417 656	12 754 019	13 106 489	13 372 438	13 706 743	14 159 584	14 429 968	14 828 755	15 163 927	15 507 888	16 025 565	16 386 164	16 836 847	17 235 134	17 683 316	18 131 422	18 510 929	18 984 265	19 367 163	19 971 913	20 393 707	20 973 809
$O\&M_{variable}$	-	9 044 366	9 302 432	9 565 487	9 728 192	9 991 568	10 267 558	10 475 767	10 737 520	11 092 129	11 303 802	11 616 058	11 878 478	12 147 781	12 553 156	12 835 484	13 188 373	13 500 217	13 851 140	14 202 000	14 499 125	10 410 511	10 620 346	10 951 834	11 182 993	11 500 957
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 425 624	2 486 265	2 548 421	2 612 132	2 677 435	2 744 371	2 812 980	2 883 305	2 955 387	3 029 272	3 105 004	3 182 629	3 262 195	3 343 749	3 427 343	3 513 027	3 600 852	3 690 874	3 783 146	3 877 724	3 974 667	4 074 034	4 175 885	4 280 282	4 387 289
(=) Profit before tax	-	12 829 384	13 184 124	13 546 193	13 804 513	14 171 201	14 553 419	14 866 402	15 238 209	15 710 376	16 034 186	16 466 633	16 849 070	17 241 406	17 780 031	18 191 588	17 430 175	17 847 374	18 308 015	18 770 847	19 179 285	9 262 783	9 468 956	9 739 415	9 961 460	10 230 218
(-) Revenue tax	-	9 038 743	9 296 789	9 559 826	9 722 575	9 985 940	10 261 916	10 470 150	10 731 904	11 086 468	11 298 174	11 610 416	11 872 849	12 142 164	12 547 493	12 829 835	13 182 710	13 494 562	13 845 479	14 196 337	14 493 484	10 404 867	10 614 729	10 946 183	11 177 363	11 495 308
(+) REPIM	1 064 339	1 198	1 218	1 238	1 245	1 266	1 287	1 301	1 321	1 352	1 366	1 392	1 412	1 434	1 471	1 285	1 320	1 351	1 387	1 422	1 451	1 489	1 519	1 566	1 599	1 645
REI_{CM}	33 704	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	293	287	281	272	266	260	252	246	242	235	230	223	218	214	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	1 030 635	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	905	931	957	974	1 000	1 028	1 049	1 075	1 110	1 131	1 163	1 189	1 216	1 257	1 285	1 320	1 351	1 387	1 422	1 451	1 489	1 519	1 566	1 599	1 645
(=) Profit after tax w/out interest	-	3 791 839	3 888 553	3 987 605	4 083 183	4 186 527	4 292 790	4 397 553	4 507 626	4 625 260	4 737 378	4 857 609	4 977 633	5 100 676	5 234 008	5 363 038	4 248 785	4 354 164	4 463 922	4 575 932	4 687 252	-1 140 596	-1 144 255	-1 205 202	-1 214 304	-1 263 446
(-) Debt payments	-	-	3 139 654	3 218 145	3 298 599	3 381 064	3 465 591	3 552 230	3 641 036	3 732 062	3 825 364	3 920 998	4 019 023	4 119 498	4 222 486	4 328 048	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 425 624	2 486 265	2 548 421	2 612 132	2 677 435	2 744 371	2 812 980	2 883 305	2 955 387	3 029 272	3 105 004	3 182 629	3 262 195	3 343 749	3 427 343	3 513 027	3 600 852	3 690 874	3 783 146	3 877 724	3 974 667	4 074 034	4 175 885	4 280 282	4 387 289
(=) Free net cashflow	-59 161 561	8 839 202	5 922 446	6 072 345	6 220 042	6 376 807	6 537 828	6 698 716	6 866 318	7 042 920	7 215 479	7 397 663	7 581 188	7 769 319	7 969 368	8 166 782	11 558 871	11 847 002	12 144 082	12 448 095	12 756 219	7 130 096	7 333 204	7 484 194	7 692 326	7 865 850
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 322 360	-44 399 914	-38 327 569	-32 107 527	-25 730 721	-19 192 893	-12 494 177	-5 627 859	1 415 061	8 630 540	16 028 202	23 609 391	31 378 710	39 348 078	47 514 860	59 073 731	70 920 733	83 064 815	95 512 910	108 269 130	115 399 226	122 732 430	130 216 624	137 908 950	145 774 800
	$LCOE_{wso}$	84.30	84.97	85.66	86.12	86.82	87.54	88.12	88.81	89.72	90.31	91.13	91.84	92.57	93.61	94.37	94.05	94.85	95.75	96.65	97.43	93.92	94.62	95.66	96.43	97.44

APPENDIX O

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85.00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2.0	[d]
$C_{md_{RM_{WT}}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3.0	[m-h]
$C_{Mhr_{R_{CT}}}$	85.00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2.0	[d]
$C_{md_{RM_{CT}}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
$\boldsymbol{RCM_{WF}}$	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	65.7637	[$/kWₑ]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	15.00%	[%]
n_{ψ}	3	[yr]
REP_{CM}	0.00000594	[$/kWₑh]
AEP_{avail}/H_{prod}	5 695	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0339	[$/kWₑh]
ε_0	0.023377	[$/kWₑh]
n_{ε}	15	[yr]
$OREP_{CM}$	21.6761	[$/kWₑ]
$LCCCM_{WF_{OREG_{CM}}}$	4.5846	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	15.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	15	[yr]
CR_f	25.0%	[%]
$GHG.R_{CM}$	3 868.4070	[$/tCO₂]
$LCER_{CO_2}$	56.2	[tCO₂/MWₑh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	48 856	[MWₑh]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00123	[tCO₂/MWₑh]
$GHG_{EM_{wecs\ CO_2}}$	0.00008	[tCO₂/MWₑh]
ε_c	37.1056	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	0.0%	[%]
ξ_2 REP_{CM}	0.0%	[%]
ξ_3 $OREP_{CM}$	50.0%	[%]
ξ_4 $GHG.R_{CM}$	50.0%	[%]
REPIM	**1 945.0415**	**[$/proj]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWₑ]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$\boldsymbol{LCCCM_{WF}}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025858	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	4 192 361	[$M]
AEP_{avail}	48 856 319	[kWh/yr]
$\boldsymbol{O\&M_{WFCM}}$	**0.124133**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$\boldsymbol{SC_{O\&M}}$	**0.000105**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$\boldsymbol{USC_{O\&M}}$	**0.000287**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$\boldsymbol{SC_{O\&M}+USC_{O\&M}}$	**184.5**	**[h/yr]**
	0.000392	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$\boldsymbol{O\&M_{WFCM}}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$\boldsymbol{P\&D_{LM}}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**

p.s.: 1= yes and 0=no

Figure O.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical $50MW_e$ wind farm in Aracati (Brazil) with sensitivity analysis of E_{pi} *(Case $_3$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (α)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWe]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
W_{FCM}	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048935	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	14 605 780	[$M]
AEP_{avail}	89 657 257	[kWh/yr]
$O\&M_{WFCM}$	**0.147210**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000057**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000156**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000214	**[$/kWh/yr]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85.00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2.0	[d]
$C_{md_{RM_{WT}}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2.0	[d]
$C_{md_{RM_{CT}}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Renewable Energy Public Incentive Model		Notes
REI_{CM}	65.7637	[$/kWe]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	15.00%	[%]
n_ψ	3	[yr]
REP_{CM}	0.00000831	[$/kWeh]
AEP_{avail}/H_{prod}	10 451	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0869	[$/kWeh]
ε_0	0.060000	[$/kWeh]
n_ε	15	[yr]
$OREP_{CM}$	39.7783	[$/kWe]
$LCCCM_{WF_{OREG_{CM}}}$	4.5846	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	15.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	15	[yr]
CR_f	25.0%	[%]
$GHG.R_{CM}$	2 487.1430	[$/tCO2]
$LCER_{CO_2}$	103.2	[tCO2/MWeh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	89 657	[MWeh]
n_ψ	25	[yr]
$GHG_{EM_{ff\,co_2}}$	0.00123	[tCO2/MWeh]
$GHG_{EM_{wecs\,co_2}}$	0.00008	[tCO2/MWeh]
ε_c	13.0000	[$/tCO2]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	0.0%	[%]
ξ_2 REP_{CM}	0.0%	[%]
ξ_3 $OREP_{CM}$	50.0%	[%]
ξ_4 $GHG.R_{CM}$	50.0%	[%]
REPIM	**1 263.4606**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWe/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	89 657 257	[kWeh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{op}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWeh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**89 657 257**	**[kWeh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 615 722	[$]
Debt payments	2 991 898	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 615 722	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.0793	yr_1	78.4116	yr_{15}
73.4776	yr_2	77.5903	yr_{15}
73.7436	yr_3	78.1098	yr_{16}
74.0885	yr_4	78.5637	yr_{17}
74.4286	yr_5	79.0704	yr_{18}
74.8887	yr_6	79.5598	yr_{19}
75.1794	yr_7	77.6767	yr_{20}
75.4693	yr_8	78.1898	yr_{21}
75.9694	yr_9	78.6500	yr_{22}
76.3656	yr_{10}	78.9953	yr_{23}
76.6792	yr_{11}	79.3896	yr_{25}
77.1795	yr_{12}	76.8138	Mean
77.5814	yr_{13}	2.0085	SD
78.0080	yr_{14}	-0.4651	ϒ (skewness)
$LCOE_{wso}$	**76.8138**	**US$/MWh**	valid !
	0.076814	**US$/kWh**	

Figure O.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of E_{pi} *(Case $_3$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.5%	[%]
Availability	97.9%	[%]
	357	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{rec}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{ec}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RMCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	65.7637	[$/kWₑ]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	15.00%	[%]
n_{ψ}	3	[yr]
REP_{CM}	0.00000053	[$/kWₑh]
AEP_{avail}/H_{prod}	24 766	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0131	[$/kWₑh]
ε_0	0.007998	[$/kWₑh]
n_{ε}	20	[yr]
$OREP_{CM}$	83.3169	[$/kWₑ]
$LCCCM_{WF_{OREGCM}}$	4.0521	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	15.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	20	[yr]
CR_f	25.0%	[%]
$GHG.R_{CM}$	10 881.1639	[$/tCO₂]
$LCER_{CO_2}$	244.5	[tCO₂/MWₑh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	212 467	[MWₑh]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00123	[tCO₂/MWₑh]
$GHG_{EM_{wecs\ CO_2}}$	0.00008	[tCO₂/MWₑh]
ε_c	24.0000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	0.0%	[%]
ξ_2 REP_{CM}	0.0%	[%]
ξ_3 $OREP_{CM}$	50.0%	[%]
ξ_4 $GHG.R_{CM}$	50.0%	[%]
REPIM	**5 482.2404**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWₑ/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 467 325	[kWₑh/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWₑh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 467 325**	**[kWₑh/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWₑ]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041531	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	113	[h]
AAR	29 394 286	[$M]
AEP_{avail}	212 467 325	[kWh/yr]
$O\&M_{WFCM}$	**0.139806**	**[$/kWh/yr]**

$O\&M_{manag(STD)}$		Notes
$SC_{O\&M}$	**0.000024**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000066**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.5	[per yr]
Repair time	3.0	[h]
Hours required	112.5	[h]
$SC_{O\&M}+USC_{O\&M}$	**184.5**	**[h/yr]**
	0.000090	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	639
March	744	735
April	720	711
May	744	735
June (*)	720	687
July	744	735
August	744	735
September	720	711
October	744	735
November (*)	720	687
December	744	735
Total [h/yr]	**8 760**	**8 579**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 071 489	[$]
Debt payments	2 936 917	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 071 489	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.2996	yr_1	94.3718	yr_{15}
84.9743	yr_2	94.0482	yr_{15}
85.6626	yr_3	94.8532	yr_{16}
86.1247	yr_4	95.7496	yr_{17}
86.8183	yr_5	96.6483	yr_{18}
87.5429	yr_6	97.4272	yr_{19}
88.1156	yr_7	93.9167	yr_{20}
88.8127	yr_8	94.6168	yr_{21}
89.7238	yr_9	95.6632	yr_{22}
90.3120	yr_{10}	96.4289	yr_{23}
91.1318	yr_{11}	97.4427	yr_{25}
91.8409	yr_{12}	91.7081	Mean
92.5685	yr_{13}	4.1890	SD
93.6087	yr_{14}	-0.3343	Υ (skewness)
$LCOE_{wso}$	**91.7081**	**US$/MWh**	valid !
	0.091708	**US$/kWh**	

Figure O.3 *I-O system representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical 50MWₑ wind farm in Cape Saint James (Canada) with sensitivity analysis of E_{pi} *(Case $_3$)*. Source: Own elaboration

Table O.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of E_{pi} *(Case 3)*

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	738	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	14 451 298	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026	10 842 026
February	11.5	1.2345	639	11 923 902	4 233 203	11 923 902	11 923 902	11 923 902	3 369 392	11 923 902	12 538 268	1 770 714	3 369 392	12 538 268	1 770 714	9 115 121	11 923 902	6 580 843	12 538 268	4 233 203	5 409 699	3 369 392	2 776 293	11 923 902	2 077 293	6 580 843	11 923 902	12 538 268
March	10.5	1.2329	735	10 471 380	3 189 384	13 698 087	13 698 087	13 698 087	6 214 620	13 698 087	13 698 087	2 386 378	3 189 384	13 698 087	2 386 378	13 698 087	13 698 087	6 214 620	13 698 087	3 870 731	7 560 022	4 863 071	13 698 087	14 403 865	2 034 182	10 471 380	14 403 865	3 189 384
April	9.5	1.2317	711	7 305 887	7 305 887	10 443 175	10 443 175	10 443 175	7 305 887	10 443 175	4 699 596	3 082 171	7 305 887	13 237 618	3 082 171	13 237 618	4 699 596	4 699 596	13 237 618	3 082 171	10 119 379	3 082 171	13 919 671	13 237 618	3 082 171	3 082 171	13 237 618	3 740 614
May	8.2	1.2282	735	4 844 807	10 432 053	10 432 053	10 432 053	6 191 280	10 432 053	10 432 053	10 432 053	3 856 194	6 191 280	10 432 053	3 856 194	14 349 768	10 432 053	3 856 194	10 432 053	2 377 416	13 646 640	6 191 280	2 377 416	10 432 053	3 856 194	14 349 768	10 432 053	4 844 807
June	7.1	1.2224	687	2 955 541	12 693 755	7 005 728	7 005 728	7 005 728	10 014 121	4 506 515	12 693 755	4 506 515	10 014 121	7 005 728	4 506 515	7 005 728	2 211 411	2 955 541	7 005 728	1 885 038	12 693 755	7 005 728	1 885 038	7 005 728	4 506 515	12 693 755	7 005 728	5 758 970
July	6.1	1.2154	735	2 005 275	13 503 424	4 793 962	6 126 305	10 322 572	13 503 424	7 452 587	3 144 060	6 126 305	2 005 275	6 126 305	6 126 305	6 126 305	2 005 275	2 352 466	6 126 305	6 126 305	14 199 172	10 322 572	3 815 724	6 126 305	6 126 305	13 503 424	3 815 724	7 452 587
August	6.4	1.2075	735	2 337 182	10 583 661	3 790 935	3 790 935	3 790 935	13 415 696	6 086 504	3 790 935	7 404 169	2 337 182	4 762 817	7 404 169	4 762 817	10 583 661	1 992 247	4 762 817	13 415 696	1 992 247	13 415 696	4 762 817	4 762 817	7 404 169	4 762 817	3 123 634	10 255 509
September	7.6	1.2064	711	3 663 832	1 925 451	5 882 434	4 603 129	4 603 129	4 603 129	1 925 451	5 882 434	9 911 660	9 911 660	3 663 832	9 911 660	3 663 832	5 882 434	9 911 660	3 663 832	12 965 892	2 258 821	12 965 892	5 882 434	3 663 832	9 911 660	3 663 832	2 258 821	1 925 451
October	8.9	1.2126	735	6 112 412	6 112 412	3 136 930	2 000 727	3 136 930	2 000 727	2 347 131	7 435 686	13 472 801	13 472 801	3 136 930	13 472 801	3 136 930	7 435 686	13 472 801	3 136 930	10 628 711	3 136 930	2 000 727	7 435 686	3 136 930	13 472 801	2 347 131	2 000 727	2 347 131
November	10.6	1.2194	687	9 990 034	3 578 305	2 206 092	2 206 092	2 206 092	2 206 092	2 948 433	2 206 092	12 663 223	4 495 676	2 206 092	12 663 223	2 206 092	2 948 433	12 663 223	2 206 092	9 680 288	3 578 305	2 206 092	9 680 288	2 206 092	12 663 223	1 880 504	5 745 118	12 663 223
December	11.5	1.2237	735	13 595 706	2 368 542	2 018 979	3 165 547	2 018 979	3 165 547	3 841 801	2 018 979	14 296 210	13 595 706	2 018 979	14 296 210	2 018 979	3 841 801	14 296 210	2 018 979	7 503 518	4 826 724	14 296 210	13 595 706	2 018 979	14 296 210	6 168 172	4 826 724	13 595 706
Annual	9.1	1.2222	8 579	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675

Table O.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of E_{pi} *(Case 3)*

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	639	847 940	6 783 520	3 662 567	6 783 520	777 316	6 783 520	777 316	777 316	4 713 419	6 783 520	6 783 520	777 316	3 662 567	6 783 520	482 342	482 342	3 290 403	4 713 419	7 693 599	1 572 412	1 572 412	7 693 599	6 783 520	4 713 419	4 713 419
March	4.0	1.1671	735	555 090	7 476 817	5 424 310	8 853 970	975 829	7 476 817	975 829	975 829	6 543 367	7 476 817	7 476 817	975 829	5 424 310	8 853 970	894 553	894 553	1 809 568	4 214 966	1 809 568	1 686 232	1 686 232	7 806 630	8 853 970	3 786 671	6 543 367
April	4.7	1.1667	711	865 098	6 327 908	6 327 908	4 076 176	1 630 708	6 327 908	1 630 708	1 630 708	7 230 621	6 327 908	6 327 908	1 749 983	6 327 908	4 076 176	943 697	943 697	1 630 708	6 327 908	1 630 708	3 661 984	943 697	7 230 621	6 327 908	1 749 983	7 230 621
May	6.0	1.1670	735	1 809 500	5 424 109	7 476 539	5 424 109	1 809 500	5 424 109	1 809 500	1 809 500	7 806 340	5 424 109	5 424 109	1 686 169	7 476 539	6 543 124	1 686 169	1 686 169	975 792	8 853 641	975 792	555 069	894 520	6 543 124	4 214 809	1 686 169	7 806 340
June	7.9	1.1686	687	3 944 904	3 944 904	7 306 444	6 124 120	3 544 051	3 944 904	3 544 051	3 544 051	8 286 679	3 944 904	3 944 904	3 544 051	7 306 444	5 076 764	1 693 625	1 693 625	837 237	7 306 444	837 237	837 237	3 544 051	5 076 764	5 076 764	913 305	8 286 679
July	8.6	1.1698	735	5 437 072	3 795 580	8 874 801	1 690 199	4 224 882	3 795 580	4 224 882	4 224 882	556 396	556 396	3 795 580	5 437 072	8 874 801	1 813 825	3 795 580	3 795 580	556 396	7 494 407	556 396	978 125	4 224 882	4 224 882	1 690 199	896 658	556 396
August	9.6	1.1677	735	7 480 694	1 810 506	1 810 506	1 810 506	8 858 561	1 810 506	5 427 123	5 427 123	895 017	895 017	1 810 506	4 217 151	1 810 506	1 687 106	5 427 123	7 810 678	7 810 678	895 017	4 217 151	7 810 678	5 427 123	1 810 506	1 810 506	555 378	895 017
September	10.1	1.1657	711	8 554 384	1 629 176	1 629 176	3 658 543	7 542 482	1 629 176	6 321 963	6 321 963	942 810	942 810	1 629 176	6 321 963	1 629 176	3 658 543	6 321 963	7 223 828	7 223 828	942 810	5 240 771	8 554 384	6 321 963	1 629 176	3 658 543	6 321 963	942 810
October	9.7	1.1645	735	7 789 201	973 650	973 650	553 851	7 460 125	973 650	7 460 125	7 460 125	1 682 467	1 682 467	973 650	8 834 203	973 650	553 851	7 460 125	6 528 759	6 528 759	1 805 528	6 528 759	4 205 556	7 460 125	973 650	973 650	8 834 203	1 682 467
November	9.2	1.1638	687	6 098 939	833 795	833 795	833 795	6 098 939	833 795	7 276 401	7 276 401	1 686 661	1 686 661	833 795	7 276 401	833 795	833 795	7 276 401	5 055 889	5 055 889	1 571 703	6 968 989	6 098 939	7 276 401	833 795	833 795	7 276 401	1 686 661
December	7.6	1.1651	735	3 780 365	554 166	554 166	974 204	5 415 277	554 166	8 839 226	8 839 226	3 780 365	3 780 365	554 166	7 464 366	554 166	974 204	8 839 226	4 207 946	4 207 946	3 780 365	7 793 630	5 415 277	8 839 226	554 166	554 166	7 464 366	3 780 365
Annual	7.4	1.1666	8 579	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354

Table O.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of E_{pi} *(Case 3)*

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	639	24 248 099	14 467 424	6 912 583	26 228 520	14 467 424	14 467 424	26 228 520	26 228 520	6 912 583	14 467 424	14 467 424	7 749 925	26 228 520	6 912 583	17 377 262	6 912 583	6 912 583	6 912 583	6 912 583	22 462 574	26 228 520	26 228 520	28 959 584	7 749 925	17 351 256
March	12.7	1.2495	735	18 226 532	18 226 532	8 896 263	27 834 779	12 376 594	18 226 532	27 834 779	27 834 779	8 896 263	12 376 594	18 226 532	9 971 944	27 834 779	8 896 263	30 108 137	8 896 263	8 896 263	8 896 263	8 896 263	22 991 460	27 834 779	27 834 779	31 414 830	9 971 944	18 921 332
April	12.4	1.2490	711	16 057 711	19 287 404	9 641 890	24 828 913	9 641 890	19 287 404	24 828 913	24 828 913	9 641 890	9 641 890	19 287 404	9 641 890	24 828 913	9 641 890	26 913 496	9 641 890	29 111 609	9 641 890	9 641 890	22 185 639	19 971 909	24 828 913	24 919 931	9 641 890	18 139 032
May	11.2	1.2425	735	12 306 614	25 533 644	9 915 560	19 834 848	9 915 560	25 533 644	19 834 848	19 834 848	9 915 560	9 915 560	25 533 644	12 306 614	19 834 848	9 915 560	25 533 644	9 915 560	27 677 395	9 915 560	9 915 560	20 989 216	19 834 848	19 834 848	19 089 277	12 306 614	16 168 320
June	10.4	1.2351	687	9 212 474	25 714 865	11 433 985	16 838 388	8 218 718	25 714 865	16 838 388	16 838 388	11 433 985	8 218 718	25 714 865	15 342 558	16 838 388	11 433 985	16 838 388	11 433 985	23 723 122	11 433 985	11 433 985	16 955 390	16 838 388	16 838 388	16 760 685	15 342 558	14 949 503
July	10.0	1.2275	735	8 739 531	29 577 699	16 314 803	16 314 803	7 795 266	29 577 699	16 314 803	16 314 803	16 314 803	7 795 266	29 577 699	17 905 422	16 314 803	16 314 803	7 795 266	16 314 803	19 596 205	16 314 803	16 314 803	15 530 715	16 046 466	16 314 803	16 760 185	17 905 422	8 625 161
August	9.7	1.2216	735	7 757 712	12 099 972	17 819 161	12 099 972	17 819 161	12 099 972	12 099 972	12 099 972	17 819 161	17 819 161	12 099 972	19 501 798	12 099 972	17 819 161	8 697 428	17 819 161	17 819 161	17 819 161	17 819 161	12 903 119	15 377 861	12 099 972	12 588 985	19 501 798	7 111 908
September	10.4	1.2234	711	9 444 238	7 515 148	18 892 028	9 444 238	26 361 791	7 515 148	9 444 238	9 444 238	18 892 028	26 361 791	7 515 148	24 319 940	9 444 238	18 892 028	9 444 238	18 892 028	15 728 541	18 892 028	18 892 028	12 321 085	13 275 521	9 444 238	8 842 059	24 319 940	19 029 793
October	13.1	1.2327	735	19 679 010	8 776 461	29 702 682	9 837 656	25 333 032	8 776 461	9 837 656	9 837 656	29 702 682	25 333 032	8 776 461	27 459 940	9 837 656	25 333 032	9 837 656	25 333 032	12 209 924	29 702 682	25 333 032	12 242 414	8 858 686	9 837 656	8 122 639	27 459 940	21 596 003
November	14.3	1.2429	687	23 874 256	9 271 165	25 878 688	8 271 078	27 992 285	9 271 165	8 271 078	8 271 078	25 878 688	27 992 285	9 271 165	27 992 285	8 271 078	25 878 688	11 506 828	25 878 688	9 271 165	25 878 688	25 878 688	7 423 013	8 271 078	8 271 078	8 870 902	27 992 285	21 951 058
December	15.1	1.2528	735	30 186 350	9 997 848	25 745 545	7 955 677	19 999 456	9 997 848	7 955 677	7 955 677	25 745 545	19 999 456	9 997 848	32 498 621	7 955 677	30 186 350	16 650 529	30 186 350	9 997 848	25 745 545	30 186 350	6 350 393	7 955 677	7 955 677	9 163 644	32 498 621	42 475 115
Annual	12.5	1.2404	8 579	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415

Table O.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of E_{pi} *(Case 3)*

Months	v_{wc} *(m/s)*	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table O.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of E_{pi} *(Case 3)*

Months	v_{wc} *(m/s)*	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table O.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of E_{pi} *(Case 3)*

Months	v_{wc} *(m/s)*	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table O.7 kWh per H_{prod} with sensitivity analysis of E_{pi} *(Case 3)*

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	*5 695*	*5 647*	*5 674*	*5 629*	*5 699*	*5 647*	*5 694*	*5 694*	*5 637*	*5 641*	*5 647*	*5 693*	*5 674*	*5 637*	*5 718*	*5 737*	*5 690*	*5 649*	*5 602*	*5 698*	*5 682*	*5 616*	*5 628*	*5 645*	*5 637*
Corvo Island (Portugal)	*10 451*	*10 535*	*10 466*	*10 473*	*10 467*	*10 570*	*10 498*	*10 419*	*10 528*	*10 530*	*10 452*	*10 528*	*10 510*	*10 504*	*10 472*	*10 452*	*10 517*	*10 522*	*10 556*	*10 569*	*10 463*	*10 523*	*10 531*	*10 446*	*10 392*
Cape Saint James (Canada)	*24 766*	*24 852*	*24 932*	*24 738*	*24 788*	*24 852*	*24 738*	*24 738*	*24 932*	*24 788*	*24 852*	*24 794*	*24 738*	*24 940*	*24 879*	*24 940*	*24 908*	*24 932*	*24 940*	*24 841*	*24 855*	*24 738*	*24 888*	*24 794*	*24 877*

Table O.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of E_{pi} *(Case 3)*

Item	Years												
	0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 856 319	48 444 328	48 676 026	48 290 403	48 895 032	48 444 328	48 844 485	48 844 485	48 356 354	48 391 173	48 444 328	48 841 866
(+) AAR ($M/yr)	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591
PPAR	-	4 297 170	4 367 456	4 498 053	4 573 979	4 747 030	4 820 855	4 982 192	5 106 747	5 182 105	5 315 483	5 454 354	5 636 591
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	3 949 353	4 013 810	4 133 691	4 203 326	4 362 211	4 455 205	4 603 526	4 717 835	4 786 682	4 909 110	5 036 591	5 204 091
$O\&M_{fixed}$	-	2 654 579	2 697 997	2 778 672	2 825 574	2 932 474	2 978 078	3 077 743	3 154 685	3 201 236	3 283 628	3 369 414	3 481 989
$O\&M_{variable}$	-	1 294 774	1 315 813	1 355 018	1 377 752	1 429 737	1 477 127	1 525 784	1 563 150	1 585 447	1 625 482	1 667 177	1 722 102
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 447 044	2 508 220	2 570 926	2 635 199	2 701 079	2 768 606	2 837 821	2 908 766	2 981 485	3 056 023	3 132 423	3 210 734
(=) Profit before tax	-	3 658 129	3 746 717	3 842 260	3 935 498	4 038 784	4 110 964	4 217 613	4 323 833	4 428 717	4 540 499	4 655 243	4 775 917
(-) Revenue tax	-	1 289 151	1 310 237	1 349 416	1 372 194	1 424 109	1 446 256	1 494 658	1 532 024	1 554 632	1 594 645	1 636 306	1 690 977
(+) REPIM	541 902	1 069	1 087	1 119	1 138	1 181	1 200	1 240	1 271	1 290	1 323	1 357	1 403
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	541 902	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	1 069	1 087	1 119	1 138	1 181	1 200	1 240	1 271	1 290	1 323	1 357	1 403
(=) Profit after tax w/out interest	-	2 370 047	2 437 567	2 493 963	2 564 442	2 615 857	2 665 907	2 724 195	2 793 080	2 875 375	2 947 177	3 020 294	3 086 343
(-) Debt payments	-	-	3 167 379	3 246 564	3 327 728	3 410 921	3 496 194	3 583 599	3 673 189	3 765 019	3 859 144	3 955 623	4 054 513
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 447 044	2 508 220	2 570 926	2 635 199	2 701 079	2 768 606	2 837 821	2 908 766	2 981 485	3 056 023	3 132 423	3 210 734
(=) Free net cashflow	-59 683 998	7 438 830	4 465 690	4 572 789	4 695 239	4 799 923	4 904 575	5 018 831	5 145 081	5 286 176	5 418 248	5 553 141	5 682 511
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 245 168	-47 779 478	-43 206 689	-38 511 450	-33 711 527	-28 806 951	-23 788 121	-18 643 040	-13 356 863	-7 938 615	-2 385 474	3 297 038
	$LCOE_{wso}$	*67.66*	*67.81*	*68.02*	*68.18*	*68.43*	*68.62*	*68.87*	*69.09*	*69.26*	*69.49*	*69.72*	*70.00*

Item	Years												
	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	48 676 026	48 362 288	49 053 015	49 213 265	48 817 403	48 463 568	48 054 765	48 883 303	48 747 993	48 179 078	48 285 240	48 430 728	48 356 354
(+) AAR ($M/yr)	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
PPAR	5 757 889	5 863 796	6 096 233	6 269 053	6 374 091	6 486 088	6 592 161	6 873 465	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 918 060	4 982 181	5 117 988	5 261 744	5 385 005
(-) $O\&M_{WFCM}$	5 315 304	5 412 299	5 626 056	5 784 761	5 880 906	5 983 464	6 080 550	6 339 242	5 846 637	5 922 095	6 082 752	6 252 834	6 398 541
$O\&M_{fixed}$	3 556 919	3 622 341	3 765 927	3 872 684	3 937 570	4 006 754	4 072 279	4 246 052	4 340 155	4 396 739	4 516 586	4 643 449	4 752 224
$O\&M_{variable}$	1 758 385	1 789 958	1 860 129	1 912 077	1 943 336	1 976 710	2 008 271	2 093 190	1 506 483	1 525 356	1 566 166	1 609 385	1 646 316
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 291 002	3 373 277	3 457 609	3 544 049	3 632 650	3 723 467	3 816 553	3 911 967	4 009 766	4 110 011	4 212 761	4 318 080	4 426 032
(=) Profit before tax	4 894 587	5 014 799	5 147 562	4 028 341	4 125 836	4 226 091	4 328 165	4 446 190	3 081 189	3 170 096	3 247 996	3 326 990	3 412 496
(-) Revenue tax	1 727 367	1 759 139	1 828 870	1 880 716	1 912 227	1 945 827	1 977 648	2 062 040	1 475 418	1 494 654	1 535 396	1 578 523	1 615 502
(+) REPIM	1 433	1 459	1 517	1 560	1 586	1 614	1 640	1 710	1 748	1 771	1 819	1 871	1 914
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	1 433	1 459	1 517	1 560	1 586	1 614	1 640	1 710	1 748	1 771	1 819	1 871	1 914
(=) Profit after tax w/out interest	3 168 653	3 257 120	3 320 209	2 149 185	2 215 195	2 281 879	2 352 157	2 385 861	1 607 520	1 677 213	1 714 420	1 750 337	1 798 909
(-) Debt payments	4 155 876	4 259 773	4 366 267	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 291 002	3 373 277	3 457 609	3 544 049	3 632 650	3 723 467	3 816 553	3 911 967	4 009 766	4 110 011	4 212 761	4 318 080	4 426 032
(=) Free net cashflow	5 829 726	5 984 720	6 115 999	9 490 294	9 739 831	9 994 631	10 257 728	10 489 072	9 913 311	10 190 649	10 440 691	10 694 765	10 966 948
$\Sigma_{free\ net\ annual\ cashflow}$	9 126 764	15 111 484	21 227 483	30 717 777	40 457 608	50 452 239	60 709 967	71 199 039	81 112 349	91 302 998	101 743 689	112 438 454	123 405 402
$LCOE_{wso}$	*70.23*	*70.44*	*70.78*	*69.81*	*70.00*	*70.20*	*70.40*	*70.76*	*70.37*	*70.55*	*70.82*	*71.11*	*71.37*

Table O.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of E_{pi} *(Case 3)*

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	89 657 257	90 377 375	89 783 574	89 846 976	89 792 106	90 681 985	90 056 935	89 381 970	90 318 367	90 339 663	89 668 733	90 318 367	90 163 301	90 113 636	89 837 428	89 668 733	90 220 267	90 263 721	90 560 856	90 671 187	89 760 146	90 272 750	90 345 823	89 615 940	89 153 675
(+) AAR ($M/yr)	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
PPAR	-	14 970 925	15 468 449	15 750 988	16 156 163	16 549 954	17 131 821	17 439 078	17 741 084	18 375 119	18 838 939	19 166 502	19 787 994	20 247 871	20 742 636	21 196 034	21 685 138	22 363 982	22 934 122	23 584 858	24 203 932	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 191 828	17 722 258	18 180 019	18 483 975	18 848 346
(-) $O\&M_{WFCM}$	-	9 368 374	9 679 566	9 856 225	10 109 621	10 355 890	10 719 839	10 911 955	11 100 782	11 497 361	11 787 429	11 992 241	12 380 956	12 668 548	12 977 965	13 261 497	13 567 366	13 991 943	14 348 504	14 755 487	15 142 655	13 154 746	13 560 473	13 910 592	14 143 024	14 421 679
$O\&M_{fixed}$	-	4 871 474	5 033 363	5 125 297	5 257 137	5 385 272	5 574 606	5 674 583	5 772 851	5 979 160	6 130 081	6 236 666	6 438 893	6 588 532	6 749 522	6 897 052	7 056 201	7 277 090	7 462 607	7 674 349	7 875 789	7 991 568	8 238 134	8 450 920	8 592 210	8 761 584
$O\&M_{variable}$	-	4 496 901	4 646 203	4 730 927	4 852 484	4 970 618	5 145 234	5 237 372	5 327 931	5 518 200	5 657 348	5 755 575	5 942 063	6 080 016	6 228 443	6 364 445	6 511 165	6 714 853	6 885 898	7 081 137	7 266 866	5 163 178	5 322 339	5 459 672	5 550 813	5 660 095
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 428 489	2 489 201	2 551 431	2 615 217	2 680 598	2 747 613	2 816 303	2 886 711	2 958 878	3 032 850	3 108 672	3 186 388	3 266 048	3 347 699	3 431 392	3 517 176	3 605 106	3 695 234	3 787 614	3 882 305	3 979 362	4 078 846	4 180 818	4 285 338	4 392 471
(=) Profit before tax	-	8 894 308	9 162 934	9 353 166	9 591 405	9 827 549	10 136 303	10 344 553	10 553 167	10 888 446	11 162 464	11 387 989	11 726 109	12 006 371	12 302 395	12 585 704	11 634 948	11 977 145	12 280 851	12 616 986	12 943 581	8 016 444	8 240 631	8 450 244	8 626 290	8 819 138
(-) Revenue tax	-	4 491 277	4 640 535	4 725 296	4 846 849	4 964 986	5 139 546	5 231 723	5 322 325	5 512 536	5 651 682	5 749 951	5 936 398	6 074 361	6 222 791	6 358 810	6 505 541	6 709 195	6 880 237	7 075 458	7 261 179	5 157 549	5 316 677	5 454 006	5 545 193	5 654 504
(+) REPIM	994 456	688	710	723	742	760	787	801	815	844	865	880	909	930	953	973	996	1 027	1 053	1 083	1 112	1 128	1 163	1 193	1 213	1 237
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	994 456	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	688	710	723	742	760	787	801	815	844	865	880	909	930	953	973	996	1 027	1 053	1 083	1 112	1 128	1 163	1 193	1 213	1 237
(=) Profit after tax w/out interest	-	4 403 718	4 523 110	4 628 593	4 745 298	4 863 323	4 997 544	5 113 631	5 231 657	5 376 754	5 511 647	5 638 919	5 790 620	5 932 940	6 080 557	6 227 867	5 130 403	5 268 978	5 401 668	5 542 612	5 683 514	2 860 024	2 925 116	2 997 431	3 082 310	3 165 871
(-) Debt payments	-	-	3 143 363	3 221 947	3 302 495	3 385 058	3 469 684	3 556 426	3 645 337	3 736 470	3 829 882	3 925 629	4 023 770	4 124 364	4 227 473	4 333 160	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 428 489	2 489 201	2 551 431	2 615 217	2 680 598	2 747 613	2 816 303	2 886 711	2 958 878	3 032 850	3 108 672	3 186 388	3 266 048	3 347 699	3 431 392	3 517 176	3 605 106	3 695 234	3 787 614	3 882 305	3 979 362	4 078 846	4 180 818	4 285 338	4 392 471
(=) Free net cashflow	-59 231 444	9 453 946	6 556 231	6 712 542	6 881 346	7 052 772	7 241 729	7 413 921	7 589 454	7 793 496	7 988 808	8 178 009	8 393 187	8 600 571	8 814 879	9 030 547	12 444 639	12 766 069	13 086 187	13 419 244	13 757 062	11 135 410	11 407 388	11 691 760	11 993 996	12 300 349
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 777 498	-43 221 267	-36 508 725	-29 627 379	-22 574 607	-15 332 878	-7 918 958	-329 504	7 463 992	15 452 800	23 630 809	32 023 996	40 624 566	49 439 445	58 469 992	70 914 631	83 680 700	96 766 887	110 186 131	123 943 193	135 078 603	146 485 991	158 177 751	170 171 747	182 472 096
	$LCOE_{wso}$	73.08	73.48	73.74	74.09	74.43	74.89	75.18	75.47	75.97	76.37	76.68	77.18	77.58	78.01	78.41	77.59	78.11	78.56	79.07	79.56	77.68	78.19	78.65	79.00	79.39

Table O.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of E_{pi} *(Case 3)*

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 467 325	213 202 961	213 887 985	212 223 670	212 655 974	213 202 961	212 223 670	212 223 670	213 887 985	212 655 974	213 202 961	212 704 429	212 223 670	213 959 139	213 437 670	213 959 139	213 678 613	213 887 985	213 959 139	213 109 827	213 228 530	212 223 670	213 512 714	212 704 429	213 419 415
(+) AAR ($M/yr)	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
PPAR	-	30 129 143	30 989 297	31 866 088	32 408 583	33 286 465	34 206 386	34 900 500	35 773 012	36 954 893	37 660 580	38 701 386	39 576 163	40 473 880	41 824 978	42 766 117	43 942 368	44 981 873	46 151 597	47 321 124	48 311 614	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 682 891	35 382 431	36 487 277	37 257 877	38 317 694
(-) $O\&M_{WFCM}$	-	20 588 652	21 176 288	21 775 288	22 145 848	22 745 587	23 374 047	23 848 205	24 444 263	25 251 713	25 733 770	26 444 813	27 042 405	27 655 668	28 578 721	29 221 647	30 025 220	30 735 351	31 534 456	32 333 422	33 010 054	29 394 775	29 987 509	30 923 746	31 576 700	32 474 765
$O\&M_{fixed}$	-	11 544 286	11 873 856	12 209 801	12 417 656	12 754 019	13 106 489	13 372 438	13 706 743	14 159 584	14 429 968	14 828 755	15 163 927	15 507 888	16 025 565	16 386 164	16 836 847	17 235 134	17 683 316	18 131 422	18 510 929	18 984 265	19 367 163	19 971 913	20 393 707	20 973 809
$O\&M_{variable}$	-	9 044 366	9 302 432	9 565 487	9 728 192	9 991 568	10 267 558	10 475 767	10 737 520	11 092 129	11 303 802	11 616 058	11 878 478	12 147 781	12 553 156	12 835 484	13 188 373	13 500 217	13 851 140	14 202 000	14 499 125	10 410 511	10 620 346	10 951 834	11 182 993	11 500 957
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 383 862	2 443 459	2 504 545	2 567 159	2 631 338	2 697 121	2 764 549	2 833 663	2 904 504	2 977 117	3 051 545	3 127 834	3 206 029	3 286 180	3 368 335	3 452 543	3 538 857	3 627 328	3 718 011	3 810 962	3 906 236	4 003 892	4 103 989	4 206 589	4 311 753
(=) Profit before tax	-	12 787 622	13 141 318	13 502 317	13 759 540	14 125 103	14 506 169	14 817 971	15 188 567	15 659 493	15 982 031	16 413 174	16 794 274	17 185 241	17 722 462	18 132 580	17 369 691	17 785 378	18 244 469	18 705 713	19 112 522	9 194 351	9 398 813	9 667 519	9 887 766	10 154 682
(-) Revenue tax	-	9 038 743	9 296 789	9 559 826	9 722 575	9 985 940	10 261 916	10 470 150	10 731 904	11 086 468	11 298 174	11 610 416	11 872 849	12 142 164	12 547 493	12 829 835	13 182 710	13 494 562	13 845 479	14 196 337	14 493 484	10 404 867	10 614 729	10 946 183	11 177 363	11 495 308
(+) REPIM	2 082 923	3 008	3 094	3 181	3 236	3 323	3 415	3 484	3 571	3 689	3 760	3 864	3 951	4 041	4 176	4 270	4 387	4 491	4 608	4 724	4 823	4 947	5 046	5 204	5 314	5 465
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	2 082 923	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	3 008	3 094	3 181	3 236	3 323	3 415	3 484	3 571	3 689	3 760	3 864	3 951	4 041	4 176	4 270	4 387	4 491	4 608	4 724	4 823	4 947	5 046	5 204	5 314	5 465
(=) Profit after tax w/out interest	-	3 751 887	3 847 623	3 945 672	4 040 200	4 142 487	4 247 668	4 351 305	4 460 235	4 576 715	4 687 617	4 806 622	4 925 377	5 047 118	5 179 144	5 307 014	4 191 368	4 295 307	4 403 597	4 514 100	4 623 861	-1 205 569	-1 210 870	-1 273 460	-1 284 283	-1 335 161
(-) Debt payments	-	-	3 085 599	3 162 739	3 241 807	3 322 852	3 405 924	3 491 072	3 578 348	3 667 807	3 759 502	3 853 490	3 949 827	4 048 573	4 149 787	4 253 532	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 383 862	2 443 459	2 504 545	2 567 159	2 631 338	2 697 121	2 764 549	2 833 663	2 904 504	2 977 117	3 051 545	3 127 834	3 206 029	3 286 180	3 368 335	3 452 543	3 538 857	3 627 328	3 718 011	3 810 962	3 906 236	4 003 892	4 103 989	4 206 589	4 311 753
(=) Free net cashflow	-58 142 978	8 757 488	5 892 765	6 041 943	6 188 878	6 344 881	6 505 123	6 665 196	6 831 973	7 007 746	7 179 424	7 360 724	7 543 332	7 730 522	7 929 633	8 126 266	11 440 971	11 726 150	12 020 211	12 321 129	12 626 066	6 996 691	7 196 447	7 344 039	7 548 654	7 718 599
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 385 490	-43 492 725	-37 450 782	-31 261 905	-24 917 023	-18 411 901	-11 746 705	-4 914 732	2 093 014	9 272 438	16 633 163	24 176 494	31 907 016	39 836 649	47 962 915	59 403 885	71 130 035	83 150 246	95 471 376	108 097 441	115 094 132	122 290 579	129 634 618	137 183 272	144 901 871
	$LCOE_{wso}$	84.30	84.97	85.66	86.12	86.82	87.54	88.12	88.81	89.72	90.31	91.13	91.84	92.57	93.61	94.37	94.05	94.85	95.75	96.65	97.43	93.92	94.62	95.66	96.43	97.44

APPENDIX P

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inv}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{inv}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85.00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2.0	[d]
$C_{md_{RM_{WT}}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2.0	[d]
$C_{md_{RM_{CT}}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_ψ	5	[yr]
REP_{CM}	0.00002485	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5 693	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1415	[$/kW$_e$h]
ε_0	0.105194	[$/kW$_e$h]
n_ε	12	[yr]
$OREP_{CM}$	20.7438	[$/kW$_e$]
$LCCCM_{WF_{OREG_{CM}}}$	4.3886	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	12	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	2 427.4170	[$/tCO$_2$]
$LCER_{CO_2}$	31.4	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	48 856	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00069	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ CO_2}}$	0.00005	[tCO$_2$/MW$_e$h]
ε_c	41.7438	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**39.7324**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	49 057 055	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**49 057 055**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025840	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mh}	48	[h]
n_{th}	100	[h]
AAR	4 209 586	[$M]
AEP_{avail}	49 057 055	[kWh/yr]
$O\&M_{WFCM}$	**0.124115**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0.000070**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000254**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000324	**[$/kWh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 551 470	[$]
Debt payments	2 985 407	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 551 470	[$]
Discount rate	9.00%	[%/yr]

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*) Period of less hours for production

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Initial Results Summary of $LCOE_{wso}$			Notes
67.6756	yr_1	70.7929	yr_{15}
67.8295	yr_2	69.8226	yr_{15}
68.0385	yr_3	70.0172	yr_{16}
68.2028	yr_4	70.2229	yr_{17}
68.4513	yr_5	70.4241	yr_{18}
68.6399	yr_6	70.7751	yr_{19}
68.8858	yr_7	70.3899	yr_{20}
69.1016	yr_8	70.5764	yr_{21}
69.2789	yr_9	70.8470	yr_{22}
69.5063	yr_{10}	71.1302	yr_{23}
69.7421	yr_{11}	71.3951	yr_{25}
70.0200	yr_{12}	69.6991	Mean
70.2471	yr_{13}	1.0849	SD
70.4639	yr_{14}	-0.4478	ϒ (skewness)
$LCOE_{wso}$	**69.6991**	**US$/MWh**	valid !
	0.069699	**US$/kWh**	

Figure P.1 *I-O representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of *$O\&M_{manag(A)}$* and *E_{pi} (Case $_1$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	*Firestar Wind Farm*	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.6%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWₑ]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer $(O\&M_{wc})$	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inv}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048925	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	14 679 146	[$M]
AEP_{avail}	90 107 610	[kWh/yr]
$O\&M_{WFCM}$	**0.147200**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0.000038**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000138**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000176	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RMCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February(*)	672	648
March	744	736
April	720	712
May	744	736
June(*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November(*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*)Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kWₑ]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_ψ	5	[yr]
REP_{CM}	0.00000982	[$/kWₑh]
AEP_{avail}/H_{prod}	10 458	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1027	[$/kWₑh]
ε_0	0.067500	[$/kWₑh]
n_ε	17	[yr]
$OREP_{CM}$	33.6767	[$/kWₑ]
$LCCCM_{WF_{OREGCM}}$	3.8789	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	17	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	1 248.5415	[$/tCO₂]
$LCER_{CO_2}$	57.6	[tCO₂/MWₑh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	89 657	[MWₑh]
n_ψ	25	[yr]
$GHG_{EM_{ff\,co_2}}$	0.00069	[tCO₂/MWₑh]
$GHG_{EM_{wecs\,co_2}}$	0.00005	[tCO₂/MWₑh]
ε_c	11.7000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**42.9657**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWₑ/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	90 107 610	[kWₑh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWₑh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**90 107 610**	**[kWₑh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 470 640	[$]
Debt payments	2 977 241	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 470 640	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.1255	yr_1	78.4712	yr_{15}
73.5187	yr_2	77.6515	yr_{15}
73.7873	yr_3	78.1612	yr_{16}
74.1334	yr_4	78.6268	yr_{17}
74.4746	yr_5	79.1175	yr_{18}
74.9273	yr_6	79.6115	yr_{19}
75.2253	yr_7	77.7347	yr_{20}
75.5275	yr_8	78.2446	yr_{21}
76.0152	yr_9	78.7103	yr_{22}
76.4118	yr_{10}	79.0644	yr_{23}
76.7332	yr_{11}	79.4723	yr_{25}
77.2289	yr_{12}	76.8666	*Mean*
77.6321	yr_{13}	2.0151	*SD*
78.0589	yr_{14}	-0.4631	Υ *(skewness)*
$LCOE_{wso}$	**76.8666**	**US$/MWh**	*valid !*
	0.076867	**US$/kWh**	

Figure P.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MWₑ wind farm in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)}$ and E_{pi} *(Case ₁)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m^2]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.7%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m^2/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m^2]
Bld_{area}	300.0	[m^2]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$w_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
$LRCM$	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041527	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	29 538 512	[$M]
AEP_{avail}	213 509 813	[kWh/yr]
$O\&M_{WFCM}$	**0.139802**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0.000016**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000058**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000074	**[$/kWh/yr]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m^2/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution		FLH_{wf} [h]	H_{prod} [h]
January		744	740
February(*)		672	648
March		744	736
April		720	712
May		744	736
June(*)		720	696
July		744	736
August		744	736
September		720	712
October		744	736
November(*)		720	696
December		744	736
Total	**[h/yr]**	**8 760**	**8 616**

(*) Period of less hours for production

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_ψ	5	[yr]
REP_{CM}	0.00000049	[$/kW$_e$h]
AEP_{avail}/H_{prod}	24 780	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0121	[$/kW$_e$h]
ε_0	0.008998	[$/kW$_e$h]
n_ε	12	[yr]
$OREP_{CM}$	90.2828	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	4.3886	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	12	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	6 827.9067	[$/tCO$_2$]
$LCER_{CO_2}$	136.4	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+\ldots+yr_n}}$	212 467	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0.00069	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ co_2}}$	0.00005	[tCO$_2$/MW$_e$h]
ε_c	27.0000	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**57.1172**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	213 509 813	[kW$_e$h/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m^2]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**213 509 813**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 116 852	[$]
Debt payments	2 941 500	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 116 852	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.3997	yr_1	94.4943	yr_{15}
85.0669	yr_2	94.1699	yr_{15}
85.7507	yr_3	94.9708	yr_{16}
86.2255	yr_4	95.8775	yr_{17}
86.9196	yr_5	96.7795	yr_{18}
87.6452	yr_6	97.5702	yr_{19}
88.2242	yr_7	94.0503	yr_{20}
88.9241	yr_8	94.7536	yr_{21}
89.8260	yr_9	95.8087	yr_{22}
90.4267	yr_{10}	96.5649	yr_{23}
91.2477	yr_{11}	97.5891	yr_{25}
91.9572	yr_{12}	91.8264	Mean
92.6946	yr_{13}	4.2043	SD
93.7245	yr_{14}	-0.3333	ϒ (skewness)
$LCOE_{wso}$	**91.8264**	**US$/MWh**	valid !
	0.091826	**US$/kWh**	

Figure P.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical $50MW_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)}$ and E_{pi} *(Case $_1$)*. Source: Own elaboration

Table P.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_1)$

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	740	1 697 720	8 914 291	3 812 469	7 527 755	558 872	8 914 291	558 872	558 872	4 243 681	8 914 291	8 914 291	558 872	3 812 469	7 527 755	4 243 681	8 914 291	8 914 291	558 872	3 812 469	7 527 755	558 872	3 812 469	7 527 755	4 243 681	4 243 681
February	4.9	1.1666	648	859 945	6 879 561	3 714 421	6 879 561	788 321	6 879 561	788 321	788 321	4 780 152	6 879 561	6 879 561	788 321	3 714 421	6 879 561	489 171	489 171	3 336 988	4 780 152	7 802 526	1 594 674	1 594 674	7 802 526	6 879 561	4 780 152	4 780 152
March	4.0	1.1671	736	555 877	7 487 419	5 432 002	8 866 525	977 212	7 487 419	977 212	977 212	6 552 645	7 487 419	7 487 419	977 212	5 432 002	8 866 525	895 822	895 822	1 812 134	4 220 942	1 812 134	1 688 623	1 688 623	7 817 699	8 866 525	3 792 040	6 552 645
April	4.7	1.1667	712	866 366	6 337 184	6 337 184	4 082 151	1 633 098	6 337 184	1 633 098	1 633 098	7 241 220	6 337 184	6 337 184	1 752 548	6 337 184	4 082 151	945 080	945 080	1 633 098	6 337 184	1 633 098	3 667 352	945 080	7 241 220	6 337 184	1 752 548	7 241 220
May	6.0	1.1670	736	1 812 066	5 431 800	7 487 140	5 431 800	1 812 066	5 431 800	1 812 066	1 812 066	7 817 409	5 431 800	5 431 800	1 688 560	7 487 140	6 552 401	1 688 560	1 688 560	977 176	8 866 195	977 176	555 856	895 788	6 552 401	4 220 785	1 688 560	7 817 409
June	7.9	1.1686	696	3 996 852	3 996 852	7 402 657	6 204 764	3 590 720	3 996 852	3 590 720	3 590 720	8 395 800	3 996 852	3 996 852	3 590 720	7 402 657	5 143 616	1 715 927	1 715 927	848 262	7 402 657	848 262	848 262	3 590 720	5 143 616	5 143 616	925 332	8 395 800
July	8.6	1.1698	736	5 444 782	3 800 962	8 887 385	1 692 596	4 230 873	3 800 962	4 230 873	4 230 873	557 185	557 185	3 800 962	5 444 782	8 887 385	1 816 397	3 800 962	3 800 962	557 185	7 505 034	557 185	979 511	4 230 873	4 230 873	1 692 596	897 929	557 185
August	9.6	1.1677	736	7 491 301	1 813 073	1 813 073	1 813 073	8 871 123	1 813 073	5 434 819	5 434 819	896 286	896 286	1 813 073	4 223 131	1 813 073	1 689 499	5 434 819	7 821 753	7 821 753	896 286	4 223 131	7 821 753	5 434 819	1 813 073	1 813 073	556 165	896 286
September	10.1	1.1657	712	8 566 923	1 631 564	1 631 564	3 663 906	7 553 538	1 631 564	6 331 230	6 331 230	944 192	944 192	1 631 564	6 331 230	1 631 564	3 663 906	6 331 230	7 234 417	7 234 417	944 192	5 248 454	8 566 923	6 331 230	1 631 564	3 663 906	6 331 230	944 192
October	9.7	1.1645	736	7 800 246	975 031	975 031	554 636	7 470 703	975 031	7 470 703	7 470 703	1 684 853	1 684 853	975 031	8 846 730	975 031	554 636	7 470 703	6 538 016	6 538 016	1 808 088	6 538 016	4 211 519	7 470 703	975 031	975 031	8 846 730	1 684 853
November	9.2	1.1638	696	6 179 252	844 775	844 775	844 775	6 179 252	844 775	7 372 218	7 372 218	1 708 872	1 708 872	844 775	7 372 218	844 775	844 775	7 372 218	5 122 467	5 122 467	1 592 399	7 060 758	6 179 252	7 372 218	844 775	844 775	7 372 218	1 708 872
December	7.6	1.1651	736	3 785 725	554 951	554 951	975 585	5 422 956	554 951	8 851 759	8 851 759	3 785 725	3 785 725	554 951	7 474 950	554 951	975 585	8 851 759	4 213 913	4 213 913	3 785 725	7 804 681	5 422 956	8 851 759	554 951	554 951	7 474 950	3 785 725
Annual	7.4	1.1666	8 616	49 057 055	48 667 462	48 892 652	48 537 127	49 088 734	48 667 462	49 051 893	49 051 893	48 608 021	48 624 219	48 667 462	49 049 275	48 892 652	48 596 807	49 239 932	49 380 379	49 009 701	48 697 726	48 317 889	49 064 437	48 965 360	48 420 199	48 519 758	48 661 536	48 608 021

Table P.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_1)$

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	740	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408
February	11.5	1.2345	648	12 092 721	4 293 137	12 092 721	12 092 721	12 092 721	3 417 096	12 092 721	12 715 785	1 795 784	3 417 096	12 715 785	1 795 784	9 244 173	12 092 721	6 674 015	12 715 785	4 293 137	5 486 290	3 417 096	2 815 600	12 092 721	2 106 703	6 674 015	12 092 721	12 715 785
March	10.5	1.2329	736	10 486 228	3 193 907	13 717 510	13 717 510	13 717 510	6 223 433	13 717 510	13 717 510	2 389 762	3 193 907	13 717 510	2 389 762	13 717 510	13 717 510	6 223 433	13 717 510	3 876 220	7 570 742	4 869 967	13 717 510	14 424 289	2 037 067	10 486 228	14 424 289	3 193 907
April	9.5	1.2317	712	7 316 597	7 316 597	10 458 483	10 458 483	10 458 483	7 316 597	10 458 483	4 706 485	3 086 689	7 316 597	13 257 022	3 086 689	13 257 022	4 706 485	4 706 485	13 257 022	3 086 689	10 134 212	3 086 689	13 940 075	13 257 022	3 086 689	3 086 689	13 257 022	3 746 098
May	8.2	1.2282	736	4 851 676	10 446 845	10 446 845	10 446 845	6 200 059	10 446 845	10 446 845	10 446 845	3 861 662	6 200 059	10 446 845	3 861 662	14 370 115	10 446 845	3 861 662	10 446 845	2 380 787	13 665 991	6 200 059	2 380 787	10 446 845	3 861 662	14 370 115	10 446 845	4 851 676
June	7.1	1.2224	696	2 994 461	12 860 910	7 097 981	7 097 981	7 097 981	10 145 990	4 565 858	12 860 910	4 565 858	10 145 990	7 097 981	4 565 858	7 097 981	2 240 532	2 994 461	7 097 981	1 909 861	12 860 910	7 097 981	1 909 861	7 097 981	4 565 858	12 860 910	7 097 981	5 834 806
July	6.1	1.2154	736	2 008 118	13 522 571	4 800 760	6 134 992	10 337 209	13 522 571	7 463 154	3 148 518	6 134 992	2 008 118	6 134 992	6 134 992	6 134 992	2 008 118	2 355 801	6 134 992	6 134 992	14 219 306	10 337 209	3 821 135	6 134 992	6 134 992	13 522 571	3 821 135	7 463 154
August	6.4	1.2075	736	2 340 496	10 598 668	3 796 310	3 796 310	3 796 310	13 434 719	6 095 134	3 796 310	7 414 668	2 340 496	4 769 571	7 414 668	4 769 571	10 598 668	1 995 072	4 769 571	13 434 719	1 995 072	13 434 719	4 769 571	4 769 571	7 414 668	4 769 571	3 128 063	10 270 051
September	7.6	1.2064	712	3 669 202	1 928 273	5 891 057	4 609 876	4 609 876	4 609 876	1 928 273	5 891 057	9 926 189	9 926 189	3 669 202	9 926 189	3 669 202	5 891 057	9 926 189	3 669 202	12 984 898	2 262 132	12 984 898	5 891 057	3 669 202	9 926 189	3 669 202	2 262 132	1 928 273
October	8.9	1.2126	736	6 121 079	6 121 079	3 141 378	2 003 564	3 141 378	2 003 564	2 350 459	7 446 229	13 491 905	13 491 905	3 141 378	13 491 905	3 141 378	7 446 229	13 491 905	3 141 378	10 643 782	3 141 378	2 003 564	7 446 229	3 141 378	13 491 905	2 350 459	2 003 564	2 350 459
November	10.6	1.2194	696	10 121 586	3 625 425	2 235 143	2 235 143	2 235 143	2 235 143	2 987 258	2 235 143	12 829 976	4 554 876	2 235 143	12 829 976	2 235 143	2 987 258	12 829 976	2 235 143	9 807 761	3 625 425	2 235 143	9 807 761	2 235 143	12 829 976	1 905 267	5 820 771	12 829 976
December	11.5	1.2237	736	13 614 984	2 371 901	2 021 842	3 170 035	2 021 842	3 170 035	3 847 249	2 021 842	14 316 481	13 614 984	2 021 842	14 316 481	2 021 842	3 847 249	14 316 481	2 021 842	7 514 158	4 833 568	14 316 481	13 614 984	2 021 842	14 316 481	6 176 918	4 833 568	13 614 984
Annual	9.1	1.2222	8 616	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577

Table P.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_1)$

Months	v_{wc}		H_{prod}	$AEP_{avail}(kWh)$																								
	(m/s)	(kg/m^3)	(h)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	740	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	8 035 210	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	40 865 255	32 823 510	32 823 510	28 095 929	8 035 210	7 120 177
February	14.7	1.2522	648	24 591 404	14 672 254	7 010 451	26 599 864	14 672 254	14 672 254	26 599 864	26 599 864	7 010 451	14 672 254	14 672 254	7 859 649	26 599 864	7 010 451	17 623 290	7 010 451	7 010 451	7 010 451	7 010 451	22 780 600	26 599 864	26 599 864	29 369 594	7 859 649	17 596 916
March	12.7	1.2495	736	18 252 376	18 252 376	8 908 878	27 874 248	12 394 144	18 252 376	27 874 248	27 874 248	8 908 878	12 394 144	18 252 376	9 986 084	27 874 248	8 908 878	30 150 829	8 908 878	8 908 878	8 908 878	8 908 878	23 024 061	27 874 248	27 874 248	31 459 374	9 986 084	18 948 162
April	12.4	1.2490	712	16 081 249	19 315 677	9 656 023	24 865 308	9 656 023	19 315 677	24 865 308	24 865 308	9 656 023	9 656 023	19 315 677	9 656 023	24 865 308	9 656 023	26 952 947	9 656 023	29 154 282	9 656 023	9 656 023	22 218 160	20 001 184	24 865 308	24 956 459	9 656 023	18 165 621
May	11.2	1.2425	736	12 324 064	25 569 850	9 929 620	19 862 973	9 929 620	25 569 850	19 862 973	19 862 973	9 929 620	9 929 620	25 569 850	12 324 064	19 862 973	9 929 620	25 569 850	9 929 620	27 716 641	9 929 620	9 929 620	21 018 978	19 862 973	19 862 973	19 116 345	12 324 064	16 191 245
June	10.4	1.2351	696	9 333 787	26 053 485	11 584 551	17 060 120	8 326 944	26 053 485	17 060 120	17 060 120	11 584 551	8 326 944	26 053 485	15 544 593	17 060 120	11 584 551	17 060 120	11 584 551	24 035 514	11 584 551	11 584 551	17 178 664	17 060 120	17 060 120	16 981 395	15 544 593	15 146 363
July	10.0	1.2275	736	8 751 923	29 619 639	16 337 936	16 337 936	7 806 320	29 619 639	16 337 936	16 337 936	16 337 936	7 806 320	29 619 639	17 930 811	16 337 936	16 337 936	7 806 320	16 337 936	19 623 991	16 337 936	16 337 936	15 552 737	16 069 219	16 337 936	16 783 950	17 930 811	8 637 391
August	9.7	1.2216	736	7 768 712	12 117 129	17 844 428	12 117 129	17 844 428	12 117 129	12 117 129	12 117 129	17 844 428	17 844 428	12 117 129	19 529 451	12 117 129	17 844 428	8 709 760	17 844 428	17 844 428	17 844 428	17 844 428	12 921 415	15 399 666	12 117 129	12 606 836	19 529 451	7 121 992
September	10.4	1.2234	712	9 458 082	7 526 165	18 919 721	9 458 082	26 400 433	7 526 165	9 458 082	9 458 082	18 919 721	26 400 433	7 526 165	24 355 589	9 458 082	18 919 721	9 458 082	18 919 721	15 751 596	18 919 721	18 919 721	12 339 146	13 294 981	9 458 082	8 855 020	24 355 589	19 057 688
October	13.1	1.2327	736	19 706 914	8 788 905	29 744 799	9 851 605	25 368 953	8 788 905	9 851 605	9 851 605	29 744 799	25 368 953	8 788 905	27 498 877	9 851 605	25 368 953	9 851 605	25 368 953	12 227 237	29 744 799	25 368 953	12 259 773	8 871 247	9 851 605	8 134 157	27 498 877	21 626 625
November	14.3	1.2429	696	24 188 639	9 393 250	26 219 466	8 379 993	28 360 895	9 393 250	8 379 993	8 379 993	26 219 466	28 360 895	9 393 250	28 360 895	8 379 993	26 219 466	11 658 353	26 219 466	9 393 250	26 219 466	26 219 466	7 520 762	8 379 993	8 379 993	8 987 716	28 360 895	22 240 116
December	15.1	1.2528	736	30 229 153	10 012 025	25 782 051	7 966 958	20 027 814	10 012 025	7 966 958	7 966 958	25 782 051	20 027 814	10 012 025	32 544 702	7 966 958	30 229 153	16 674 139	30 229 153	10 012 025	25 782 051	30 229 153	6 359 397	7 966 958	7 966 958	9 176 637	32 544 702	42 535 343
Annual	12.5	1.2404	8 616	213 509 813	214 144 266	214 761 434	213 197 728	213 611 337	214 144 266	213 197 728	213 197 728	214 761 434	213 611 337	214 144 266	213 625 948	213 197 728	214 832 689	214 338 805	214 832 689	214 501 803	214 761 434	214 832 689	214 038 947	214 203 964	213 197 728	214 523 412	213 625 948	214 387 639

Table P.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_1)$

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table P.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_1)$

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table P.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_1)$

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table P.7 kWh per H_{prod} with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case\ _1)$

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 693	5 648	5 674	5 633	5 697	5 648	5 693	5 693	5 641	5 643	5 648	5 693	5 674	5 640	5 715	5 731	5 688	5 652	5 608	5 694	5 683	5 620	5 631	5 648	5 641
Corvo Island (Portugal)	10 458	10 535	10 467	10 475	10 468	10 563	10 497	10 429	10 525	10 527	10 454	10 525	10 507	10 500	10 474	10 454	10 510	10 523	10 545	10 560	10 464	10 520	10 532	10 452	10 407
Cape Saint James (Canada)	24 780	24 853	24 925	24 743	24 791	24 853	24 743	24 743	24 925	24 791	24 853	24 793	24 743	24 933	24 876	24 933	24 895	24 925	24 933	24 841	24 860	24 743	24 897	24 793	24 882

Table P.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case\ _1)$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	49 057 055	48 667 462	48 892 652	48 537 127	49 088 734	48 667 462	49 051 893	49 051 893	48 608 021	48 624 219	48 667 462	49 049 275	48 892 652	48 596 807	49 239 932	49 380 379	49 009 701	48 697 726	48 317 889	49 064 437	48 965 360	48 420 199	48 519 758	48 661 536	48 608 021
(+) AAR ($M/yr)	-	4 314 826	4 387 573	4 518 071	4 597 349	4 765 836	4 843 059	5 003 348	5 128 432	5 209 075	5 341 081	5 479 477	5 660 527	5 783 513	5 892 231	6 119 463	6 290 341	6 399 200	6 517 427	6 628 256	6 898 935	4 939 990	5 007 115	5 142 845	5 286 820	5 413 031
PPAR	-	4 314 826	4 387 573	4 518 071	4 597 349	4 765 836	4 843 059	5 003 348	5 128 432	5 209 075	5 341 081	5 479 477	5 660 527	5 783 513	5 892 231	6 119 463	6 290 341	6 399 200	6 517 427	6 628 256	6 898 935	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4 939 990	5 007 115	5 142 845	5 286 820	5 413 031
(-) $O\&M_{WFCM}$	-	3 964 703	4 031 427	4 151 213	4 223 934	4 378 615	4 471 031	4 618 343	4 733 137	4 806 905	4 928 061	5 055 095	5 221 459	5 334 243	5 433 856	5 642 744	5 799 641	5 899 344	6 007 676	6 109 183	6 357 999	5 867 984	5 947 062	6 107 615	6 277 939	6 427 153
$O\&M_{fixed}$	-	2 665 486	2 710 424	2 791 038	2 840 010	2 944 091	2 991 795	3 090 812	3 168 081	3 217 896	3 299 441	3 384 934	3 496 775	3 572 748	3 639 907	3 780 277	3 885 835	3 953 081	4 026 113	4 094 576	4 261 785	4 359 507	4 418 743	4 538 523	4 665 578	4 776 957
$O\&M_{variable}$	-	1 299 217	1 321 003	1 360 175	1 383 923	1 434 523	1 479 236	1 527 531	1 565 056	1 589 009	1 628 620	1 670 162	1 724 683	1 761 494	1 793 950	1 862 467	1 913 806	1 946 264	1 981 563	2 014 606	2 096 214	1 508 477	1 528 319	1 569 092	1 612 361	1 650 196
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 423 221	2 483 801	2 545 896	2 609 544	2 674 782	2 741 652	2 810 193	2 880 448	2 952 459	3 026 270	3 101 927	3 179 475	3 258 962	3 340 436	3 423 947	3 509 546	3 597 285	3 687 217	3 779 397	3 873 882	3 970 729	4 069 997	4 171 747	4 276 041	4 382 942
(=) Profit before tax	-	3 636 612	3 724 797	3 819 726	3 912 604	4 014 890	4 090 389	4 196 325	4 301 898	4 406 438	4 517 395	4 631 365	4 751 227	4 869 233	4 988 836	5 120 442	4 000 245	4 097 140	4 196 967	4 298 471	4 414 818	3 042 735	3 130 050	3 206 977	3 284 921	3 368 820
(-) Revenue tax	-	1 294 448	1 316 272	1 355 421	1 379 205	1 429 751	1 452 918	1 501 004	1 538 530	1 562 723	1 602 324	1 643 843	1 698 158	1 735 054	1 767 669	1 835 839	1 887 102	1 919 760	1 955 228	1 988 477	2 069 680	1 481 997	1 502 134	1 542 854	1 586 046	1 623 909
(+) REPIM	1 122 960	1 725	1 670	1 637	1 585	1 564	1 513	1 488	1 451	1 403	1 369	1 337	1 315	-	-	-	-	-	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 725	1 670	1 637	1 585	1 564	1 513	1 488	1 451	1 403	1 369	1 337	1 315	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	259 298	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	2 343 889	2 410 195	2 465 941	2 534 985	2 586 703	2 638 984	2 696 808	2 764 820	2 845 118	2 916 440	2 988 859	3 054 383	3 134 179	3 221 167	3 284 603	2 113 143	2 177 380	2 241 739	2 309 994	2 345 137	1 560 738	1 627 915	1 664 124	1 698 875	1 744 911
(-) Debt payments	-	-	3 136 543	3 214 957	3 295 331	3 377 714	3 462 157	3 548 711	3 637 428	3 728 364	3 821 573	3 917 112	4 015 040	4 115 416	4 218 302	4 323 759	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 423 221	2 483 801	2 545 896	2 609 544	2 674 782	2 741 652	2 810 193	2 880 448	2 952 459	3 026 270	3 101 927	3 179 475	3 258 962	3 340 436	3 423 947	3 509 546	3 597 285	3 687 217	3 779 397	3 873 882	3 970 729	4 069 997	4 171 747	4 276 041	4 382 942
(=) Free net cashflow	-59 102 941	7 388 849	4 444 735	4 551 345	4 672 524	4 777 681	4 884 735	4 998 704	5 124 263	5 263 547	5 395 329	5 529 722	5 658 767	5 803 672	5 957 397	6 089 239	9 419 749	9 666 651	9 918 241	10 178 409	10 410 263	9 827 491	10 101 337	10 349 381	10 601 265	10 869 860
$\Sigma_{free\ net\ annual\ cashflow}$	-	-51 714 092	-47 269 357	-42 718 012	-38 045 489	-33 267 808	-28 383 073	-23 384 369	-18 260 106	-12 996 559	-7 601 229	-2 071 508	3 587 259	9 390 931	15 348 328	21 437 567	30 857 316	40 523 967	50 442 208	60 620 617	71 030 879	80 858 371	90 959 708	101 309 090	111 910 354	122 780 214
	$LCOE_{wso}$	67.68	67.83	68.04	68.20	68.45	68.64	68.89	69.10	69.28	69.51	69.74	70.02	70.25	70.46	70.79	69.82	70.02	70.22	70.42	70.78	70.39	70.58	70.85	71.13	71.40

Table P.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ (Case $_1$)

Item	Years 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577
(+) AAR ($M/yr)	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
PPAR	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
(-) $O\&M_{WFCM}$	-	9 414 550	9 720 704	9 900 012	10 154 527	10 401 931	10 758 472	10 957 897	11 159 028	11 543 192	11 833 646	12 046 185	12 430 378	12 719 232	13 028 853	13 321 057	13 628 511	14 043 351	14 411 633	14 802 558	15 194 336	13 212 815	13 615 294	13 970 912	14 212 144	14 504 416
$O\&M_{fixed}$	-	4 895 943	5 055 217	5 148 526	5 280 948	5 409 674	5 595 159	5 698 935	5 803 599	6 003 456	6 154 579	6 265 179	6 465 057	6 615 352	6 776 449	6 928 488	7 088 460	7 304 288	7 495 901	7 699 294	7 903 132	8 027 381	8 271 977	8 488 105	8 634 738	8 812 382
$O\&M_{variable}$	-	4 518 607	4 665 487	4 751 486	4 873 579	4 992 258	5 163 313	5 258 962	5 355 430	5 539 736	5 679 068	5 781 006	5 965 321	6 103 880	6 252 405	6 392 569	6 540 051	6 739 063	6 915 732	7 103 264	7 291 205	5 185 434	5 343 317	5 482 807	5 577 406	5 692 034
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 416 592	2 477 007	2 538 932	2 602 406	2 667 466	2 734 153	2 802 506	2 872 569	2 944 383	3 017 993	3 093 443	3 170 779	3 250 048	3 331 299	3 414 582	3 499 946	3 587 445	3 677 131	3 769 060	3 863 286	3 959 868	4 058 865	4 160 336	4 264 345	4 370 954
(=) Profit before tax	-	8 911 435	9 176 763	9 368 266	9 606 864	9 843 367	10 147 375	10 359 653	10 575 273	10 902 786	11 176 673	11 406 441	11 741 486	12 022 111	12 317 857	12 605 942	11 655 712	11 991 661	12 301 941	12 628 019	12 956 912	8 015 924	8 238 634	8 449 437	8 627 664	8 824 163
(-) Revenue tax	-	4 513 837	4 660 683	4 746 712	4 868 802	4 987 484	5 158 496	5 254 175	5 350 673	5 534 936	5 674 267	5 776 238	5 960 521	6 099 089	6 247 616	6 387 792	6 535 283	6 734 270	6 910 933	7 098 455	7 286 389	5 180 661	5 338 519	5 478 004	5 572 639	5 687 288
(+) REPIM	1 284 621	1 253	1 231	1 193	1 165	1 136	1 118	1 084	1 051	1 035	1 010	978	961	936	912	888	865	848	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 253	1 231	1 193	1 165	1 136	1 118	1 084	1 051	1 035	1 010	978	961	936	912	888	865	848	-	-	-	-	-	-	-	-
$OREP_{CM}$	420 959	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	4 398 850	4 517 311	4 622 747	4 739 227	4 857 019	4 989 997	5 106 562	5 225 651	5 368 885	5 503 416	5 631 182	5 781 926	5 923 958	6 071 154	6 219 037	5 121 294	5 258 239	5 391 008	5 529 564	5 670 523	2 835 263	2 900 115	2 971 434	3 055 025	3 136 875
(-) Debt payments	-	-	3 127 964	3 206 163	3 286 317	3 368 475	3 452 687	3 539 004	3 627 479	3 718 166	3 811 120	3 906 398	4 004 058	4 104 160	4 206 764	4 311 933	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 416 592	2 477 007	2 538 932	2 602 406	2 667 466	2 734 153	2 802 506	2 872 569	2 944 383	3 017 993	3 093 443	3 170 779	3 250 048	3 331 299	3 414 582	3 499 946	3 587 445	3 677 131	3 769 060	3 863 286	3 959 868	4 058 865	4 160 336	4 264 345	4 370 954
(=) Free net cashflow	-58 941 280	9 437 182	6 553 636	6 709 981	6 878 642	7 049 919	7 237 720	7 410 477	7 587 164	7 789 436	7 984 481	8 174 273	8 388 595	8 595 794	8 809 785	9 026 135	12 418 300	12 737 670	13 057 425	13 387 641	13 725 053	11 091 155	11 362 405	11 645 281	11 945 718	12 249 836
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 504 098	-42 950 462	-36 240 481	-29 361 839	-22 311 920	-15 074 200	-7 663 723	-76 559	7 712 878	15 697 359	23 871 632	32 260 227	40 856 021	49 665 807	58 691 941	71 110 241	83 847 911	96 905 336	110 292 978	124 018 031	135 109 186	146 471 591	158 116 872	170 062 590	182 312 426
	$LCOE_{wso}$	*73.13*	*73.52*	*73.79*	*74.13*	*74.47*	*74.93*	*75.23*	*75.53*	*76.02*	*76.41*	*76.73*	*77.23*	*77.63*	*78.06*	*78.47*	*77.65*	*78.16*	*78.63*	*79.12*	*79.61*	*77.73*	*78.24*	*78.71*	*79.06*	*79.47*

Table P.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ (Case $_1$)

Item	Years 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	213 509 813	214 144 266	214 761 434	213 197 728	213 611 337	214 144 266	213 197 728	213 197 728	214 761 434	213 611 337	214 144 266	213 625 948	213 197 728	214 832 689	214 338 805	214 832 689	214 501 803	214 761 434	214 832 689	214 038 947	214 203 964	213 197 728	214 523 412	213 625 948	214 387 639
(+) AAR ($M/yr)	-	30 276 974	31 126 117	31 996 219	32 557 331	33 436 006	34 357 409	35 060 685	35 937 202	37 105 804	37 829 772	38 872 255	39 747 622	40 659 646	41 995 741	42 946 676	44 121 775	45 155 164	46 340 065	47 514 326	48 522 244	34 841 551	35 544 828	36 659 995	37 419 293	38 491 531
PPAR	-	30 276 974	31 126 117	31 996 219	32 557 331	33 436 006	34 357 409	35 060 685	35 937 202	37 105 804	37 829 772	38 872 255	39 747 622	40 659 646	41 995 741	42 946 676	44 121 775	45 155 164	46 340 065	47 514 326	48 522 244	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 841 551	35 544 828	36 659 995	37 419 293	38 491 531
(-) $O\&M_{WFCM}$	-	20 688 790	21 268 898	21 863 324	22 246 612	22 846 890	23 476 361	23 956 782	24 555 577	25 353 946	25 848 498	26 560 685	27 158 681	27 781 721	28 694 515	29 344 137	30 146 919	30 852 873	31 662 346	32 464 546	33 153 088	29 528 360	30 124 265	31 069 244	31 712 621	32 621 209
$O\&M_{fixed}$	-	11 600 929	11 926 280	12 259 661	12 474 651	12 811 317	13 164 355	13 433 815	13 769 654	14 217 407	14 494 795	14 894 225	15 229 623	15 579 065	16 090 994	16 455 346	16 905 588	17 301 532	17 755 529	18 205 449	18 591 634	19 071 110	19 456 054	20 066 453	20 482 061	21 068 961
$O\&M_{variable}$	-	9 087 862	9 342 619	9 603 663	9 771 962	10 035 573	10 312 006	10 522 968	10 785 923	11 136 539	11 353 703	11 666 460	11 929 059	12 202 656	12 603 521	12 888 791	13 241 331	13 551 341	13 906 817	14 259 097	14 561 454	10 457 250	10 668 211	11 002 791	11 230 560	11 552 248
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 387 582	2 447 271	2 508 453	2 571 165	2 635 444	2 701 330	2 768 863	2 838 085	2 909 037	2 981 763	3 056 307	3 132 714	3 211 032	3 291 308	3 373 591	3 457 930	3 544 379	3 632 988	3 723 813	3 816 908	3 912 331	4 010 139	4 110 393	4 213 152	4 318 481
(=) Profit before tax	-	12 839 034	13 189 340	13 548 319	13 811 529	14 177 446	14 559 087	14 873 892	15 245 865	15 712 704	16 041 140	16 472 933	16 854 338	17 249 956	17 782 558	18 195 905	17 432 786	17 846 670	18 310 707	18 773 593	19 186 064	9 225 522	9 430 702	9 701 144	9 919 825	10 188 803
(-) Revenue tax	-	9 083 092	9 337 835	9 598 866	9 767 199	10 030 802	10 307 223	10 518 205	10 781 161	11 131 741	11 348 931	11 661 677	11 924 287	12 197 894	12 598 722	12 884 003	13 236 533	13 546 549	13 902 019	14 254 298	14 556 673	10 452 465	10 663 448	10 997 999	11 225 788	11 547 459
(+) REPIM	1 992 197	148	144	141	137	134	131	127	124	122	118	116	113	-	-	-	-	-	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	148	144	141	137	134	131	127	124	122	118	116	113	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	1 128 535	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	3 756 090	3 851 649	3 949 595	4 044 466	4 146 778	4 251 995	4 355 814	4 464 828	4 581 084	4 692 327	4 811 372	4 930 164	5 052 063	5 183 836	5 311 903	4 196 254	4 300 121	4 408 688	4 519 295	4 629 391	-1 226 944	-1 232 746	-1 296 854	-1 305 963	-1 358 656
(-) Debt payments	-	-	3 090 413	3 167 674	3 246 866	3 328 037	3 411 238	3 496 519	3 583 932	3 673 530	3 765 369	3 859 503	3 955 990	4 054 890	4 156 262	4 260 169	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 387 582	2 447 271	2 508 453	2 571 165	2 635 444	2 701 330	2 768 863	2 838 085	2 909 037	2 981 763	3 056 307	3 132 714	3 211 032	3 291 308	3 373 591	3 457 930	3 544 379	3 632 988	3 723 813	3 816 908	3 912 331	4 010 139	4 110 393	4 213 152	4 318 481
(=) Free net cashflow	-58 233 703	8 765 410	5 895 790	6 044 838	6 192 091	6 348 094	6 508 343	6 668 571	6 835 404	7 010 925	7 182 913	7 364 223	7 546 836	7 734 152	7 932 977	8 129 773	11 451 244	11 736 485	12 030 961	12 332 126	12 637 542	6 981 412	7 180 818	7 327 049	7 533 538	7 701 832
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 468 293	-43 572 504	-37 527 665	-31 335 574	-24 987 480	-18 479 137	-11 810 566	-4 975 162	2 035 763	9 218 676	16 582 900	24 129 736	31 863 888	39 796 865	47 926 638	59 377 881	71 114 367	83 145 328	95 477 454	108 114 996	115 096 408	122 277 226	129 604 275	137 137 813	144 839 645
	$LCOE_{wso}$	*84.40*	*85.07*	*85.75*	*86.23*	*86.92*	*87.65*	*88.22*	*88.92*	*89.83*	*90.43*	*91.25*	*91.96*	*92.69*	*93.72*	*94.49*	*94.17*	*94.97*	*95.88*	*96.78*	*97.57*	*94.05*	*94.75*	*95.81*	*96.56*	*97.59*

APPENDIX Q

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inv}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{inv}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{MhrRMWT}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{MhrRMCT}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{MhrS\&RV}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kWe]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_ψ	5	[yr]
REP_{CM}	0.00002485	[$/kWeh]
AEP_{avail}/H_{prod}	5 693	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1415	[$/kWeh]
ε_0	0.105194	[$/kWeh]
n_ε	12	[yr]
$OREP_{CM}$	20.7438	[$/kWe]
$LCCCM_{WF_{OREGCM}}$	4.3886	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	12	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	2 427.4170	[$/tCO₂]
$LCER_{CO_2}$	31.4	[tCO₂/MWeh]
$\sum AEP_{avail\ yr_1+...+yr_n}$	48 856	[MWeh]
n_ψ	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0.00069	[tCO₂/MWeh]
$GHG_{EM_{wecs\ co_2}}$	0.00005	[tCO₂/MWeh]
ε_c	41.7438	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**39.7324**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWe/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	49 057 055	[kWeh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWeh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**49 057 055**	**[kWeh/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWe]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025840	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	4 209 586	[$M]
AEP_{avail}	49 057 055	[kWh/yr]
$O\&M_{WFCM}$	**0.124115**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0.000070**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000254**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000324	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0 = no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 551 470	[$]
Debt payments	2 985 407	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 551 470	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67.6756	yr_1	70.7929	yr_{15}
67.8295	yr_2	69.8226	yr_{15}
68.0385	yr_3	70.0172	yr_{16}
68.2028	yr_4	70.2229	yr_{17}
68.4513	yr_5	70.4241	yr_{18}
68.6399	yr_6	70.7751	yr_{19}
68.8858	yr_7	70.3899	yr_{20}
69.1016	yr_8	70.5764	yr_{21}
69.2789	yr_9	70.8470	yr_{22}
69.5063	yr_{10}	71.1302	yr_{23}
69.7421	yr_{11}	71.3951	yr_{25}
70.0200	yr_{12}	69.6991	Mean
70.2471	yr_{13}	1.0849	SD
70.4639	yr_{14}	-0.4478	ϒ (skewness)
$LCOE_{wso}$	**69.6991**	**US$/MWh**	valid !
	0.069699	**US$/kWh**	

Figure Q.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)}$ and E_{pi} *(Case $_2$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.6%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWₑ]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer $(O\&M_{ccm})$	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048925	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	14 679 146	[$M]
AEP_{avail}	90 107 610	[kWh/yr]
$O\&M_{WFCM}$	**0.147200**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0.000038**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000138**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000176	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kWₑ]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_ψ	5	[yr]
REP_{CM}	0.00000982	[$/kWₑh]
AEP_{avail}/H_{prod}	10 458	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1027	[$/kWₑh]
ε_0	0.067500	[$/kWₑh]
n_ε	17	[yr]
$OREP_{CM}$	33.6767	[$/kWₑ]
$LCCCM_{WF_{OREGCM}}$	3.8789	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	17	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	1 248.5415	[$/tCO₂]
$LCER_{CO_2}$	57.6	[tCO₂/MWₑh]
$\sum AEP_{avail_{yr_1+\ldots+yr_n}}$	89 657	[MWₑh]
n_ψ	25	[yr]
$GHG_{EM_{ff\,CO_2}}$	0.00069	[tCO₂/MWₑh]
$GHG_{EM_{wecs\,CO_2}}$	0.00005	[tCO₂/MWₑh]
ε_c	11.7000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**42.9657**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWₑ/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	90 107 610	[kWₑh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWₑh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**90 107 610**	**[kWₑh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 470 640	[$]
Debt payments	2 977 241	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 470 640	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.1255	yr_1	78.4712	yr_{15}
73.5187	yr_2	77.6515	yr_{15}
73.7873	yr_3	78.1612	yr_{16}
74.1334	yr_4	78.6268	yr_{17}
74.4746	yr_5	79.1175	yr_{18}
74.9273	yr_6	79.6115	yr_{19}
75.2253	yr_7	77.7347	yr_{20}
75.5275	yr_8	78.2446	yr_{21}
76.0152	yr_9	78.7103	yr_{22}
76.4118	yr_{10}	79.0644	yr_{23}
76.7332	yr_{11}	79.4723	yr_{25}
77.2289	yr_{12}	76.8666	Mean
77.6321	yr_{13}	2.0151	SD
78.0589	yr_{14}	-0.4631	ϒ (skewness)
$LCOE_{wso}$	**76.8666**	**US$/MWh**	valid !
	0.076867	**US$/kWh**	

Figure Q.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MWₑ wind farm in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)}$ and E_{pi} *(Case ₂)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.7%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inv}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041527	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	29 538 512	[$M]
AEP_{avail}	213 509 813	[kWh/yr]
$O\&M_{WFCM}$	**0.139802**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0.000016**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000058**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000074	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_ψ	5	[yr]
REP_{CM}	0.00000049	[$/kW$_e$h]
AEP_{avail}/H_{prod}	24 780	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0121	[$/kW$_e$h]
ε_0	0.008998	[$/kW$_e$h]
n_ε	12	[yr]
$OREP_{CM}$	90.2828	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	4.3886	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	12	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	6 827.9067	[$/tCO$_2$]
$LCER_{CO_2}$	136.4	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	212 467	[MW$_e$h]
n_ψ	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0.00069	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ co_2}}$	0.00005	[tCO$_2$/MW$_e$h]
ε_c	27.0000	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**57.1172**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	213 509 813	[kW$_e$h/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**213 509 813**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 116 852	[$]
Debt payments	2 941 500	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 116 852	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.3997	yr_1	94.4943	yr_{15}
85.0669	yr_2	94.1699	yr_{15}
85.7507	yr_3	94.9708	yr_{16}
86.2255	yr_4	95.8775	yr_{17}
86.9196	yr_5	96.7795	yr_{18}
87.6452	yr_6	97.5702	yr_{19}
88.2242	yr_7	94.0503	yr_{20}
88.9241	yr_8	94.7536	yr_{21}
89.8260	yr_9	95.8087	yr_{22}
90.4267	yr_{10}	96.5649	yr_{23}
91.2477	yr_{11}	97.5891	yr_{25}
91.9572	yr_{12}	91.8264	Mean
92.6946	yr_{13}	4.2043	SD
93.7245	yr_{14}	-0.3333	Υ (skewness)
$LCOE_{wso}$	**91.8264**	**US$/MWh**	valid !
	0.091826	**US$/kWh**	

Figure Q.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)}$ and E_{pi} *(Case $_2$)*. Source: Own elaboration

Table Q.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_2)$

Months	v_{wc} (m/s)	ρ (kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	740	1 697 720	8 914 291	3 812 469	7 527 755	558 872	8 914 291	558 872	558 872	4 243 681	8 914 291	8 914 291	558 872	3 812 469	7 527 755	4 243 681	8 914 291	8 914 291	558 872	3 812 469	7 527 755	558 872	3 812 469	7 527 755	4 243 681	4 243 681
February	4.9	1.1666	648	859 945	6 879 561	3 714 421	6 879 561	788 321	6 879 561	788 321	788 321	4 780 152	6 879 561	6 879 561	788 321	3 714 421	6 879 561	489 171	489 171	3 336 988	4 780 152	7 802 526	1 594 674	1 594 674	7 802 526	6 879 561	4 780 152	4 780 152
March	4.0	1.1671	736	555 877	7 487 419	5 432 002	8 866 525	977 212	7 487 419	977 212	977 212	6 552 645	7 487 419	7 487 419	977 212	5 432 002	8 866 525	895 822	895 822	1 812 134	4 220 942	1 812 134	1 688 623	1 688 623	7 817 699	8 866 525	3 792 040	6 552 645
April	4.7	1.1667	712	866 366	6 337 184	6 337 184	4 082 151	1 633 098	6 337 184	1 633 098	1 633 098	7 241 220	6 337 184	6 337 184	1 752 548	6 337 184	4 082 151	945 080	945 080	1 633 098	6 337 184	1 633 098	3 667 352	945 080	7 241 220	6 337 184	1 752 548	7 241 220
May	6.0	1.1670	736	1 812 066	5 431 800	7 487 140	5 431 800	1 812 066	5 431 800	1 812 066	1 812 066	7 817 409	5 431 800	5 431 800	1 688 560	7 487 140	6 552 401	1 688 560	1 688 560	977 176	8 866 195	977 176	555 856	895 788	6 552 401	4 220 785	1 688 560	7 817 409
June	7.9	1.1686	696	3 996 852	3 996 852	7 402 657	6 204 764	3 590 720	3 996 852	3 590 720	3 590 720	8 395 800	3 996 852	3 996 852	3 590 720	7 402 657	5 143 616	1 715 927	1 715 927	848 262	7 402 657	848 262	848 262	3 590 720	5 143 616	5 143 616	925 332	8 395 800
July	8.6	1.1698	736	5 444 782	3 800 962	8 887 385	1 692 596	4 230 873	3 800 962	4 230 873	4 230 873	557 185	557 185	3 800 962	5 444 782	8 887 385	1 816 397	3 800 962	3 800 962	557 185	7 505 034	557 185	979 511	4 230 873	4 230 873	1 692 596	897 929	557 185
August	9.6	1.1677	736	7 491 301	1 813 073	1 813 073	1 813 073	8 871 123	1 813 073	5 434 819	5 434 819	896 286	896 286	1 813 073	4 223 131	1 813 073	1 689 499	5 434 819	7 821 753	7 821 753	896 286	4 223 131	7 821 753	5 434 819	1 813 073	1 813 073	556 165	896 286
September	10.1	1.1657	712	8 566 923	1 631 564	1 631 564	3 663 906	7 553 538	1 631 564	6 331 230	6 331 230	944 192	944 192	1 631 564	6 331 230	1 631 564	3 663 906	6 331 230	7 234 417	7 234 417	944 192	5 248 454	8 566 923	6 331 230	1 631 564	3 663 906	6 331 230	944 192
October	9.7	1.1645	736	7 800 246	975 031	975 031	554 636	7 470 703	975 031	7 470 703	7 470 703	1 684 853	1 684 853	975 031	8 846 730	975 031	554 636	7 470 703	6 538 016	6 538 016	1 808 088	6 538 016	4 211 519	7 470 703	975 031	975 031	8 846 730	1 684 853
November	9.2	1.1638	696	6 179 252	844 775	844 775	844 775	6 179 252	844 775	7 372 218	7 372 218	1 708 872	1 708 872	844 775	7 372 218	844 775	844 775	7 372 218	5 122 467	5 122 467	1 592 399	7 060 758	6 179 252	7 372 218	844 775	844 775	7 372 218	1 708 872
December	7.6	1.1651	736	3 785 725	554 951	554 951	975 585	5 422 956	554 951	8 851 759	8 851 759	3 785 725	3 785 725	554 951	7 474 950	554 951	975 585	8 851 759	4 213 913	4 213 913	3 785 725	7 804 681	5 422 956	8 851 759	554 951	554 951	7 474 950	3 785 725
Annual	7.4	1.1666	8 616	49 057 055	48 667 462	48 892 652	48 537 127	49 088 734	48 667 462	49 051 893	49 051 893	48 608 021	48 624 219	48 667 462	49 049 275	48 892 652	48 596 807	49 239 932	49 380 379	49 009 701	48 697 726	48 317 889	49 064 437	48 965 360	48 420 199	48 519 758	48 661 536	48 608 021

Table Q.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_2)$

Months	v_{wc} (m/s)	ρ (kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	740	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408
February	11.5	1.2345	648	12 092 721	4 293 137	12 092 721	12 092 721	12 092 721	3 417 096	12 092 721	12 715 785	1 795 784	3 417 096	12 715 785	1 795 784	9 244 173	12 092 721	6 674 015	12 715 785	4 293 137	5 486 290	3 417 096	2 815 600	12 092 721	2 106 703	6 674 015	12 092 721	12 715 785
March	10.5	1.2329	736	10 486 228	3 193 907	13 717 510	13 717 510	13 717 510	6 223 433	13 717 510	13 717 510	2 389 762	3 193 907	13 717 510	2 389 762	13 717 510	13 717 510	6 223 433	13 717 510	3 876 220	7 570 742	4 869 967	13 717 510	14 424 289	2 037 067	10 486 228	14 424 289	3 193 907
April	9.5	1.2317	712	7 316 597	7 316 597	10 458 483	10 458 483	10 458 483	7 316 597	10 458 483	4 706 485	3 086 689	7 316 597	13 257 022	3 086 689	13 257 022	4 706 485	4 706 485	13 257 022	3 086 689	10 134 212	3 086 689	13 940 075	13 257 022	3 086 689	3 086 689	13 257 022	3 746 098
May	8.2	1.2282	736	4 851 676	10 446 845	10 446 845	10 446 845	6 200 059	10 446 845	10 446 845	10 446 845	3 861 662	6 200 059	10 446 845	3 861 662	14 370 115	10 446 845	3 861 662	10 446 845	2 380 787	13 665 991	6 200 059	2 380 787	10 446 845	3 861 662	14 370 115	10 446 845	4 851 676
June	7.1	1.2224	696	2 994 461	12 860 910	7 097 981	7 097 981	7 097 981	10 145 990	4 565 858	12 860 910	4 565 858	10 145 990	7 097 981	4 565 858	7 097 981	2 240 532	2 994 461	7 097 981	1 909 861	12 860 910	7 097 981	1 909 861	7 097 981	4 565 858	12 860 910	7 097 981	5 834 806
July	6.1	1.2154	736	2 008 118	13 522 571	4 800 760	6 134 992	10 337 209	13 522 571	7 463 154	3 148 518	6 134 992	2 008 118	6 134 992	6 134 992	6 134 992	2 008 118	2 355 801	6 134 992	6 134 992	14 219 306	10 337 209	3 821 135	6 134 992	6 134 992	13 522 571	3 821 135	7 463 154
August	6.4	1.2075	736	2 340 496	10 598 668	3 796 310	3 796 310	3 796 310	13 434 719	6 095 134	3 796 310	7 414 668	2 340 496	4 769 571	7 414 668	4 769 571	10 598 668	1 995 072	4 769 571	13 434 719	1 995 072	13 434 719	4 769 571	4 769 571	7 414 668	4 769 571	3 128 063	10 270 051
September	7.6	1.2064	712	3 669 202	1 928 273	5 891 057	4 609 876	4 609 876	4 609 876	1 928 273	5 891 057	9 926 189	9 926 189	3 669 202	9 926 189	3 669 202	5 891 057	9 926 189	3 669 202	12 984 898	2 262 132	12 984 898	5 891 057	3 669 202	9 926 189	3 669 202	2 262 132	1 928 273
October	8.9	1.2126	736	6 121 079	6 121 079	3 141 378	2 003 564	3 141 378	2 003 564	2 350 459	7 446 229	13 491 905	13 491 905	3 141 378	13 491 905	3 141 378	7 446 229	13 491 905	3 141 378	10 643 782	3 141 378	2 003 564	7 446 229	3 141 378	13 491 905	2 350 459	2 003 564	2 350 459
November	10.6	1.2194	696	10 121 586	3 625 425	2 235 143	2 235 143	2 235 143	2 235 143	2 987 258	2 235 143	12 829 976	4 554 876	2 235 143	12 829 976	2 235 143	2 987 258	12 829 976	2 235 143	9 807 761	3 625 425	2 235 143	9 807 761	2 235 143	12 829 976	1 905 267	5 820 771	12 829 976
December	11.5	1.2237	736	13 614 984	2 371 901	2 021 842	3 170 035	2 021 842	3 170 035	3 847 249	2 021 842	14 316 481	13 614 984	2 021 842	14 316 481	2 021 842	3 847 249	14 316 481	2 021 842	7 514 158	4 833 568	14 316 481	13 614 984	2 021 842	14 316 481	6 176 918	4 833 568	13 614 984
Annual	9.1	1.2222	8 616	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577

Table Q.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_2)$

Months	v_{wc} (m/s)	ρ (kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	740	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	8 035 210	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	40 865 255	32 823 510	32 823 510	28 095 929	8 035 210	7 120 177
February	14.7	1.2522	648	24 591 404	14 672 254	7 010 451	26 599 864	14 672 254	14 672 254	26 599 864	26 599 864	7 010 451	14 672 254	14 672 254	7 859 649	26 599 864	7 010 451	17 623 290	7 010 451	7 010 451	7 010 451	7 010 451	22 780 600	26 599 864	26 599 864	29 369 594	7 859 649	17 596 916
March	12.7	1.2495	736	18 252 376	18 252 376	8 908 878	27 874 248	12 394 144	18 252 376	27 874 248	27 874 248	8 908 878	12 394 144	18 252 376	9 986 084	27 874 248	8 908 878	30 150 829	8 908 878	8 908 878	8 908 878	8 908 878	23 024 061	27 874 248	27 874 248	31 459 374	9 986 084	18 948 162
April	12.4	1.2490	712	16 081 249	19 315 677	9 656 023	24 865 308	9 656 023	19 315 677	24 865 308	24 865 308	9 656 023	9 656 023	19 315 677	9 656 023	24 865 308	9 656 023	26 952 947	9 656 023	29 154 282	9 656 023	9 656 023	22 218 160	20 001 184	24 865 308	24 956 459	9 656 023	18 165 621
May	11.2	1.2425	736	12 324 064	25 569 850	9 929 620	19 862 973	9 929 620	25 569 850	19 862 973	19 862 973	9 929 620	9 929 620	25 569 850	12 324 064	19 862 973	9 929 620	25 569 850	9 929 620	27 716 641	9 929 620	9 929 620	21 018 978	19 862 973	19 862 973	19 116 345	12 324 064	16 191 245
June	10.4	1.2351	696	9 333 787	26 053 485	11 584 551	17 060 120	8 326 944	26 053 485	17 060 120	17 060 120	11 584 551	8 326 944	26 053 485	15 544 593	17 060 120	11 584 551	17 060 120	11 584 551	24 035 514	11 584 551	11 584 551	17 178 664	17 060 120	17 060 120	16 981 395	15 544 593	15 146 363
July	10.0	1.2275	736	8 751 923	29 619 639	16 337 936	16 337 936	7 806 320	29 619 639	16 337 936	16 337 936	16 337 936	7 806 320	29 619 639	17 930 811	16 337 936	16 337 936	7 806 320	16 337 936	19 623 991	16 337 936	16 337 936	15 552 737	16 069 219	16 337 936	16 783 950	17 930 811	8 637 391
August	9.7	1.2216	736	7 768 712	12 117 129	17 844 428	12 117 129	17 844 428	12 117 129	12 117 129	12 117 129	17 844 428	17 844 428	12 117 129	19 529 451	12 117 129	17 844 428	8 709 760	17 844 428	17 844 428	17 844 428	17 844 428	12 921 415	15 399 666	12 117 129	12 606 836	19 529 451	7 121 992
September	10.4	1.2234	712	9 458 082	7 526 165	18 919 721	9 458 082	26 400 433	7 526 165	9 458 082	9 458 082	18 919 721	26 400 433	7 526 165	24 355 589	9 458 082	18 919 721	9 458 082	18 919 721	15 751 596	18 919 721	18 919 721	12 339 146	13 294 981	9 458 082	8 855 020	24 355 589	19 057 688
October	13.1	1.2327	736	19 706 914	8 788 905	29 744 799	9 851 605	25 368 953	8 788 905	9 851 605	9 851 605	29 744 799	25 368 953	8 788 905	27 498 877	9 851 605	25 368 953	9 851 605	25 368 953	12 227 237	29 744 799	25 368 953	12 259 773	8 871 247	9 851 605	8 134 157	27 498 877	21 626 625
November	14.3	1.2429	696	24 188 639	9 393 250	26 219 466	8 379 993	28 360 895	9 393 250	8 379 993	8 379 993	26 219 466	28 360 895	9 393 250	28 360 895	8 379 993	26 219 466	11 658 353	26 219 466	9 393 250	26 219 466	26 219 466	7 520 762	8 379 993	8 379 993	8 987 716	28 360 895	22 240 116
December	15.1	1.2528	736	30 229 153	10 012 025	25 782 051	7 966 958	20 027 814	10 012 025	7 966 958	7 966 958	25 782 051	20 027 814	10 012 025	32 544 702	7 966 958	30 229 153	16 674 139	30 229 153	10 012 025	25 782 051	30 229 153	6 359 397	7 966 958	7 966 958	9 176 637	32 544 702	42 535 343
Annual	12.5	1.2404	8 616	213 509 813	214 144 266	214 761 434	213 197 728	213 611 337	214 144 266	213 197 728	213 197 728	214 761 434	213 611 337	214 144 266	213 625 948	213 197 728	214 832 689	214 338 805	214 832 689	214 501 803	214 761 434	214 832 689	214 038 947	214 203 964	213 197 728	214 523 412	213 625 948	214 387 639

Table Q.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_{\ 2})$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table Q.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_{\ 2})$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table Q.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_{\ 2})$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table Q.7 kWh per H_{prod} with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ ($Case_{\ 2}$)

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 693	5 648	5 674	5 633	5 697	5 648	5 693	5 693	5 641	5 643	5 648	5 693	5 674	5 640	5 715	5 731	5 688	5 652	5 608	5 694	5 683	5 620	5 631	5 648	5 641
Corvo Island (Portugal)	10 458	10 535	10 467	10 475	10 468	10 563	10 497	10 429	10 525	10 527	10 454	10 525	10 507	10 500	10 474	10 454	10 510	10 523	10 545	10 560	10 464	10 520	10 532	10 452	10 407
Cape Saint James (Canada)	24 780	24 853	24 925	24 743	24 791	24 853	24 743	24 743	24 925	24 791	24 853	24 793	24 743	24 933	24 876	24 933	24 895	24 925	24 933	24 841	24 860	24 743	24 897	24 793	24 882

Table Q.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ ($Case_{\ 2}$)

Item	Years												
	0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	49 057 055	48 667 462	48 892 652	48 537 127	49 088 734	48 667 462	49 051 893	49 051 893	48 608 021	48 624 219	48 667 462	49 049 275
(+) AAR ($M/yr)	-	4 314 826	4 387 573	4 518 071	4 597 349	4 765 836	4 843 059	5 003 348	5 128 432	5 209 075	5 341 081	5 479 477	5 660 527
PPAR	-	4 314 826	4 387 573	4 518 071	4 597 349	4 765 836	4 843 059	5 003 348	5 128 432	5 209 075	5 341 081	5 479 477	5 660 527
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	3 964 703	4 031 427	4 151 213	4 223 934	4 378 615	4 471 031	4 618 343	4 733 137	4 806 905	4 928 061	5 055 095	5 221 459
$O\&M_{fixed}$	-	2 665 486	2 710 424	2 791 038	2 840 010	2 944 091	2 991 795	3 090 812	3 168 081	3 217 896	3 299 441	3 384 934	3 496 775
$O\&M_{variable}$	-	1 299 217	1 321 003	1 360 175	1 383 923	1 434 523	1 479 236	1 527 531	1 565 056	1 589 009	1 628 620	1 670 162	1 724 683
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 423 221	2 483 801	2 545 896	2 609 544	2 674 782	2 741 652	2 810 193	2 880 448	2 952 459	3 026 270	3 101 927	3 179 475
(=) Profit before tax	-	3 636 612	3 724 797	3 819 726	3 912 604	4 014 890	4 090 389	4 196 325	4 301 898	4 406 438	4 517 395	4 631 365	4 751 227
(-) Revenue tax	-	1 294 448	1 316 272	1 355 421	1 379 205	1 429 751	1 452 918	1 501 004	1 538 530	1 562 723	1 602 324	1 643 843	1 698 158
(+) REPIM	1 122 960	1 725	1 670	1 637	1 585	1 564	1 513	1 488	1 451	1 403	1 369	1 337	1 315
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 725	1 670	1 637	1 585	1 564	1 513	1 488	1 451	1 403	1 369	1 337	1 315
$OREP_{CM}$	259 298	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	2 343 889	2 410 195	2 465 941	2 534 985	2 586 703	2 638 984	2 696 808	2 764 820	2 845 118	2 916 440	2 988 859	3 054 383
(-) Debt payments	-	-	3 136 543	3 214 957	3 295 331	3 377 714	3 462 157	3 548 711	3 637 428	3 728 364	3 821 573	3 917 112	4 015 040
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 423 221	2 483 801	2 545 896	2 609 544	2 674 782	2 741 652	2 810 193	2 880 448	2 952 459	3 026 270	3 101 927	3 179 475
(=) Free net cashflow	-59 102 941	7 388 849	4 444 735	4 551 345	4 672 524	4 777 681	4 884 735	4 998 704	5 124 263	5 263 547	5 395 329	5 529 722	5 658 767
$\Sigma_{free\ net\ annual\ cashflow}$	-	-51 714 092	-47 269 357	-42 718 012	-38 045 489	-33 267 808	-28 383 073	-23 384 369	-18 260 106	-12 996 559	-7 601 229	-2 071 508	3 587 259
$LCOE_{wso}$		67.68	67.83	68.04	68.20	68.45	68.64	68.89	69.10	69.28	69.51	69.74	70.02

Item	Years												
	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	48 892 652	48 596 807	49 239 932	49 380 379	49 009 701	48 697 726	48 317 889	49 064 437	48 965 360	48 420 199	48 519 758	48 661 536	48 608 021
(+) AAR ($M/yr)	5 783 513	5 892 231	6 119 463	6 290 341	6 399 200	6 517 427	6 628 256	6 898 935	4 939 990	5 007 115	5 142 845	5 286 820	5 413 031
PPAR	5 783 513	5 892 231	6 119 463	6 290 341	6 399 200	6 517 427	6 628 256	6 898 935	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 939 990	5 007 115	5 142 845	5 286 820	5 413 031
(-) $O\&M_{WFCM}$	5 334 243	5 433 856	5 642 744	5 799 641	5 899 344	6 007 676	6 109 183	6 357 999	5 867 984	5 947 062	6 107 615	6 277 939	6 427 153
$O\&M_{fixed}$	3 572 748	3 639 907	3 780 277	3 885 835	3 953 081	4 026 113	4 094 576	4 261 785	4 359 507	4 418 743	4 538 523	4 665 578	4 776 957
$O\&M_{variable}$	1 761 494	1 793 950	1 862 467	1 913 806	1 946 264	1 981 563	2 014 606	2 096 214	1 508 477	1 528 319	1 569 092	1 612 361	1 650 196
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 258 962	3 340 436	3 423 947	3 509 546	3 597 285	3 687 217	3 779 397	3 873 882	3 970 729	4 069 997	4 171 747	4 276 041	4 382 942
(=) Profit before tax	4 869 233	4 988 836	5 120 442	4 000 245	4 097 140	4 196 967	4 298 471	4 414 818	3 042 735	3 130 050	3 206 977	3 284 921	3 368 820
(-) Revenue tax	1 735 054	1 767 669	1 835 839	1 887 102	1 919 760	1 955 228	1 988 477	2 069 680	1 481 997	1 502 134	1 542 854	1 586 046	1 623 909
(+) REPIM	-	-	-	-	-	-	-	-	-	-	-	-	-
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	3 134 179	3 221 167	3 284 603	2 113 143	2 177 380	2 241 739	2 309 994	2 345 137	1 560 738	1 627 915	1 664 124	1 698 875	1 744 911
(-) Debt payments	4 115 416	4 218 302	4 323 759	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 258 962	3 340 436	3 423 947	3 509 546	3 597 285	3 687 217	3 779 397	3 873 882	3 970 729	4 069 997	4 171 747	4 276 041	4 382 942
(=) Free net cashflow	5 803 672	5 957 397	6 089 239	9 419 749	9 666 651	9 918 241	10 178 409	10 410 263	9 827 491	10 101 337	10 349 381	10 601 265	10 869 860
$\Sigma_{free\ net\ annual\ cashflow}$	9 390 931	15 348 328	21 437 567	30 857 316	40 523 967	50 442 208	60 620 617	71 030 879	80 858 371	90 959 708	101 309 090	111 910 354	122 780 214
$LCOE_{wso}$	70.25	70.46	70.79	69.82	70.02	70.22	70.42	70.78	70.39	70.58	70.85	71.13	71.40

Table Q.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_{2})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577
(+) AAR ($M/yr)	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
PPAR	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
(-) $O\&M_{WFCM}$	-	9 414 550	9 720 704	9 900 012	10 154 527	10 401 931	10 758 472	10 957 897	11 159 028	11 543 192	11 833 646	12 046 185	12 430 378	12 719 232	13 028 853	13 321 057	13 628 511	14 043 351	14 411 633	14 802 558	15 194 336	13 212 815	13 615 294	13 970 912	14 212 144	14 504 416
$O\&M_{fixed}$	-	4 895 943	5 055 217	5 148 526	5 280 948	5 409 674	5 595 159	5 698 935	5 803 599	6 003 456	6 154 579	6 265 179	6 465 057	6 615 352	6 776 449	6 928 488	7 088 460	7 304 288	7 495 901	7 699 294	7 903 132	8 027 381	8 271 977	8 488 105	8 634 738	8 812 382
$O\&M_{variable}$	-	4 518 607	4 665 487	4 751 486	4 873 579	4 992 258	5 163 313	5 258 962	5 355 430	5 539 736	5 679 068	5 781 006	5 965 321	6 103 880	6 252 405	6 392 569	6 540 051	6 739 063	6 915 732	7 103 264	7 291 205	5 185 434	5 343 317	5 482 807	5 577 406	5 692 034
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 416 592	2 477 007	2 538 932	2 602 406	2 667 466	2 734 153	2 802 506	2 872 569	2 944 383	3 017 993	3 093 443	3 170 779	3 250 048	3 331 299	3 414 582	3 499 946	3 587 445	3 677 131	3 769 060	3 863 286	3 959 868	4 058 865	4 160 336	4 264 345	4 370 954
(=) Profit before tax	-	8 911 435	9 176 763	9 368 266	9 606 864	9 843 367	10 147 375	10 359 653	10 575 273	10 902 786	11 176 673	11 406 441	11 741 486	12 022 111	12 317 857	12 605 942	11 655 712	11 991 661	12 301 941	12 628 019	12 956 912	8 015 924	8 238 634	8 449 437	8 627 664	8 824 163
(-) Revenue tax	-	4 513 837	4 660 683	4 746 712	4 868 802	4 987 484	5 158 496	5 254 175	5 350 673	5 534 936	5 674 267	5 776 238	5 960 521	6 099 089	6 247 616	6 387 792	6 535 283	6 734 270	6 910 933	7 098 455	7 286 389	5 180 661	5 338 519	5 478 004	5 572 639	5 687 288
(+) REPIM	1 284 621	1 253	1 231	1 193	1 165	1 136	1 118	1 084	1 051	1 035	1 010	978	961	936	912	888	865	848	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 253	1 231	1 193	1 165	1 136	1 118	1 084	1 051	1 035	1 010	978	961	936	912	888	865	848	-	-	-	-	-	-	-	-
$OREP_{CM}$	420 959	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	4 398 850	4 517 311	4 622 747	4 739 227	4 857 019	4 989 997	5 106 562	5 225 651	5 368 885	5 503 416	5 631 182	5 781 926	5 923 958	6 071 154	6 219 037	5 121 294	5 258 239	5 391 008	5 529 564	5 670 523	2 835 263	2 900 115	2 971 434	3 055 025	3 136 875
(-) Debt payments	-	-	3 127 964	3 206 163	3 286 317	3 368 475	3 452 687	3 539 004	3 627 479	3 718 166	3 811 120	3 906 398	4 004 058	4 104 160	4 206 764	4 311 933	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 416 592	2 477 007	2 538 932	2 602 406	2 667 466	2 734 153	2 802 506	2 872 569	2 944 383	3 017 993	3 093 443	3 170 779	3 250 048	3 331 299	3 414 582	3 499 946	3 587 445	3 677 131	3 769 060	3 863 286	3 959 868	4 058 865	4 160 336	4 264 345	4 370 954
(=) Free net cashflow	-58 941 280	9 437 182	6 553 636	6 709 981	6 878 642	7 049 919	7 237 720	7 410 477	7 587 164	7 789 436	7 984 481	8 174 273	8 388 595	8 595 794	8 809 785	9 026 135	12 418 300	12 737 670	13 057 425	13 387 641	13 725 053	11 091 155	11 362 405	11 645 281	11 945 718	12 249 836
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 504 098	-42 950 462	-36 240 481	-29 361 839	-22 311 920	-15 074 200	-7 663 723	-76 559	7 712 878	15 697 359	23 871 632	32 260 227	40 856 021	49 665 807	58 691 941	71 110 241	83 847 911	96 905 336	110 292 978	124 018 031	135 109 186	146 471 591	158 116 872	170 062 590	182 312 426
	$LCOE_{wso}$	*73.13*	*73.52*	*73.79*	*74.13*	*74.47*	*74.93*	*75.23*	*75.53*	*76.02*	*76.41*	*76.73*	*77.23*	*77.63*	*78.06*	*78.47*	*77.65*	*78.16*	*78.63*	*79.12*	*79.61*	*77.73*	*78.24*	*78.71*	*79.06*	*79.47*

Table Q.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_{2})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	213 509 813	214 144 266	214 761 434	213 197 728	213 611 337	214 144 266	213 197 728	213 197 728	214 761 434	213 611 337	214 144 266	213 625 948	213 197 728	214 832 689	214 338 805	214 832 689	214 501 803	214 761 434	214 832 689	214 038 947	214 203 964	213 197 728	214 523 412	213 625 948	214 387 639
(+) AAR ($M/yr)	-	30 276 974	31 126 117	31 996 219	32 557 331	33 436 006	34 357 409	35 060 685	35 937 202	37 105 804	37 829 772	38 872 255	39 747 622	40 659 646	41 995 741	42 946 676	44 121 775	45 155 164	46 340 065	47 514 326	48 522 244	34 841 551	35 544 828	36 659 995	37 419 293	38 491 531
PPAR	-	30 276 974	31 126 117	31 996 219	32 557 331	33 436 006	34 357 409	35 060 685	35 937 202	37 105 804	37 829 772	38 872 255	39 747 622	40 659 646	41 995 741	42 946 676	44 121 775	45 155 164	46 340 065	47 514 326	48 522 244	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 841 551	35 544 828	36 659 995	37 419 293	38 491 531
(-) $O\&M_{WFCM}$	-	20 688 790	21 268 898	21 863 324	22 246 612	22 846 890	23 476 361	23 956 782	24 555 577	25 353 946	25 848 498	26 560 685	27 158 681	27 781 721	28 694 515	29 344 137	30 146 919	30 852 873	31 662 346	32 464 546	33 153 088	29 528 360	30 124 265	31 069 244	31 712 621	32 621 209
$O\&M_{fixed}$	-	11 600 929	11 926 280	12 259 661	12 474 651	12 811 317	13 164 355	13 433 815	13 769 654	14 217 407	14 494 795	14 894 225	15 229 623	15 579 065	16 090 994	16 455 346	16 905 588	17 301 532	17 755 529	18 205 449	18 591 634	19 071 110	19 456 054	20 066 453	20 482 061	21 068 961
$O\&M_{variable}$	-	9 087 862	9 342 619	9 603 663	9 771 962	10 035 573	10 312 006	10 522 968	10 785 923	11 136 539	11 353 703	11 666 460	11 929 059	12 202 656	12 603 521	12 888 791	13 241 331	13 551 341	13 906 817	14 259 097	14 561 454	10 457 250	10 668 211	11 002 791	11 230 560	11 552 248
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 387 582	2 447 271	2 508 453	2 571 165	2 635 444	2 701 330	2 768 863	2 838 085	2 909 037	2 981 763	3 056 307	3 132 714	3 211 032	3 291 308	3 373 591	3 457 930	3 544 379	3 632 988	3 723 813	3 816 908	3 912 331	4 010 139	4 110 393	4 213 152	4 318 481
(=) Profit before tax	-	12 839 034	13 189 340	13 548 319	13 811 529	14 177 446	14 559 087	14 873 892	15 245 865	15 712 704	16 041 140	16 472 933	16 854 338	17 249 956	17 782 558	18 195 905	17 432 786	17 846 670	18 310 707	18 773 593	19 186 064	9 225 522	9 430 702	9 701 144	9 919 825	10 188 803
(-) Revenue tax	-	9 083 092	9 337 835	9 598 866	9 767 199	10 030 802	10 307 223	10 518 205	10 781 161	11 131 741	11 348 931	11 661 677	11 924 287	12 197 894	12 598 722	12 884 003	13 236 533	13 546 549	13 902 019	14 254 298	14 556 673	10 452 465	10 663 448	10 997 999	11 225 788	11 547 459
(+) REPIM	1 992 197	148	144	141	137	134	131	127	124	122	118	116	113	-	-	-	-	-	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	148	144	141	137	134	131	127	124	122	118	116	113	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	1 128 535	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	3 756 090	3 851 649	3 949 595	4 044 466	4 146 778	4 251 995	4 355 814	4 464 828	4 581 084	4 692 327	4 811 372	4 930 164	5 052 063	5 183 836	5 311 903	4 196 254	4 300 121	4 408 688	4 519 295	4 629 391	-1 226 944	-1 232 746	-1 296 854	-1 305 963	-1 358 656
(-) Debt payments	-	-	3 090 413	3 167 674	3 246 866	3 328 037	3 411 238	3 496 519	3 583 932	3 673 530	3 765 369	3 859 503	3 955 990	4 054 890	4 156 262	4 260 169	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 387 582	2 447 271	2 508 453	2 571 165	2 635 444	2 701 330	2 768 863	2 838 085	2 909 037	2 981 763	3 056 307	3 132 714	3 211 032	3 291 308	3 373 591	3 457 930	3 544 379	3 632 988	3 723 813	3 816 908	3 912 331	4 010 139	4 110 393	4 213 152	4 318 481
(=) Free net cashflow	-58 233 703	8 765 410	5 895 790	6 044 838	6 192 091	6 348 094	6 508 343	6 668 571	6 835 404	7 010 925	7 182 913	7 364 223	7 546 836	7 734 152	7 932 977	8 129 773	11 451 244	11 736 485	12 030 961	12 332 126	12 637 542	6 981 412	7 180 818	7 327 049	7 533 538	7 701 832
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 468 293	-43 572 504	-37 527 665	-31 335 574	-24 987 480	-18 479 137	-11 810 566	-4 975 162	2 035 763	9 218 676	16 582 900	24 129 736	31 863 888	39 796 865	47 926 638	59 377 881	71 114 367	83 145 328	95 477 454	108 114 996	115 096 408	122 277 226	129 604 275	137 137 813	144 839 645
	$LCOE_{wso}$	*84.40*	*85.07*	*85.75*	*86.23*	*86.92*	*87.65*	*88.22*	*88.92*	*89.83*	*90.43*	*91.25*	*91.96*	*92.69*	*93.72*	*94.49*	*94.17*	*94.97*	*95.88*	*96.78*	*97.57*	*94.05*	*94.75*	*95.81*	*96.56*	*97.59*

APPENDIX R

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	65.7637	[$/kWe]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	15.00%	[%]
n_ψ	3	[yr]
REP_{CM}	0.00000595	[$/kWeh]
AEP_{avail}/H_{prod}	5 693	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0339	[$/kWeh]
ε_0	0.023377	[$/kWeh]
n_ε	15	[yr]
$OREP_{CM}$	21.6705	[$/kWe]
$LCCCM_{WF_{OREGCM}}$	4.5846	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	15.0%	[%]
ifr	2.5%	[%/yr]
n_ψ	15	[yr]
CR_f	25.0%	[%]
$GHG.R_{CM}$	3 868.4070	[$/tCO₂]
$LCER_{CO_2}$	56.2	[tCO₂/MWeh]
$\sum AEP_{avail\ yr_{1+\dots+yr_n}}$	48 856	[MWeh]
n_ψ	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0.00123	[tCO₂/MWeh]
$GHG_{EM_{wecs\ co_2}}$	0.00008	[tCO₂/MWeh]
ε_c	37.1056	[$/tCO₂]
REPIM distribution	105.0%	[%]
ξ_1 REI_{CM}	0.0%	[%]
ξ_2 REP_{CM}	0.0%	[%]
ξ_3 $OREP_{CM}$	50.0%	[%]
ξ_4 $GHG.R_{CM}$	55.0%	[%]
REPIM	**2 138.4591**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWe/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	49 057 055	[kWeh/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWeh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**49 057 055**	**[kWeh/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWe]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$w_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025840	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	4 209 586	[$M]
AEP_{avail}	49 057 055	[kWh/yr]
$O\&M_{WFCM}$	**0.124115**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0.000070**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000254**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000324	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	[1/0]
(%) ccm	80.0%	[%]
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	[1/0]
ξ_2 REP_{CM}	1	[1/0]
ξ_3 $OREP_{CM}$	1	[1/0]
ξ_4 $GHG.R_{CM}$	1	[1/0]
$P\&D_{LM}$		
λ_a	1	[1/0]
$\lambda_{s\&i}$	0	[1/0]
λ_d	1	[1/0]
λ_m	1	[1/0]
	p.s.: 1= yes and 0=no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 842 069	[$]
Debt payments	3 014 764	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 842 069	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67.6756	yr_1	70.7929	yr_{15}
67.8295	yr_2	69.8226	yr_{15}
68.0385	yr_3	70.0172	yr_{16}
68.2028	yr_4	70.2229	yr_{17}
68.4513	yr_5	70.4241	yr_{18}
68.6399	yr_6	70.7751	yr_{19}
68.8858	yr_7	70.3899	yr_{20}
69.1016	yr_8	70.5764	yr_{21}
69.2789	yr_9	70.8470	yr_{22}
69.5063	yr_{10}	71.1302	yr_{23}
69.7421	yr_{11}	71.3951	yr_{25}
70.0200	yr_{12}	69.6991	Mean
70.2471	yr_{13}	1.0849	SD
70.4639	yr_{14}	-0.4478	ϒ (skewness)
$LCOE_{wso}$	**69.6991**	**US$/MWh**	valid !
	0.069699	**US$/kWh**	

Figure R.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical $50MW_e$ wind farm in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)}$ and E_{pi} *(Case* $_3$*)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.6%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	65.7637	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
Ψ_{total}	15.00%	[%]
n_{Ψ}	3	[yr]
REP_{CM}	0.00000831	[$/kW$_e$h]
AEP_{avail}/H_{prod}	10 458	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0869	[$/kW$_e$h]
ε_0	0.060000	[$/kW$_e$h]
n_{ε}	15	[yr]
$OREP_{CM}$	39.8043	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	4.5846	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
Ψ_{total}	15.0%	[%]
ifr	2.5%	[%/yr]
n_{Ψ}	15	[yr]
CR_f	25.0%	[%]
$GHG.R_{CM}$	2 487.1430	[$/tCO$_2$]
$LCER_{CO_2}$	103.2	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	89 657	[MW$_e$h]
n_{Ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00123	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ CO_2}}$	0.00008	[tCO$_2$/MW$_e$h]
ε_c	13.0000	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	0.0%	[%]
ξ_2 REP_{CM}	0.0%	[%]
ξ_3 $OREP_{CM}$	50.0%	[%]
ξ_4 $GHG.R_{CM}$	50.0%	[%]
REPIM	**1 263.4736**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	90 107 610	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**90 107 610**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048925	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	14 679 146	[$M]
AEP_{avail}	90 107 610	[kWh/yr]
$O\&M_{WFCM}$	**0.147200**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(A)}$		Notes
$SC_{O\&M}$	**0.000038**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000138**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000176	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0=no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 615 397	[$]
Debt payments	2 991 865	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 615 397	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.1255	yr_1	78.4712	yr_{15}
73.5187	yr_2	77.6515	yr_{15}
73.7873	yr_3	78.1612	yr_{16}
74.1334	yr_4	78.6268	yr_{17}
74.4746	yr_5	79.1175	yr_{18}
74.9273	yr_6	79.6115	yr_{19}
75.2253	yr_7	77.7347	yr_{20}
75.5275	yr_8	78.2446	yr_{21}
76.0152	yr_9	78.7103	yr_{22}
76.4118	yr_{10}	79.0644	yr_{23}
76.7332	yr_{11}	79.4723	yr_{25}
77.2289	yr_{12}	76.8666	Mean
77.6321	yr_{13}	2.0151	SD
78.0589	yr_{14}	-0.4631	Υ (skewness)
$LCOE_{wso}$	**76.8666**	**US$/MWh**	valid !
	0.076867	**US$/kWh**	

Figure R.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)}$ and E_{pi} *(Case $_3$)*. Source: Own elaboration

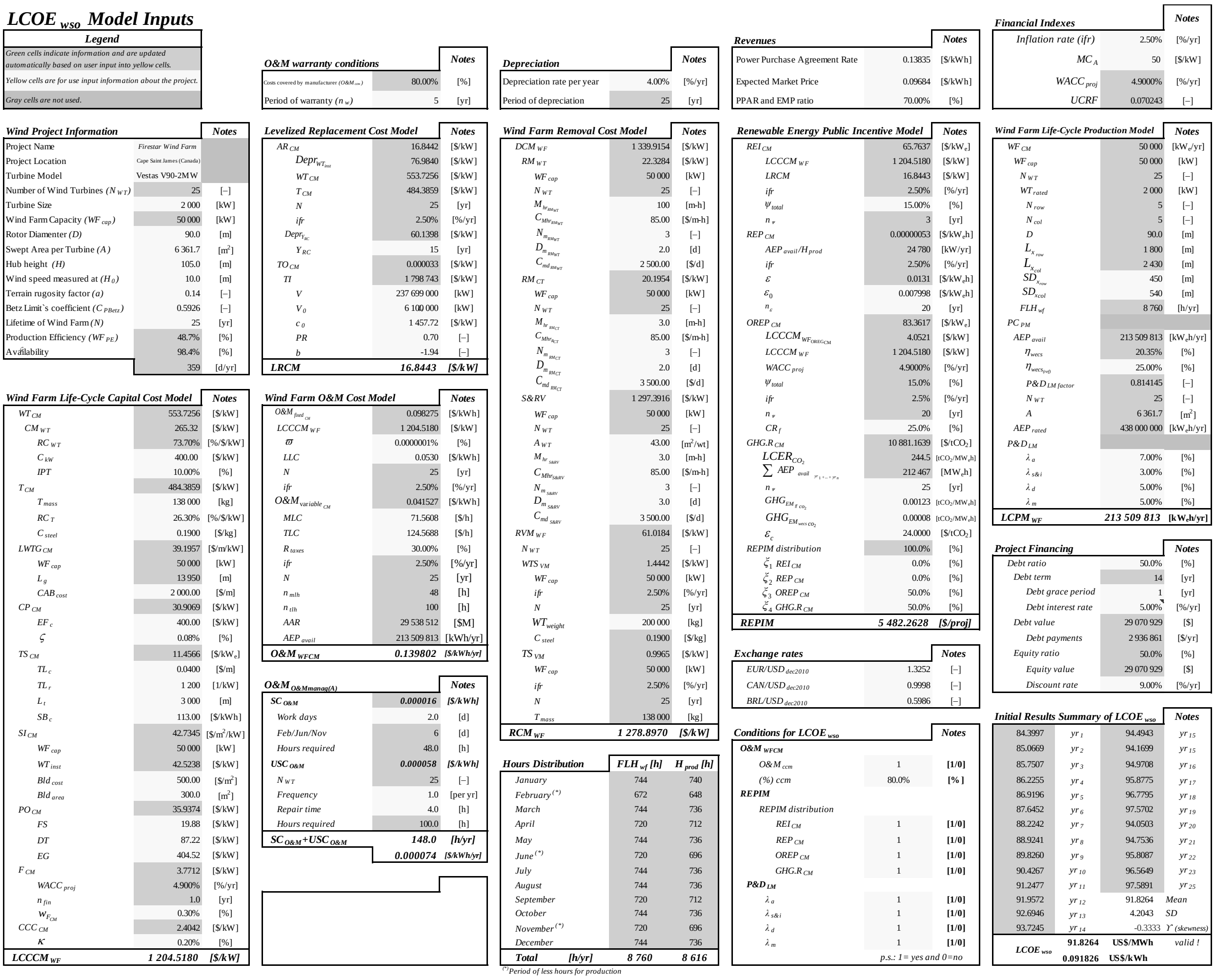

Figure R.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)}$ and E_{pi} *(Case $_3$)*. Source: Own elaboration

Table R.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_3)$

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	740	1 697 720	8 914 291	3 812 469	7 527 755	558 872	8 914 291	558 872	558 872	4 243 681	8 914 291	8 914 291	558 872	3 812 469	7 527 755	4 243 681	8 914 291	8 914 291	558 872	3 812 469	7 527 755	558 872	3 812 469	7 527 755	4 243 681	4 243 681
February	4.9	1.1666	648	859 945	6 879 561	3 714 421	6 879 561	788 321	6 879 561	788 321	788 321	4 780 152	6 879 561	6 879 561	788 321	3 714 421	6 879 561	489 171	489 171	3 336 988	4 780 152	7 802 526	1 594 674	1 594 674	7 802 526	6 879 561	4 780 152	4 780 152
March	4.0	1.1671	736	555 877	7 487 419	5 432 002	8 866 525	977 212	7 487 419	977 212	977 212	6 552 645	7 487 419	7 487 419	977 212	5 432 002	8 866 525	895 822	895 822	1 812 134	4 220 942	1 812 134	1 688 623	1 688 623	7 817 699	8 866 525	3 792 040	6 552 645
April	4.7	1.1667	712	866 366	6 337 184	6 337 184	4 082 151	1 633 098	6 337 184	1 633 098	1 633 098	7 241 220	6 337 184	6 337 184	1 752 548	6 337 184	4 082 151	945 080	945 080	1 633 098	6 337 184	1 633 098	3 667 352	945 080	7 241 220	6 337 184	1 752 548	7 241 220
May	6.0	1.1670	736	1 812 066	5 431 800	7 487 140	5 431 800	1 812 066	5 431 800	1 812 066	1 812 066	7 817 409	5 431 800	5 431 800	1 688 560	7 487 140	6 552 401	1 688 560	1 688 560	977 176	8 866 195	977 176	555 856	895 788	6 552 401	4 220 785	1 688 560	7 817 409
June	7.9	1.1686	696	3 996 852	3 996 852	7 402 657	6 204 764	3 590 720	3 996 852	3 590 720	3 590 720	8 395 800	3 996 852	3 996 852	3 590 720	7 402 657	5 143 616	1 715 927	1 715 927	848 262	7 402 657	848 262	848 262	3 590 720	5 143 616	5 143 616	925 332	8 395 800
July	8.6	1.1698	736	5 444 782	3 800 962	8 887 385	1 692 596	4 230 873	3 800 962	4 230 873	4 230 873	557 185	557 185	3 800 962	5 444 782	8 887 385	1 816 397	3 800 962	3 800 962	557 185	7 505 034	557 185	979 511	4 230 873	4 230 873	1 692 596	897 929	557 185
August	9.6	1.1677	736	7 491 301	1 813 073	1 813 073	1 813 073	8 871 123	1 813 073	5 434 819	5 434 819	896 286	896 286	1 813 073	4 223 131	1 813 073	1 689 499	5 434 819	7 821 753	7 821 753	896 286	4 223 131	7 821 753	5 434 819	1 813 073	1 813 073	556 165	896 286
September	10.1	1.1657	712	8 566 923	1 631 564	1 631 564	3 663 906	7 553 538	1 631 564	6 331 230	6 331 230	944 192	944 192	1 631 564	6 331 230	1 631 564	3 663 906	6 331 230	7 234 417	7 234 417	944 192	5 248 454	8 566 923	6 331 230	1 631 564	3 663 906	6 331 230	944 192
October	9.7	1.1645	736	7 800 246	975 031	975 031	554 636	7 470 703	975 031	7 470 703	7 470 703	1 684 853	1 684 853	975 031	8 846 730	975 031	554 636	7 470 703	6 538 016	6 538 016	1 808 088	6 538 016	4 211 519	7 470 703	975 031	975 031	8 846 730	1 684 853
November	9.2	1.1638	696	6 179 252	844 775	844 775	844 775	6 179 252	844 775	7 372 218	7 372 218	1 708 872	1 708 872	844 775	7 372 218	844 775	844 775	7 372 218	5 122 467	5 122 467	1 592 399	7 060 758	6 179 252	7 372 218	844 775	844 775	7 372 218	1 708 872
December	7.6	1.1651	736	3 785 725	554 951	554 951	975 585	5 422 956	554 951	8 851 759	8 851 759	3 785 725	3 785 725	554 951	7 474 950	554 951	975 585	8 851 759	4 213 913	4 213 913	3 785 725	7 804 681	5 422 956	8 851 759	554 951	554 951	7 474 950	3 785 725
Annual	7.4	1.1666	8 616	49 057 055	48 667 462	48 892 652	48 537 127	49 088 734	48 667 462	49 051 893	49 051 893	48 608 021	48 624 219	48 667 462	49 049 275	48 892 652	48 596 807	49 239 932	49 380 379	49 009 701	48 697 726	48 317 889	49 064 437	48 965 360	48 420 199	48 519 758	48 661 536	48 608 021

Table R.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_3)$

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	740	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408
February	11.5	1.2345	648	12 092 721	4 293 137	12 092 721	12 092 721	12 092 721	3 417 096	12 092 721	12 715 785	1 795 784	3 417 096	12 715 785	1 795 784	9 244 173	12 092 721	6 674 015	12 715 785	4 293 137	5 486 290	3 417 096	2 815 600	12 092 721	2 106 703	6 674 015	12 092 721	12 715 785
March	10.5	1.2329	736	10 486 228	3 193 907	13 717 510	13 717 510	13 717 510	6 223 433	13 717 510	13 717 510	2 389 762	3 193 907	13 717 510	2 389 762	13 717 510	13 717 510	6 223 433	13 717 510	3 876 220	7 570 742	4 869 967	13 717 510	14 424 289	2 037 067	10 486 228	14 424 289	3 193 907
April	9.5	1.2317	712	7 316 597	7 316 597	10 458 483	10 458 483	10 458 483	7 316 597	10 458 483	4 706 485	3 086 689	7 316 597	13 257 022	3 086 689	13 257 022	4 706 485	4 706 485	13 257 022	3 086 689	10 134 212	3 086 689	13 940 075	13 257 022	3 086 689	3 086 689	13 257 022	3 746 098
May	8.2	1.2282	736	4 851 676	10 446 845	10 446 845	10 446 845	6 200 059	10 446 845	10 446 845	10 446 845	3 861 662	6 200 059	10 446 845	3 861 662	14 370 115	10 446 845	3 861 662	10 446 845	2 380 787	13 665 991	6 200 059	2 380 787	10 446 845	3 861 662	14 370 115	10 446 845	4 851 676
June	7.1	1.2224	696	2 994 461	12 860 910	7 097 981	7 097 981	7 097 981	10 145 990	4 565 858	12 860 910	4 565 858	10 145 990	7 097 981	4 565 858	7 097 981	2 240 532	2 994 461	7 097 981	1 909 861	12 860 910	7 097 981	1 909 861	7 097 981	4 565 858	12 860 910	7 097 981	5 834 806
July	6.1	1.2154	736	2 008 118	13 522 571	4 800 760	6 134 992	10 337 209	13 522 571	7 463 154	3 148 518	6 134 992	2 008 118	6 134 992	6 134 992	6 134 992	2 008 118	2 355 801	6 134 992	6 134 992	14 219 306	10 337 209	3 821 135	6 134 992	6 134 992	13 522 571	3 821 135	7 463 154
August	6.4	1.2075	736	2 340 496	10 598 668	3 796 310	3 796 310	3 796 310	13 434 719	6 095 134	3 796 310	7 414 668	2 340 496	4 769 571	7 414 668	4 769 571	10 598 668	1 995 072	4 769 571	13 434 719	1 995 072	13 434 719	4 769 571	4 769 571	7 414 668	4 769 571	3 128 063	10 270 051
September	7.6	1.2064	712	3 669 202	1 928 273	5 891 057	4 609 876	4 609 876	4 609 876	1 928 273	5 891 057	9 926 189	9 926 189	3 669 202	9 926 189	3 669 202	5 891 057	9 926 189	3 669 202	12 984 898	2 262 132	12 984 898	5 891 057	3 669 202	9 926 189	3 669 202	2 262 132	1 928 273
October	8.9	1.2126	736	6 121 079	6 121 079	3 141 378	2 003 564	3 141 378	2 003 564	2 350 459	7 446 229	13 491 905	13 491 905	3 141 378	13 491 905	3 141 378	7 446 229	13 491 905	3 141 378	10 643 782	3 141 378	2 003 564	7 446 229	3 141 378	13 491 905	2 350 459	2 003 564	2 350 459
November	10.6	1.2194	696	10 121 586	3 625 425	2 235 143	2 235 143	2 235 143	2 235 143	2 987 258	2 235 143	12 829 976	4 554 876	2 235 143	12 829 976	2 235 143	2 987 258	12 829 976	2 235 143	9 807 761	3 625 425	2 235 143	9 807 761	2 235 143	12 829 976	1 905 267	5 820 771	12 829 976
December	11.5	1.2237	736	13 614 984	2 371 901	2 021 842	3 170 035	2 021 842	3 170 035	3 847 249	2 021 842	14 316 481	13 614 984	2 021 842	14 316 481	2 021 842	3 847 249	14 316 481	2 021 842	7 514 158	4 833 568	14 316 481	13 614 984	2 021 842	14 316 481	6 176 918	4 833 568	13 614 984
Annual	9.1	1.2222	8 616	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577

Table R.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_3)$

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	740	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	8 035 210	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	32 823 510	40 865 255	32 823 510	32 823 510	28 095 929	8 035 210	7 120 177
February	14.7	1.2522	648	24 591 404	14 672 254	7 010 451	26 599 864	14 672 254	14 672 254	26 599 864	26 599 864	7 010 451	14 672 254	14 672 254	7 859 649	26 599 864	7 010 451	17 623 290	7 010 451	7 010 451	7 010 451	7 010 451	22 780 600	26 599 864	26 599 864	29 369 594	7 859 649	17 596 916
March	12.7	1.2495	736	18 252 376	18 252 376	8 908 878	27 874 248	12 394 144	18 252 376	27 874 248	27 874 248	8 908 878	12 394 144	18 252 376	9 986 084	27 874 248	8 908 878	30 150 829	8 908 878	8 908 878	8 908 878	8 908 878	23 024 061	27 874 248	27 874 248	31 459 374	9 986 084	18 948 162
April	12.4	1.2490	712	16 081 249	19 315 677	9 656 023	24 865 308	9 656 023	19 315 677	24 865 308	24 865 308	9 656 023	9 656 023	19 315 677	9 656 023	24 865 308	9 656 023	26 952 947	9 656 023	29 154 282	9 656 023	9 656 023	22 218 160	20 001 184	24 865 308	24 956 459	9 656 023	18 165 621
May	11.2	1.2425	736	12 324 064	25 569 850	9 929 620	19 862 973	9 929 620	25 569 850	19 862 973	19 862 973	9 929 620	9 929 620	25 569 850	12 324 064	19 862 973	9 929 620	25 569 850	9 929 620	27 716 641	9 929 620	9 929 620	21 018 978	19 862 973	19 862 973	19 116 345	12 324 064	16 191 245
June	10.4	1.2351	696	9 333 787	26 053 485	11 584 551	17 060 120	8 326 944	26 053 485	17 060 120	17 060 120	11 584 551	8 326 944	26 053 485	15 544 593	17 060 120	11 584 551	17 060 120	11 584 551	24 035 514	11 584 551	11 584 551	17 178 664	17 060 120	17 060 120	16 981 395	15 544 593	15 146 363
July	10.0	1.2275	736	8 751 923	29 619 639	16 337 936	16 337 936	7 806 320	29 619 639	16 337 936	16 337 936	16 337 936	7 806 320	29 619 639	17 930 811	16 337 936	16 337 936	7 806 320	16 337 936	19 623 991	16 337 936	16 337 936	15 552 737	16 069 219	16 337 936	16 783 950	17 930 811	8 637 391
August	9.7	1.2216	736	7 768 712	12 117 129	17 844 428	12 117 129	17 844 428	12 117 129	12 117 129	12 117 129	17 844 428	17 844 428	12 117 129	19 529 451	12 117 129	17 844 428	8 709 760	17 844 428	17 844 428	17 844 428	17 844 428	12 921 415	15 399 666	12 117 129	12 606 836	19 529 451	7 121 992
September	10.4	1.2234	712	9 458 082	7 526 165	18 919 721	9 458 082	26 400 433	7 526 165	9 458 082	9 458 082	18 919 721	26 400 433	7 526 165	24 355 589	9 458 082	18 919 721	9 458 082	18 919 721	15 751 596	18 919 721	18 919 721	12 339 146	13 294 981	9 458 082	8 855 020	24 355 589	19 057 688
October	13.1	1.2327	736	19 706 914	8 788 905	29 744 799	9 851 605	25 368 953	8 788 905	9 851 605	9 851 605	29 744 799	25 368 953	8 788 905	27 498 877	9 851 605	25 368 953	9 851 605	25 368 953	12 227 237	29 744 799	25 368 953	12 259 773	8 871 247	9 851 605	8 134 157	27 498 877	21 626 625
November	14.3	1.2429	696	24 188 639	9 393 250	26 219 466	8 379 993	28 360 895	9 393 250	8 379 993	8 379 993	26 219 466	28 360 895	9 393 250	28 360 895	8 379 993	26 219 466	11 658 353	26 219 466	9 393 250	26 219 466	26 219 466	7 520 762	8 379 993	8 379 993	8 987 716	28 360 895	22 240 116
December	15.1	1.2528	736	30 229 153	10 012 025	25 782 051	7 966 958	20 027 814	10 012 025	7 966 958	7 966 958	25 782 051	20 027 814	10 012 025	32 544 702	7 966 958	30 229 153	16 674 139	30 229 153	10 012 025	25 782 051	30 229 153	6 359 397	7 966 958	7 966 958	9 176 637	32 544 702	42 535 343
Annual	12.5	1.2404	8 616	213 509 813	214 144 266	214 761 434	213 197 728	213 611 337	214 144 266	213 197 728	213 197 728	214 761 434	213 611 337	214 144 266	213 625 948	213 197 728	214 832 689	214 338 805	214 832 689	214 501 803	214 761 434	214 832 689	214 038 947	214 203 964	213 197 728	214 523 412	213 625 948	214 387 639

Table R.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_{3})$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table R.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_{3})$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table R.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_{3})$

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table R.7 kWh per H_{prod} with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_3)$

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 693	5 648	5 674	5 633	5 697	5 648	5 693	5 693	5 641	5 643	5 648	5 693	5 674	5 640	5 715	5 731	5 688	5 652	5 608	5 694	5 683	5 620	5 631	5 648	5 641
Corvo Island (Portugal)	10 458	10 535	10 467	10 475	10 468	10 563	10 497	10 429	10 525	10 527	10 454	10 525	10 507	10 500	10 474	10 454	10 510	10 523	10 545	10 560	10 464	10 520	10 532	10 452	10 407
Cape Saint James (Canada)	24 780	24 853	24 925	24 743	24 791	24 853	24 743	24 743	24 925	24 791	24 853	24 793	24 743	24 933	24 876	24 933	24 895	24 925	24 933	24 841	24 860	24 743	24 897	24 793	24 882

Table R.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_3)$

Item	Years 0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	49 057 055	48 667 462	48 892 652	48 537 127	49 088 734	48 667 462	49 051 893	49 051 893	48 608 021	48 624 219	48 667 462	49 049 275
(+) AAR ($M/yr)	-	4 314 826	4 387 573	4 518 071	4 597 349	4 765 836	4 843 059	5 003 348	5 128 432	5 209 075	5 341 081	5 479 477	5 660 527
PPAR	-	4 314 826	4 387 573	4 518 071	4 597 349	4 765 836	4 843 059	5 003 348	5 128 432	5 209 075	5 341 081	5 479 477	5 660 527
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	3 964 703	4 031 427	4 151 213	4 223 934	4 378 615	4 471 031	4 618 343	4 733 137	4 806 905	4 928 061	5 055 095	5 221 459
$O\&M_{fixed}$	-	2 665 486	2 710 424	2 791 038	2 840 010	2 944 091	2 991 795	3 090 812	3 168 081	3 217 896	3 299 441	3 384 934	3 496 775
$O\&M_{variable}$	-	1 299 217	1 321 003	1 360 175	1 383 923	1 434 523	1 479 236	1 527 531	1 565 056	1 589 009	1 628 620	1 670 162	1 724 683
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 447 050	2 508 226	2 570 932	2 635 205	2 701 085	2 768 612	2 837 827	2 908 773	2 981 492	3 056 030	3 132 430	3 210 741
(=) Profit before tax	-	3 660 441	3 749 221	3 844 761	3 938 265	4 041 193	4 117 349	4 223 960	4 330 223	4 435 471	4 547 154	4 661 869	4 782 493
(-) Revenue tax	-	1 294 448	1 316 272	1 355 421	1 379 205	1 429 751	1 452 918	1 501 004	1 538 530	1 562 723	1 602 324	1 643 843	1 698 158
(+) REPIM	541 763	1 181	1 201	1 237	1 258	1 305	1 326	1 370	1 404	1 426	1 462	1 500	1 550
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	541 763	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	1 181	1 201	1 237	1 258	1 305	1 326	1 370	1 404	1 426	1 462	1 500	1 550
(=) Profit after tax w/out interest	-	2 367 174	2 434 151	2 490 577	2 560 319	2 612 747	2 665 757	2 724 325	2 793 097	2 874 174	2 946 292	3 019 526	3 085 884
(-) Debt payments	-	-	3 167 387	3 246 571	3 327 736	3 410 929	3 496 202	3 583 607	3 673 197	3 765 027	3 859 153	3 955 632	4 054 523
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 447 050	2 508 226	2 570 932	2 635 205	2 701 085	2 768 612	2 837 827	2 908 773	2 981 492	3 056 030	3 132 430	3 210 741
(=) Free net cashflow	-59 684 137	7 435 963	4 462 272	4 569 401	4 691 115	4 796 812	4 904 424	5 018 958	5 145 097	5 284 973	5 417 361	5 552 371	5 682 051
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 248 175	-47 785 903	-43 216 501	-38 525 387	-33 728 575	-28 824 152	-23 805 194	-18 660 097	-13 375 124	-7 957 763	-2 405 392	3 276 659
$LCOE_{wso}$		67.68	67.83	68.04	68.20	68.45	68.64	68.89	69.10	69.28	69.51	69.74	70.02

Item	Years 13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	48 892 652	48 596 807	49 239 932	49 380 379	49 009 701	48 697 726	48 317 889	49 064 437	48 965 360	48 420 199	48 519 758	48 661 536	48 608 021
(+) AAR ($M/yr)	5 783 513	5 892 231	6 119 463	6 290 341	6 399 200	6 517 427	6 628 256	6 898 935	4 939 990	5 007 115	5 142 845	5 286 820	5 413 031
PPAR	5 783 513	5 892 231	6 119 463	6 290 341	6 399 200	6 517 427	6 628 256	6 898 935	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 939 990	5 007 115	5 142 845	5 286 820	5 413 031
(-) $O\&M_{WFCM}$	5 334 243	5 433 856	5 642 744	5 799 641	5 899 344	6 007 676	6 109 183	6 357 999	5 867 984	5 947 062	6 107 615	6 277 939	6 427 153
$O\&M_{fixed}$	3 572 748	3 639 907	3 780 277	3 885 835	3 953 081	4 026 113	4 094 576	4 261 785	4 359 507	4 418 743	4 538 523	4 665 578	4 776 957
$O\&M_{variable}$	1 761 494	1 793 950	1 862 467	1 913 806	1 946 264	1 981 563	2 014 606	2 096 214	1 508 477	1 528 319	1 569 092	1 612 361	1 650 196
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 291 010	3 373 285	3 457 617	3 544 057	3 632 659	3 723 475	3 816 562	3 911 976	4 009 776	4 110 020	4 212 771	4 318 090	4 426 042
(=) Profit before tax	4 901 280	5 021 684	5 154 111	4 034 757	4 132 514	4 233 226	4 335 636	4 452 912	3 081 782	3 170 072	3 248 001	3 326 970	3 411 921
(-) Revenue tax	1 735 054	1 767 669	1 835 839	1 887 102	1 919 760	1 955 228	1 988 477	2 069 680	1 481 997	1 502 134	1 542 854	1 586 046	1 623 909
(+) REPIM	1 583	1 613	1 675	1 722	1 752	1 784	1 814	1 889	1 932	1 958	2 011	2 067	2 117
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	1 583	1 613	1 675	1 722	1 752	1 784	1 814	1 889	1 932	1 958	2 011	2 067	2 117
(=) Profit after tax w/out interest	3 167 810	3 255 628	3 319 948	2 149 377	2 214 506	2 279 782	2 348 973	2 385 120	1 601 716	1 669 896	1 707 158	1 742 992	1 790 128
(-) Debt payments	4 155 886	4 259 783	4 366 278	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 291 010	3 373 285	3 457 617	3 544 057	3 632 659	3 723 475	3 816 562	3 911 976	4 009 776	4 110 020	4 212 771	4 318 090	4 426 042
(=) Free net cashflow	5 828 881	5 983 226	6 115 736	9 490 494	9 739 151	9 992 543	10 254 553	10 488 340	9 907 517	10 183 341	10 433 439	10 687 430	10 958 177
$\Sigma_{free\ net\ annual\ cashflow}$	9 105 540	15 088 766	21 204 502	30 694 996	40 434 147	50 426 690	60 681 243	71 169 583	81 077 099	91 260 440	101 693 880	112 381 310	123 339 487
$LCOE_{wso}$	70.25	70.46	70.79	69.82	70.02	70.22	70.42	70.78	70.39	70.58	70.85	71.13	71.40

Table R.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_3)$

Item	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Years																									
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577
(+) AAR ($M/yr)	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
PPAR	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
(-) $O\&M_{WFCM}$	-	9 414 550	9 720 704	9 900 012	10 154 527	10 401 931	10 758 472	10 957 897	11 159 028	11 543 192	11 833 646	12 046 185	12 430 378	12 719 232	13 028 853	13 321 057	13 628 511	14 043 351	14 411 633	14 802 558	15 194 336	13 212 815	13 615 294	13 970 912	14 212 144	14 504 416
$O\&M_{fixed}$	-	4 895 943	5 055 217	5 148 526	5 280 948	5 409 674	5 595 159	5 698 935	5 803 599	6 003 456	6 154 579	6 265 179	6 465 057	6 615 352	6 776 449	6 928 488	7 088 460	7 304 288	7 495 901	7 699 294	7 903 132	8 027 381	8 271 977	8 488 105	8 634 738	8 812 382
$O\&M_{variable}$	-	4 518 607	4 665 487	4 751 486	4 873 579	4 992 258	5 163 313	5 258 962	5 355 430	5 539 736	5 679 068	5 781 006	5 965 321	6 103 880	6 252 405	6 392 569	6 540 051	6 739 063	6 915 732	7 103 264	7 291 205	5 185 434	5 343 317	5 482 807	5 577 406	5 692 034
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 428 463	2 489 174	2 551 403	2 615 189	2 680 568	2 747 582	2 816 272	2 886 679	2 958 846	3 032 817	3 108 637	3 186 353	3 266 012	3 347 662	3 431 354	3 517 138	3 605 066	3 695 193	3 787 573	3 882 262	3 979 319	4 078 802	4 180 772	4 285 291	4 392 423
(=) Profit before tax	-	8 923 305	9 188 929	9 380 737	9 619 647	9 856 469	10 160 805	10 373 418	10 589 383	10 917 249	11 191 497	11 421 636	11 757 060	12 038 075	12 334 220	12 622 714	11 672 904	12 009 282	12 320 003	12 646 533	12 975 888	8 035 375	8 258 571	8 469 873	8 648 610	8 845 633
(-) Revenue tax	-	4 513 837	4 660 683	4 746 712	4 868 802	4 987 484	5 158 496	5 254 175	5 350 673	5 534 936	5 674 267	5 776 238	5 960 521	6 099 089	6 247 616	6 387 792	6 535 283	6 734 270	6 910 933	7 098 455	7 286 389	5 180 661	5 338 519	5 478 004	5 572 639	5 687 288
(+) REPIM	995 107	691	713	727	745	764	790	804	819	847	869	884	912	934	956	978	1 000	1 031	1 058	1 087	1 115	1 133	1 167	1 198	1 219	1 244
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	995 107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	691	713	727	745	764	790	804	819	847	869	884	912	934	956	978	1 000	1 031	1 058	1 087	1 115	1 133	1 167	1 198	1 219	1 244
(=) Profit after tax w/out interest	-	4 410 159	4 528 960	4 634 751	4 751 590	4 869 749	5 003 099	5 120 048	5 239 529	5 383 160	5 518 099	5 646 282	5 797 452	5 939 920	6 087 561	6 235 899	5 138 621	5 276 043	5 410 128	5 549 164	5 690 615	2 855 846	2 921 219	2 993 067	3 077 190	3 159 589
(-) Debt payments	-	-	3 143 328	3 221 911	3 302 459	3 385 021	3 469 646	3 556 387	3 645 297	3 736 429	3 829 840	3 925 586	4 023 726	4 124 319	4 227 427	4 333 113	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 428 463	2 489 174	2 551 403	2 615 189	2 680 568	2 747 582	2 816 272	2 886 679	2 958 846	3 032 817	3 108 637	3 186 353	3 266 012	3 347 662	3 431 354	3 517 138	3 605 066	3 695 193	3 787 573	3 882 262	3 979 319	4 078 802	4 180 772	4 285 291	4 392 423
(=) Free net cashflow	-59 230 794	9 460 360	6 562 088	6 718 708	6 887 646	7 059 206	7 247 292	7 420 346	7 597 334	7 799 911	7 995 269	8 185 381	8 400 028	8 607 561	8 821 892	9 038 589	12 452 818	12 773 095	13 094 606	13 425 755	13 764 120	11 131 189	11 403 446	11 687 349	11 988 829	12 294 019
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 770 434	-43 208 345	-36 489 638	-29 601 992	-22 542 786	-15 295 494	-7 875 149	-277 814	7 522 096	15 517 365	23 702 746	32 102 774	40 710 335	49 532 227	58 570 816	71 023 635	83 796 730	96 891 337	110 317 091	124 081 212	135 212 401	146 615 847	158 303 196	170 292 025	182 586 044
	$LCOE_{wso}$	73.13	73.52	73.79	74.13	74.47	74.93	75.23	75.53	76.02	76.41	76.73	77.23	77.63	78.06	78.47	77.65	78.16	78.63	79.12	79.61	77.73	78.24	78.71	79.06	79.47

Table R.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(A)} + E_{pi}$ $(Case_3)$

Item	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Years																									
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	213 509 813	214 144 266	214 761 434	213 197 728	213 611 337	214 144 266	213 197 728	213 197 728	214 761 434	213 611 337	214 144 266	213 625 948	213 197 728	214 832 689	214 338 805	214 832 689	214 501 803	214 761 434	214 832 689	214 038 947	214 203 964	213 197 728	214 523 412	213 625 948	214 387 639
(+) AAR ($M/yr)	-	30 276 974	31 126 117	31 996 219	32 557 331	33 436 006	34 357 409	35 060 685	35 937 202	37 105 804	37 829 772	38 872 255	39 747 622	40 659 646	41 995 741	42 946 676	44 121 775	45 155 164	46 340 065	47 514 326	48 522 244	34 841 551	35 544 828	36 659 995	37 419 293	38 491 531
PPAR	-	30 276 974	31 126 117	31 996 219	32 557 331	33 436 006	34 357 409	35 060 685	35 937 202	37 105 804	37 829 772	38 872 255	39 747 622	40 659 646	41 995 741	42 946 676	44 121 775	45 155 164	46 340 065	47 514 326	48 522 244	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 841 551	35 544 828	36 659 995	37 419 293	38 491 531
(-) $O\&M_{WFCM}$	-	20 688 790	21 268 898	21 863 324	22 246 612	22 846 890	23 476 361	23 956 782	24 555 577	25 353 946	25 848 498	26 560 685	27 158 681	27 781 721	28 694 515	29 344 137	30 146 919	30 852 873	31 662 346	32 464 546	33 153 088	29 528 360	30 124 265	31 069 244	31 712 621	32 621 209
$O\&M_{fixed}$	-	11 600 929	11 926 280	12 259 661	12 474 651	12 811 317	13 164 355	13 433 815	13 769 654	14 217 407	14 494 795	14 894 225	15 229 623	15 579 065	16 090 994	16 455 346	16 905 588	17 301 532	17 755 529	18 205 449	18 591 634	19 071 110	19 456 054	20 066 453	20 482 061	21 068 961
$O\&M_{variable}$	-	9 087 862	9 342 619	9 603 663	9 771 962	10 035 573	10 312 006	10 522 968	10 785 923	11 136 539	11 353 703	11 666 460	11 929 059	12 202 656	12 603 521	12 888 791	13 241 331	13 551 341	13 906 817	14 259 097	14 561 454	10 457 250	10 668 211	11 002 791	11 230 560	11 552 248
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 383 816	2 443 412	2 504 497	2 567 109	2 631 287	2 697 069	2 764 496	2 833 608	2 904 449	2 977 060	3 051 486	3 127 773	3 205 968	3 286 117	3 368 270	3 452 477	3 538 788	3 627 258	3 717 940	3 810 888	3 906 160	4 003 814	4 103 910	4 206 507	4 311 670
(=) Profit before tax	-	12 835 269	13 185 480	13 544 363	13 807 474	14 173 290	14 554 827	14 869 525	15 241 389	15 708 116	16 036 437	16 468 113	16 849 397	17 244 892	17 777 367	18 190 584	17 427 332	17 841 080	18 304 977	18 767 720	19 180 044	9 219 351	9 424 378	9 694 662	9 913 180	10 181 992
(-) Revenue tax	-	9 083 092	9 337 835	9 598 866	9 767 199	10 030 802	10 307 223	10 518 205	10 781 161	11 131 741	11 348 931	11 661 677	11 924 287	12 197 894	12 598 722	12 884 003	13 236 533	13 546 549	13 902 019	14 254 298	14 556 673	10 452 465	10 663 448	10 997 999	11 225 788	11 547 459
(+) REPIM	2 084 043	3 023	3 107	3 194	3 250	3 338	3 430	3 500	3 588	3 704	3 777	3 881	3 968	4 059	4 193	4 288	4 405	4 508	4 626	4 744	4 844	4 969	5 069	5 229	5 337	5 490
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	2 084 043	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	3 023	3 107	3 194	3 250	3 338	3 430	3 500	3 588	3 704	3 777	3 881	3 968	4 059	4 193	4 288	4 405	4 508	4 626	4 744	4 844	4 969	5 069	5 229	5 337	5 490
(=) Profit after tax w/out interest	-	3 755 199	3 850 753	3 948 691	4 043 525	4 145 826	4 251 034	4 354 820	4 463 816	4 580 079	4 691 282	4 810 317	4 929 079	5 051 057	5 182 838	5 310 869	4 195 205	4 299 039	4 407 584	4 518 166	4 628 215	-1 228 145	-1 234 001	-1 298 109	-1 307 271	-1 359 978
(-) Debt payments	-	-	3 085 539	3 162 678	3 241 745	3 322 788	3 405 858	3 491 004	3 578 279	3 667 736	3 759 430	3 853 416	3 949 751	4 048 495	4 149 707	4 253 450	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 383 816	2 443 412	2 504 497	2 567 109	2 631 287	2 697 069	2 764 496	2 833 608	2 904 449	2 977 060	3 051 486	3 127 773	3 205 968	3 286 117	3 368 270	3 452 477	3 538 788	3 627 258	3 717 940	3 810 888	3 906 160	4 003 814	4 103 910	4 206 507	4 311 670
(=) Free net cashflow	-58 141 858	8 760 754	5 895 907	6 044 975	6 192 215	6 348 234	6 508 502	6 668 725	6 835 568	7 011 125	7 183 105	7 364 435	7 547 050	7 734 478	7 933 343	8 130 138	11 444 741	11 729 813	12 024 128	12 325 123	12 630 347	6 974 040	7 173 238	7 319 312	7 525 585	7 693 699
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 381 104	-43 485 196	-37 440 221	-31 248 006	-24 899 772	-18 391 270	-11 722 546	-4 886 978	2 124 147	9 307 252	16 671 687	24 218 737	31 953 214	39 886 558	48 016 695	59 461 436	71 191 249	83 215 377	95 540 500	108 170 847	115 144 887	122 318 125	129 637 437	137 163 021	144 856 721
	$LCOE_{wso}$	84.40	85.07	85.75	86.23	86.92	87.65	88.22	88.92	89.83	90.43	91.25	91.96	92.69	93.72	94.49	94.17	94.97	95.88	96.78	97.57	94.05	94.75	95.81	96.56	97.59

APPENDIX S

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m^2]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	98.2%	[%]
	358	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inv}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m^2/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
Ψ_{total}	25.00%	[%]
n_{Ψ}	5	[yr]
REP_{CM}	0.00002484	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5 696	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1415	[$/kW$_e$h]
ε_0	0.105194	[$/kW$_e$h]
n_{ε}	12	[yr]
$OREP_{CM}$	20.7516	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	4.3886	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
Ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_{Ψ}	12	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	2 427.4170	[$/tCO$_2$]
$LCER_{CO_2}$	31.4	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail\ yr_1+\ldots+yr_n}$	48 856	[MW$_e$h]
n_{Ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00069	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ CO_2}}$	0.00005	[tCO$_2$/MW$_e$h]
ε_c	41.7438	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**39.7344**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	48 979 624	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m^2]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**48 979 624**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m^2/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m^2]
Bld_{area}	300.0	[m^2]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
W_{FCM}	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025839	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	90	[h]
AAR	4 202 942	[$M]
AEP_{avail}	48 979 624	[kWh/yr]
$O\&M_{WFCM}$	**0.124114**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$		Notes
$SC_{O\&M}$	**0.000105**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000229**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.8	[per yr]
Repair time	2.0	[h]
Hours required	90.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**162.0**	**[h/yr]**
	0.000334	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	641
March	744	737
April	720	713
May	744	737
June (*)	720	689
July	744	737
August	744	737
September	720	713
October	744	737
November (*)	720	689
December	744	737
Total [h/yr]	**8 760**	**8 600**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 551 422	[$]
Debt payments	2 985 402	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 551 422	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
67.6693	yr_1	70.7843	yr_{15}
67.8196	yr_2	69.8148	yr_{15}
68.0301	yr_3	70.0062	yr_{16}
68.1907	yr_4	70.2090	yr_{17}
68.4452	yr_5	70.4052	yr_{18}
68.6285	yr_6	70.7652	yr_{19}
68.8776	yr_7	70.3784	yr_{20}
69.0932	yr_8	70.5607	yr_{21}
69.2651	yr_9	70.8306	yr_{22}
69.4927	yr_{10}	71.1149	yr_{23}
69.7293	yr_{11}	71.3767	yr_{25}
70.0108	yr_{12}	69.6873	Mean
70.2358	yr_{13}	1.0827	SD
70.4493	yr_{14}	-0.4490	Υ (skewness)
$LCOE_{wso}$	**69.6873**	**US$/MWh**	valid !
	0.069687	**US$/kWh**	

Figure S.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$ and E_{pi} *(Case $_1$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.6%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inv}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{T_{inv}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048925	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	14 679 146	[$M]
AEP_{avail}	90 107 610	[kWh/yr]
$O\&M_{WFCM}$	**0.147200**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$		Notes
$SC_{O\&M}$	**0.000038**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000138**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000176	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{WT}}}$	100	[m-h]
$C_{Mhr_{RM_{WT}}}$	85.00	[$/m-h]
$N_{m_{RM_{WT}}}$	3	[–]
$D_{m_{RM_{WT}}}$	2.0	[d]
$C_{md_{RM_{WT}}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RM_{CT}}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RM_{CT}}}$	3	[–]
$D_{m_{RM_{CT}}}$	2.0	[d]
$C_{md_{RM_{CT}}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	740
February (*)	672	648
March	744	736
April	720	712
May	744	736
June (*)	720	696
July	744	736
August	744	736
September	720	712
October	744	736
November (*)	720	696
December	744	736
Total [h/yr]	**8 760**	**8 616**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_{ψ}	5	[yr]
REP_{CM}	0.00000982	[$/kW$_e$h]
AEP_{avail}/H_{prod}	10 458	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.1027	[$/kW$_e$h]
ε_0	0.067500	[$/kW$_e$h]
n_{ε}	17	[yr]
$OREP_{CM}$	33.6767	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	3.8789	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	17	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	1 248.5415	[$/tCO₂]
$LCER_{CO_2}$	57.6	[tCO₂/MW$_e$h]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	89 657	[MW$_e$h]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\,co_2}}$	0.00069	[tCO₂/MW$_e$h]
$GHG_{EM_{wecs\,co_2}}$	0.00005	[tCO₂/MW$_e$h]
ε_c	11.7000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**42.9657**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	90 107 610	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**90 107 610**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 470 640	[$]
Debt payments	2 977 241	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 470 640	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
73.1255	yr_1	78.4712	yr_{15}
73.5187	yr_2	77.6515	yr_{15}
73.7873	yr_3	78.1612	yr_{16}
74.1334	yr_4	78.6268	yr_{17}
74.4746	yr_5	79.1175	yr_{18}
74.9273	yr_6	79.6115	yr_{19}
75.2253	yr_7	77.7347	yr_{20}
75.5275	yr_8	78.2446	yr_{21}
76.0152	yr_9	78.7103	yr_{22}
76.4118	yr_{10}	79.0644	yr_{23}
76.7332	yr_{11}	79.4723	yr_{25}
77.2289	yr_{12}	76.8666	Mean
77.6321	yr_{13}	2.0151	SD
78.0589	yr_{14}	-0.4631	ϒ (skewness)
$LCOE_{wso}$	**76.8666**	**US$/MWh**	valid !
	0.076867	**US$/kWh**	

Figure S.2 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)}$ and E_{pi} *(Case $_1$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m^2]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.6%	[%]
Availability	98.2%	[%]
	358	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m^2/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m^2]
Bld_{area}	300.0	[m^2]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$w_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
$LRCM$	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041526	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	90	[h]
AAR	29 460 159	[$M]
AEP_{avail}	212 943 465	[kWh/yr]
$O\&M_{WFCM}$	**0.139801**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$		Notes
$SC_{O\&M}$	**0.000024**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000053**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.8	[per yr]
Repair time	2.0	[h]
Hours required	90.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**162.0**	**[h/yr]**
	0.000077	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m^2/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	641
March	744	737
April	720	713
May	744	737
June (*)	720	689
July	744	737
August	744	737
September	720	713
October	744	737
November (*)	720	689
December	744	737
Total [h/yr]	**8 760**	**8 600**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	69.0930	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	25.00%	[%]
n_{ψ}	5	[yr]
REP_{CM}	0.00000049	[$/kW$_e$h]
AEP_{avail}/H_{prod}	24 762	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0121	[$/kW$_e$h]
ε_0	0.008998	[$/kW$_e$h]
n_{ε}	12	[yr]
$OREP_{CM}$	90.2196	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	4.3886	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	25.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	12	[yr]
CR_f	60.0%	[%]
$GHG.R_{CM}$	6 827.9067	[$/t$CO_2$]
$LCER_{CO_2}$	136.4	[tCO_2/MW$_e$h]
$\sum AEP_{avail\ yr_1+...+yr_n}$	212 467	[MW$_e$h]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00069	[tCO_2/MW$_e$h]
$GHG_{EM_{wecs\ CO_2}}$	0.00005	[tCO_2/MW$_e$h]
ε_c	27.0000	[$/t$CO_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	50.0%	[%]
ξ_2 REP_{CM}	25.0%	[%]
ξ_3 $OREP_{CM}$	25.0%	[%]
ξ_4 $GHG.R_{CM}$	0.0%	[%]
REPIM	**57.1014**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 943 465	[kW$_e$h/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs(ref)}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m^2]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 943 465**	**[kW$_e$h/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 117 247	[$]
Debt payments	2 941 540	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 117 247	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.3448	yr_1	94.4360	yr_{15}
85.0205	yr_2	94.1138	yr_{15}
85.7100	yr_3	94.9205	yr_{16}
86.1734	yr_4	95.8186	yr_{17}
86.8681	yr_5	96.7191	yr_{18}
87.5940	yr_6	97.4969	yr_{19}
88.1682	yr_7	93.9817	yr_{20}
88.8666	yr_8	94.6831	yr_{21}
89.7788	yr_9	95.7335	yr_{22}
90.3684	yr_{10}	96.5076	yr_{23}
91.1898	yr_{11}	97.5244	yr_{25}
91.9082	yr_{12}	91.7691	Mean
92.6296	yr_{13}	4.1987	SD
93.6712	yr_{14}	-0.3338	Υ (skewness)
$LCOE_{wso}$	**91.7691**	**US$/MWh**	valid !
	0.091769	**US$/kWh**	

Figure S.3 *I-O system representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$ and E_{pi} *(Case $_1$)*. Source: Own elaboration

Table S.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$ + Epi ($Case_1$)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	641	850 430	6 803 436	3 673 320	6 803 436	779 598	6 803 436	779 598	779 598	4 727 258	6 803 436	6 803 436	779 598	3 673 320	6 803 436	483 758	483 758	3 300 063	4 727 258	7 716 188	1 577 029	1 577 029	7 716 188	6 803 436	4 727 258	4 727 258
March	4.0	1.1671	737	556 507	7 495 900	5 438 155	8 876 568	978 319	7 495 900	978 319	978 319	6 560 068	7 495 900	7 495 900	978 319	5 438 155	8 876 568	896 836	896 836	1 814 186	4 225 724	1 814 186	1 690 536	1 690 536	7 826 555	8 876 568	3 796 335	6 560 068
April	4.7	1.1667	713	867 380	6 344 604	6 344 604	4 086 931	1 635 011	6 344 604	1 635 011	1 635 011	7 249 700	6 344 604	6 344 604	1 754 600	6 344 604	4 086 931	946 187	946 187	1 635 011	6 344 604	1 635 011	3 671 646	946 187	7 249 700	6 344 604	1 754 600	7 249 700
May	6.0	1.1670	737	1 814 119	5 437 953	7 495 621	5 437 953	1 814 119	5 437 953	1 814 119	1 814 119	7 826 264	5 437 953	5 437 953	1 690 473	7 495 621	6 559 824	1 690 473	1 690 473	978 283	8 876 238	978 283	556 486	896 803	6 559 824	4 225 566	1 690 473	7 826 264
June	7.9	1.1686	689	3 955 677	3 955 677	7 326 396	6 140 844	3 553 729	3 955 677	3 553 729	3 553 729	8 309 307	3 955 677	3 955 677	3 553 729	7 326 396	5 090 627	1 698 250	1 698 250	839 524	7 326 396	839 524	839 524	3 553 729	5 090 627	5 090 627	915 799	8 309 307
July	8.6	1.1698	737	5 450 949	3 805 267	8 897 452	1 694 513	4 235 665	3 805 267	4 235 665	4 235 665	557 816	557 816	3 805 267	5 450 949	8 897 452	1 818 455	3 805 267	3 805 267	557 816	7 513 536	557 816	980 621	4 235 665	4 235 665	1 694 513	898 946	557 816
August	9.6	1.1677	737	7 499 787	1 815 127	1 815 127	1 815 127	8 881 171	1 815 127	5 440 975	5 440 975	897 302	897 302	1 815 127	4 227 915	1 815 127	1 691 413	5 440 975	7 830 614	7 830 614	897 302	4 227 915	7 830 614	5 440 975	1 815 127	1 815 127	556 795	897 302
September	10.1	1.1657	713	8 576 955	1 633 475	1 633 475	3 668 197	7 562 383	1 633 475	6 338 644	6 338 644	945 298	945 298	1 633 475	6 338 644	1 633 475	3 668 197	6 338 644	7 242 889	7 242 889	945 298	5 254 599	8 576 955	6 338 644	1 633 475	3 668 197	6 338 644	945 298
October	9.7	1.1645	737	7 809 082	976 135	976 135	555 264	7 479 165	976 135	7 479 165	7 479 165	1 686 762	1 686 762	976 135	8 856 751	976 135	555 264	7 479 165	6 545 422	6 545 422	1 810 136	6 545 422	4 216 289	7 479 165	976 135	976 135	8 856 751	1 686 762
November	9.2	1.1638	689	6 115 594	836 072	836 072	836 072	6 115 594	836 072	7 296 271	7 296 271	1 691 267	1 691 267	836 072	7 296 271	836 072	836 072	7 296 271	5 069 696	5 069 696	1 575 994	6 988 019	6 115 594	7 296 271	836 072	836 072	7 296 271	1 691 267
December	7.6	1.1651	737	3 790 014	555 580	555 580	976 690	5 429 099	555 580	8 861 786	8 861 786	3 790 014	3 790 014	555 580	7 483 417	555 580	976 690	8 861 786	4 218 687	4 218 687	3 790 014	7 813 521	5 429 099	8 861 786	555 580	555 580	7 483 417	3 790 014
Annual	7.4	1.1666	8 600	48 979 624	48 549 424	48 794 102	48 399 005	49 021 215	48 549 424	48 970 644	48 970 644	48 473 266	48 496 226	48 549 424	48 968 028	48 794 102	48 470 887	49 169 824	49 318 276	48 922 388	48 589 860	48 172 649	48 991 802	48 874 151	48 297 112	48 393 836	48 547 502	48 473 266

Table S.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)}$ + Epi ($Case_1$)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	740	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408
February	11.5	1.2345	648	12 092 721	4 293 137	12 092 721	12 092 721	12 092 721	3 417 096	12 092 721	12 715 785	1 795 784	3 417 096	12 715 785	1 795 784	9 244 173	12 092 721	6 674 015	12 715 785	4 293 137	5 486 290	3 417 096	2 815 600	12 092 721	2 106 703	6 674 015	12 092 721	12 715 785
March	10.5	1.2329	736	10 486 228	3 193 907	13 717 510	13 717 510	13 717 510	6 223 433	13 717 510	13 717 510	2 389 762	3 193 907	13 717 510	2 389 762	13 717 510	13 717 510	6 223 433	13 717 510	3 876 220	7 570 742	4 869 967	13 717 510	14 424 289	2 037 067	10 486 228	14 424 289	3 193 907
April	9.5	1.2317	712	7 316 597	7 316 597	10 458 483	10 458 483	10 458 483	7 316 597	10 458 483	4 706 485	3 086 689	7 316 597	13 257 022	3 086 689	13 257 022	4 706 485	4 706 485	13 257 022	3 086 689	10 134 212	3 086 689	13 940 075	13 257 022	3 086 689	3 086 689	13 257 022	3 746 098
May	8.2	1.2282	736	4 851 676	10 446 845	10 446 845	10 446 845	6 200 059	10 446 845	10 446 845	10 446 845	3 861 662	6 200 059	10 446 845	3 861 662	14 370 115	10 446 845	3 861 662	10 446 845	2 380 787	13 665 991	6 200 059	2 380 787	10 446 845	3 861 662	14 370 115	10 446 845	4 851 676
June	7.1	1.2224	696	2 994 461	12 860 910	7 097 981	7 097 981	7 097 981	10 145 990	4 565 858	12 860 910	4 565 858	10 145 990	7 097 981	4 565 858	7 097 981	2 240 532	2 994 461	7 097 981	1 909 861	12 860 910	7 097 981	1 909 861	7 097 981	4 565 858	12 860 910	7 097 981	5 834 806
July	6.1	1.2154	736	2 008 118	13 522 571	4 800 760	6 134 992	10 337 209	13 522 571	7 463 154	3 148 518	6 134 992	2 008 118	6 134 992	6 134 992	6 134 992	2 008 118	2 355 801	6 134 992	6 134 992	14 219 306	10 337 209	3 821 135	6 134 992	6 134 992	13 522 571	3 821 135	7 463 154
August	6.4	1.2075	736	2 340 496	10 598 668	3 796 310	3 796 310	3 796 310	13 434 719	6 095 134	3 796 310	7 414 668	2 340 496	4 769 571	7 414 668	4 769 571	10 598 668	1 995 072	4 769 571	13 434 719	1 995 072	13 434 719	4 769 571	4 769 571	7 414 668	4 769 571	3 128 063	10 270 051
September	7.6	1.2064	712	3 669 202	1 928 273	5 891 057	4 609 876	4 609 876	4 609 876	1 928 273	5 891 057	9 926 189	9 926 189	3 669 202	9 926 189	3 669 202	5 891 057	9 926 189	3 669 202	12 984 898	2 262 132	12 984 898	5 891 057	3 669 202	9 926 189	3 669 202	2 262 132	1 928 273
October	8.9	1.2126	736	6 121 079	6 121 079	3 141 378	2 003 564	3 141 378	2 003 564	2 350 459	7 446 229	13 491 905	13 491 905	3 141 378	13 491 905	3 141 378	7 446 229	13 491 905	3 141 378	10 643 782	3 141 378	2 003 564	7 446 229	3 141 378	13 491 905	2 350 459	2 003 564	2 350 459
November	10.6	1.2194	696	10 121 586	3 625 425	2 235 143	2 235 143	2 235 143	2 235 143	2 987 258	2 235 143	12 829 976	4 554 876	2 235 143	12 829 976	2 235 143	2 987 258	12 829 976	2 235 143	9 807 761	3 625 425	2 235 143	9 807 761	2 235 143	12 829 976	1 905 267	5 820 771	12 829 976
December	11.5	1.2237	736	13 614 984	2 371 901	2 021 842	3 170 035	2 021 842	3 170 035	3 847 249	2 021 842	14 316 481	13 614 984	2 021 842	14 316 481	2 021 842	3 847 249	14 316 481	2 021 842	7 514 158	4 833 568	14 316 481	13 614 984	2 021 842	14 316 481	6 176 918	4 833 568	13 614 984
Annual	9.1	1.2222	8 616	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577

Table S.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$ + Epi ($Case_1$)

Months	v_{wc} (m/s)	(kg/m³)	H_{prod} (h)	$AEP_{avail}(kWh)$ yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	641	24 319 291	14 509 901	6 932 878	26 305 527	14 509 901	14 509 901	26 305 527	26 305 527	6 932 878	14 509 901	14 509 901	7 772 679	26 305 527	6 932 878	17 428 282	6 932 878	6 932 878	6 932 878	6 932 878	22 528 524	26 305 527	26 305 527	29 044 609	7 772 679	17 402 199
March	12.7	1.2495	737	18 273 052	18 273 052	8 918 969	27 905 823	12 408 183	18 273 052	27 905 823	27 905 823	8 918 969	12 408 183	18 273 052	9 997 395	27 905 823	8 918 969	30 184 982	8 918 969	8 918 969	8 918 969	8 918 969	23 050 141	27 905 823	27 905 823	31 495 010	9 997 395	18 969 625
April	12.4	1.2490	713	16 100 080	19 338 295	9 667 330	24 894 425	9 667 330	19 338 295	24 894 425	24 894 425	9 667 330	9 667 330	19 338 295	9 667 330	24 894 425	9 667 330	26 984 508	9 667 330	29 188 421	9 667 330	9 667 330	22 244 176	20 024 605	24 894 425	24 985 682	9 667 330	18 186 892
May	11.2	1.2425	737	12 338 025	25 598 814	9 940 868	19 885 473	9 940 868	25 598 814	19 885 473	19 885 473	9 940 868	9 940 868	25 598 814	12 338 025	19 885 473	9 940 868	25 598 814	9 940 868	27 748 037	9 940 868	9 940 868	21 042 787	19 885 473	19 885 473	19 137 999	12 338 025	16 209 586
June	10.4	1.2351	689	9 237 631	25 785 086	11 465 208	16 884 369	8 241 161	25 785 086	16 884 369	16 884 369	11 465 208	8 241 161	25 785 086	15 384 455	16 884 369	11 465 208	16 884 369	11 465 208	23 787 904	11 465 208	11 465 208	17 001 691	16 884 369	16 884 369	16 806 455	15 384 455	14 990 327
July	10.0	1.2275	737	8 761 837	29 653 191	16 356 443	16 356 443	7 815 162	29 653 191	16 356 443	16 356 443	16 356 443	7 815 162	29 653 191	17 951 122	16 356 443	16 356 443	7 815 162	16 356 443	19 646 221	16 356 443	16 356 443	15 570 355	16 087 422	16 356 443	16 802 962	17 951 122	8 647 175
August	9.7	1.2216	737	7 777 512	12 130 855	17 864 641	12 130 855	17 864 641	12 130 855	12 130 855	12 130 855	17 864 641	17 864 641	12 130 855	19 551 573	12 130 855	17 864 641	8 719 626	17 864 641	17 864 641	17 864 641	17 864 641	12 936 052	15 417 110	12 130 855	12 621 116	19 551 573	7 130 060
September	10.4	1.2234	713	9 469 157	7 534 977	18 941 875	9 469 157	26 431 347	7 534 977	9 469 157	9 469 157	18 941 875	26 431 347	7 534 977	24 384 108	9 469 157	18 941 875	9 469 157	18 941 875	15 770 041	18 941 875	18 941 875	12 353 594	13 310 548	9 469 157	8 865 389	24 384 108	19 080 004
October	13.1	1.2327	737	19 729 237	8 798 861	29 778 493	9 862 764	25 397 690	8 798 861	9 862 764	9 862 764	29 778 493	25 397 690	8 798 861	27 530 026	9 862 764	25 397 690	9 862 764	25 397 690	12 241 087	29 778 493	25 397 690	12 273 661	8 881 296	9 862 764	8 143 371	27 530 026	21 651 123
November	14.3	1.2429	689	23 939 450	9 296 482	25 949 356	8 293 664	28 068 725	9 296 482	8 293 664	8 293 664	25 949 356	28 068 725	9 296 482	28 068 725	8 293 664	25 949 356	11 538 250	25 949 356	9 296 482	25 949 356	25 949 356	7 443 284	8 293 664	8 293 664	8 895 126	28 068 725	22 011 001
December	15.1	1.2528	737	30 263 395	10 023 366	25 811 256	7 975 983	20 050 501	10 023 366	7 975 983	7 975 983	25 811 256	20 050 501	10 023 366	32 581 568	7 975 983	30 263 395	16 693 026	30 263 395	10 023 366	25 811 256	30 263 395	6 366 601	7 975 983	7 975 983	9 187 032	32 581 568	42 583 526
Annual	12.5	1.2404	8 600	212 943 465	213 677 678	214 362 116	212 699 281	213 130 306	213 677 678	212 699 281	212 699 281	214 362 116	213 130 306	213 677 678	213 240 500	212 699 281	214 433 451	213 913 741	214 433 451	214 152 844	214 362 116	214 433 451	213 565 675	213 706 617	212 699 281	214 004 745	213 240 500	213 962 451

Table S.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$ + Epi ($Case_1$)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table S.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)}$ + Epi ($Case_1$)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table S.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$ + Epi ($Case_1$)

Months	v_{wc} (m/s)	Wind speed data series for simulations (m/s)																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table S.7 kWh per H_{prod} with sensitivity analysis of $O\&M_{manag(B)} + Epi\ (Case_{1})$

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 696	5 646	5 674	5 628	5 700	5 646	5 695	5 695	5 637	5 639	5 646	5 694	5 674	5 636	5 718	5 735	5 689	5 650	5 602	5 697	5 683	5 616	5 628	5 645	5 637
Corvo Island (Portugal)	10 458	10 535	10 467	10 475	10 468	10 563	10 497	10 429	10 525	10 527	10 454	10 525	10 507	10 500	10 474	10 454	10 510	10 523	10 545	10 560	10 464	10 520	10 532	10 452	10 407
Cape Saint James (Canada)	24 762	24 848	24 927	24 734	24 784	24 848	24 734	24 734	24 927	24 784	24 848	24 797	24 734	24 936	24 875	24 936	24 903	24 927	24 936	24 835	24 851	24 734	24 886	24 797	24 881

Table S.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)} + Epi\ (Case_{1})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 979 624	48 549 424	48 794 102	48 399 005	49 021 215	48 549 424	48 970 644	48 970 644	48 473 266	48 496 226	48 549 424	48 968 028	48 794 102	48 470 887	49 169 824	49 318 276	48 922 388	48 589 860	48 172 649	48 991 802	48 874 151	48 297 112	48 393 836	48 547 502	48 473 266
(+) AAR ($M/yr)	-	4 308 015	4 376 931	4 508 965	4 584 266	4 759 280	4 831 313	4 995 061	5 119 937	5 194 634	5 327 022	5 466 187	5 651 151	5 771 856	5 876 963	6 110 750	6 282 430	6 387 799	6 502 991	6 608 332	6 888 721	4 930 788	4 994 386	5 129 498	5 274 431	5 398 025
PPAR	-	4 308 015	4 376 931	4 508 965	4 584 266	4 759 280	4 831 313	4 995 061	5 119 937	5 194 634	5 327 022	5 466 187	5 651 151	5 771 856	5 876 963	6 110 750	6 282 430	6 387 799	6 502 991	6 608 332	6 888 721	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4 930 788	4 994 386	5 129 498	5 274 431	5 398 025
(-) $O\&M_{WFCM}$	-	3 958 388	4 021 593	4 142 789	4 211 857	4 372 535	4 459 642	4 610 143	4 724 747	4 793 035	4 914 544	5 042 290	5 212 260	5 322 943	5 419 232	5 634 158	5 791 793	5 888 285	5 993 824	6 090 278	6 348 036	5 856 505	5 931 402	6 091 221	6 262 682	6 408 790
$O\&M_{fixed}$	-	2 661 279	2 703 850	2 785 412	2 831 928	2 940 042	2 984 539	3 085 692	3 162 833	3 208 975	3 290 756	3 376 724	3 490 983	3 565 547	3 630 475	3 774 895	3 880 948	3 946 038	4 017 195	4 082 268	4 255 476	4 351 387	4 407 510	4 526 744	4 654 645	4 763 714
$O\&M_{variable}$	-	1 297 109	1 317 743	1 357 376	1 379 929	1 432 493	1 475 103	1 524 451	1 561 914	1 584 059	1 623 788	1 665 566	1 721 276	1 757 396	1 788 757	1 859 263	1 910 846	1 942 247	1 976 628	2 008 010	2 092 560	1 505 118	1 523 892	1 564 477	1 608 038	1 645 077
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 423 217	2 483 797	2 545 892	2 609 539	2 674 778	2 741 647	2 810 188	2 880 443	2 952 454	3 026 265	3 101 922	3 179 470	3 258 957	3 340 431	3 423 942	3 509 540	3 597 279	3 687 211	3 779 391	3 873 876	3 970 723	4 069 991	4 171 740	4 276 034	4 382 935
(=) Profit before tax	-	3 636 112	3 723 985	3 819 039	3 911 594	4 014 410	4 090 027	4 196 233	4 301 788	4 405 862	4 516 847	4 630 876	4 751 044	4 868 870	4 988 187	5 120 309	4 000 176	4 096 793	4 196 378	4 297 445	4 414 561	3 045 006	3 132 975	3 210 018	3 287 782	3 372 169
(-) Revenue tax	-	1 292 405	1 313 079	1 352 689	1 375 280	1 427 784	1 449 394	1 498 518	1 535 981	1 558 390	1 598 107	1 639 856	1 695 345	1 731 557	1 763 089	1 833 225	1 884 729	1 916 340	1 950 897	1 982 500	2 066 616	1 479 236	1 498 316	1 538 850	1 582 329	1 619 407
(+) REPIM	1 123 057	1 725	1 668	1 636	1 583	1 564	1 512	1 487	1 451	1 401	1 368	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 725	1 668	1 636	1 583	1 564	1 512	1 487	1 451	1 401	1 368	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	259 395	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	2 345 433	2 412 574	2 467 986	2 537 897	2 588 190	2 642 145	2 699 202	2 767 258	2 848 873	2 920 108	2 991 020	3 055 699	3 137 313	3 225 098	3 287 084	2 115 448	2 180 453	2 245 480	2 314 945	2 347 944	1 565 769	1 634 659	1 671 168	1 705 453	1 752 762
(-) Debt payments	-	-	3 136 538	3 214 951	3 295 325	3 377 708	3 462 151	3 548 705	3 637 422	3 728 358	3 821 567	3 917 106	4 015 034	4 115 410	4 218 295	4 323 752	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 423 217	2 483 797	2 545 892	2 609 539	2 674 778	2 741 647	2 810 188	2 880 443	2 952 454	3 026 265	3 101 922	3 179 470	3 258 957	3 340 431	3 423 942	3 509 540	3 597 279	3 687 211	3 779 391	3 873 876	3 970 723	4 069 991	4 171 740	4 276 034	4 382 935
(=) Free net cashflow	-59 102 843	7 390 388	4 447 116	4 553 391	4 675 437	4 779 169	4 887 898	5 001 099	5 126 703	5 267 304	5 399 000	5 531 884	5 660 084	5 806 808	5 961 330	6 091 722	9 422 047	9 669 718	9 921 977	10 183 354	10 413 063	9 832 516	10 108 074	10 356 419	10 607 835	10 877 703
$\Sigma_{free\ net\ annual\ cashflow}$	-	-51 712 455	-47 265 339	-42 711 948	-38 036 511	-33 257 342	-28 369 445	-23 368 346	-18 241 643	-12 974 339	-7 575 340	-2 043 456	3 616 628	9 423 436	15 384 766	21 476 488	30 898 535	40 568 253	50 490 230	60 673 584	71 086 647	80 919 163	91 027 238	101 383 657	111 991 492	122 869 195
$LCOE_{wso}$		67.67	67.82	68.03	68.19	68.45	68.63	68.88	69.09	69.27	69.49	69.73	70.01	70.24	70.45	70.78	69.81	70.01	70.21	70.41	70.77	70.38	70.56	70.83	71.11	71.38

Table S.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)} + Epi\ (Case_1)$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577
(+) AAR ($M/yr)	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
PPAR	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
(-) $O\&M_{WFCM}$	-	9 414 550	9 720 704	9 900 012	10 154 527	10 401 931	10 758 472	10 957 897	11 159 028	11 543 192	11 833 646	12 046 185	12 430 378	12 719 232	13 028 853	13 321 057	13 628 511	14 043 351	14 411 633	14 802 558	15 194 336	13 212 815	13 615 294	13 970 912	14 212 144	14 504 416
$O\&M_{fixed}$	-	4 895 943	5 055 217	5 148 526	5 280 948	5 409 674	5 595 159	5 698 935	5 803 599	6 003 456	6 154 579	6 265 179	6 465 057	6 615 352	6 776 449	6 928 488	7 088 460	7 304 288	7 495 901	7 699 294	7 903 132	8 027 381	8 271 977	8 488 105	8 634 738	8 812 382
$O\&M_{variable}$	-	4 518 607	4 665 487	4 751 486	4 873 579	4 992 258	5 163 313	5 258 962	5 355 430	5 539 736	5 679 068	5 781 006	5 965 321	6 103 880	6 252 405	6 392 569	6 540 051	6 739 063	6 915 732	7 103 264	7 291 205	5 185 434	5 343 317	5 482 807	5 577 406	5 692 034
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 416 592	2 477 007	2 538 932	2 602 406	2 667 466	2 734 153	2 802 506	2 872 569	2 944 383	3 017 993	3 093 443	3 170 779	3 250 048	3 331 299	3 414 582	3 499 946	3 587 445	3 677 131	3 769 060	3 863 286	3 959 868	4 058 865	4 160 336	4 264 345	4 370 954
(=) Profit before tax	-	8 911 435	9 176 763	9 368 266	9 606 864	9 843 367	10 147 375	10 359 653	10 575 273	10 902 786	11 176 673	11 406 441	11 741 486	12 022 111	12 317 857	12 605 942	11 655 712	11 991 661	12 301 941	12 628 019	12 956 912	8 015 924	8 238 634	8 449 437	8 627 664	8 824 163
(-) Revenue tax	-	4 513 837	4 660 683	4 746 712	4 868 802	4 987 484	5 158 496	5 254 175	5 350 673	5 534 936	5 674 267	5 776 238	5 960 521	6 099 089	6 247 616	6 387 792	6 535 283	6 734 270	6 910 933	7 098 455	7 286 389	5 180 661	5 338 519	5 478 004	5 572 639	5 687 288
(+) REPIM	1 284 621	1 253	1 231	1 193	1 165	1 136	1 118	1 084	1 051	1 035	1 010	978	961	936	912	888	-	-	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	1 253	1 231	1 193	1 165	1 136	1 118	1 084	1 051	1 035	1 010	978	961	936	912	888	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	420 959	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	4 398 850	4 517 311	4 622 747	4 739 227	4 857 019	4 989 997	5 106 562	5 225 651	5 368 885	5 503 416	5 631 182	5 781 926	5 923 958	6 071 154	6 219 037	5 120 429	5 257 391	5 391 008	5 529 564	5 670 523	2 835 263	2 900 115	2 971 434	3 055 025	3 136 875
(-) Debt payments	-	-	3 127 964	3 206 163	3 286 317	3 368 475	3 452 687	3 539 004	3 627 479	3 718 166	3 811 120	3 906 398	4 004 058	4 104 160	4 206 764	4 311 933	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 416 592	2 477 007	2 538 932	2 602 406	2 667 466	2 734 153	2 802 506	2 872 569	2 944 383	3 017 993	3 093 443	3 170 779	3 250 048	3 331 299	3 414 582	3 499 946	3 587 445	3 677 131	3 769 060	3 863 286	3 959 868	4 058 865	4 160 336	4 264 345	4 370 954
(=) Free net cashflow	-58 941 280	9 437 182	6 553 636	6 709 981	6 878 642	7 049 919	7 237 720	7 410 477	7 587 164	7 789 436	7 984 481	8 174 273	8 388 595	8 595 794	8 809 785	9 026 135	12 417 435	12 736 822	13 057 425	13 387 641	13 725 053	11 091 155	11 362 405	11 645 281	11 945 718	12 249 836
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 504 098	-42 950 462	-36 240 481	-29 361 839	-22 311 920	-15 074 200	-7 663 723	-76 559	7 712 878	15 697 359	23 871 632	32 260 227	40 856 021	49 665 807	58 691 941	71 109 377	83 846 199	96 903 624	110 291 265	124 016 318	135 107 474	146 469 878	158 115 159	170 060 877	182 310 713
	$LCOE_{wso}$	73.13	73.52	73.79	74.13	74.47	74.93	75.23	75.53	76.02	76.41	76.73	77.23	77.63	78.06	78.47	77.65	78.16	78.63	79.12	79.61	77.73	78.24	78.71	79.06	79.47

Table S.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)} + Epi\ (Case_1)$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 943 465	213 677 678	214 362 116	212 699 281	213 130 306	213 677 678	212 699 281	212 699 281	214 362 116	213 130 306	213 677 678	213 240 500	212 699 281	214 433 451	213 913 741	214 433 451	214 152 844	214 362 116	214 433 451	213 565 675	213 706 617	212 699 281	214 004 745	213 240 500	213 962 451
(+) AAR ($M/yr)	-	30 196 663	31 058 298	31 936 726	32 481 214	33 360 711	34 282 550	34 978 715	35 853 182	37 036 811	37 744 583	38 787 558	39 675 905	40 564 585	41 917 697	42 861 506	44 039 781	45 081 704	46 253 902	47 426 027	48 414 954	34 760 655	35 461 726	36 571 360	37 351 777	38 415 192
PPAR	-	30 196 663	31 058 298	31 936 726	32 481 214	33 360 711	34 282 550	34 978 715	35 853 182	37 036 811	37 744 583	38 787 558	39 675 905	40 564 585	41 917 697	42 861 506	44 039 781	45 081 704	46 253 902	47 426 027	48 414 954	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 760 655	35 461 726	36 571 360	37 351 777	38 415 192
(-) $O\&M_{WFCM}$	-	20 633 860	21 222 504	21 822 620	22 194 549	22 795 389	23 425 157	23 900 721	24 498 115	25 306 751	25 790 238	26 502 761	27 109 626	27 716 717	28 641 138	29 285 891	30 090 843	30 802 628	31 603 422	32 404 162	33 079 730	29 459 748	30 053 783	30 994 073	31 655 349	32 556 460
$O\&M_{fixed}$	-	11 570 156	11 900 294	12 236 866	12 445 485	12 782 467	13 135 671	13 402 407	13 737 461	14 190 972	14 462 154	14 861 773	15 202 144	15 542 642	16 061 091	16 422 713	16 874 171	17 273 385	17 722 515	18 171 617	18 550 525	19 026 830	19 410 567	20 017 937	20 445 105	21 027 176
$O\&M_{variable}$	-	9 063 703	9 322 210	9 585 754	9 749 063	10 012 922	10 289 486	10 498 314	10 760 654	11 115 779	11 328 084	11 640 988	11 907 483	12 174 075	12 580 047	12 863 178	13 216 672	13 529 243	13 880 907	14 232 546	14 529 205	10 432 918	10 643 217	10 976 136	11 210 244	11 529 285
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 387 614	2 447 305	2 508 487	2 571 199	2 635 479	2 701 366	2 768 901	2 838 123	2 909 076	2 981 803	3 056 348	3 132 757	3 211 076	3 291 353	3 373 636	3 457 977	3 544 427	3 633 037	3 723 863	3 816 960	3 912 384	4 010 194	4 110 448	4 213 210	4 318 540
(=) Profit before tax	-	12 813 686	13 167 948	13 529 565	13 787 510	14 153 688	14 535 468	14 848 021	15 219 346	15 690 945	16 014 252	16 446 202	16 831 718	17 219 944	17 757 937	18 169 028	17 406 915	17 823 503	18 283 518	18 745 728	19 152 185	9 213 291	9 418 136	9 687 735	9 909 638	10 177 271
(-) Revenue tax	-	9 058 999	9 317 489	9 581 018	9 744 364	10 008 213	10 284 765	10 493 614	10 755 955	11 111 043	11 323 375	11 636 267	11 902 772	12 169 376	12 575 309	12 858 452	13 211 934	13 524 511	13 876 171	14 227 808	14 524 486	10 428 196	10 638 518	10 971 408	11 205 533	11 524 558
(+) REPIM	1 991 407	148	144	141	137	134	131	127	124	122	118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REI_{CM}	863 662	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	148	144	141	137	134	131	127	124	122	118	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	1 127 745	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(=) Profit after tax w/out interest	-	3 754 834	3 850 603	3 948 688	4 043 283	4 145 609	4 250 834	4 354 534	4 463 515	4 580 023	4 690 995	4 809 934	4 928 947	5 050 568	5 182 628	5 310 576	4 194 981	4 298 992	4 407 347	4 517 920	4 627 698	-1 214 906	-1 220 382	-1 283 673	-1 295 895	-1 347 286
(-) Debt payments	-	-	3 090 455	3 167 717	3 246 910	3 328 082	3 411 284	3 496 567	3 583 981	3 673 580	3 765 420	3 859 555	3 956 044	4 054 945	4 156 319	4 260 227	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 387 614	2 447 305	2 508 487	2 571 199	2 635 479	2 701 366	2 768 901	2 838 123	2 909 076	2 981 803	3 056 348	3 132 757	3 211 076	3 291 353	3 373 636	3 457 977	3 544 427	3 633 037	3 723 863	3 816 960	3 912 384	4 010 194	4 110 448	4 213 210	4 318 540
(=) Free net cashflow	-58 234 494	8 764 187	5 894 735	6 043 923	6 190 898	6 346 915	6 507 173	6 667 281	6 834 081	7 009 853	7 181 571	7 362 775	7 545 608	7 732 646	7 931 757	8 128 434	11 450 018	11 735 404	12 029 670	12 330 801	12 635 902	6 993 503	7 193 237	7 340 286	7 543 663	7 713 261
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 470 306	-43 575 572	-37 531 648	-31 340 750	-24 993 835	-18 486 662	-11 819 381	-4 985 300	2 024 553	9 206 124	16 568 899	24 114 507	31 847 153	39 778 910	47 907 344	59 357 362	71 092 766	83 122 436	95 453 237	108 089 139	115 082 642	122 275 878	129 616 165	137 159 827	144 873 088
	$LCOE_{wso}$	84.34	85.02	85.71	86.17	86.87	87.59	88.17	88.87	89.78	90.37	91.19	91.91	92.63	93.67	94.44	94.11	94.92	95.82	96.72	97.50	93.98	94.68	95.73	96.51	97.52

APPENDIX T

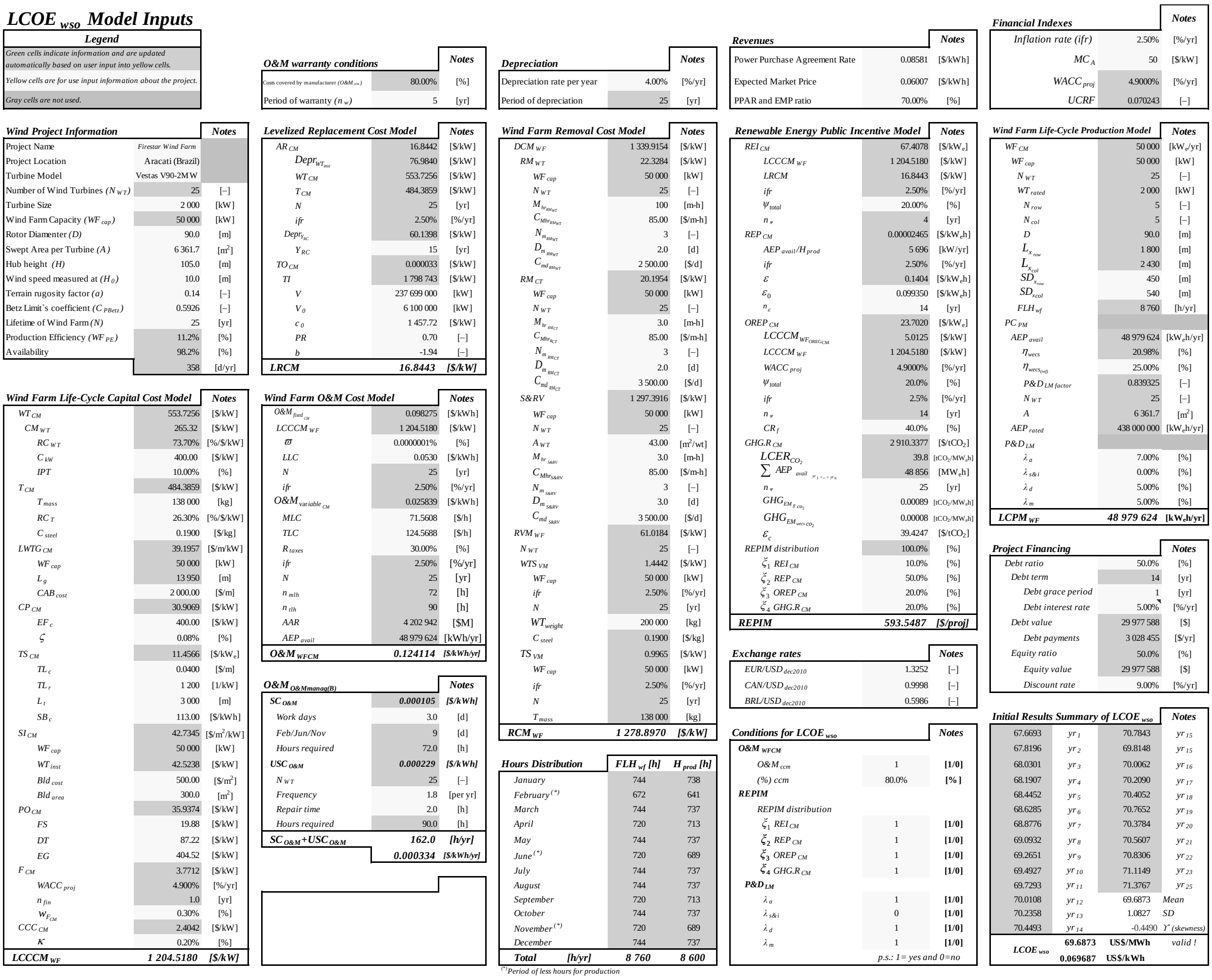

Figure T.1 *I-O representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of *$O\&M_{manag(B)}$* and *E_{pi} (Case $_2$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions

		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation

		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues

		Notes
Power Purchase Agreement Rate	0.16291	[$/kWh]
Expected Market Price	0.11403	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes

		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information

		Notes
Project Name	Firestar Wind Farm	
Project Location	Corvo Island (Portugal)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	20.6%	[%]
Availability	98.4%	[%]
	359	[d/yr]

Levelized Replacement Cost Model

		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model

		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model

		Notes
REI_{CM}	67.4078	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
Ψ_{total}	20.00%	[%]
n_Ψ	4	[yr]
REP_{CM}	0.00000951	[$/kW$_e$h]
AEP_{avail}/H_{prod}	10 458	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0994	[$/kW$_e$h]
ε_0	0.063750	[$/kW$_e$h]
n_ε	18	[yr]
$OREP_{CM}$	39.4264	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	4.5411	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
Ψ_{total}	20.0%	[%]
ifr	2.5%	[%/yr]
n_Ψ	18	[yr]
CR_f	40.0%	[%]
$GHG.R_{CM}$	1 496.9316	[$/tCO$_2$]
$LCER_{CO_2}$	73.1	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail\ yr_1+...+yr_n}$	89 657	[MW$_e$h]
n_Ψ	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00089	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ CO_2}}$	0.00008	[tCO$_2$/MW$_e$h]
ε_c	11.0500	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	10.0%	[%]
ξ_2 REP_{CM}	50.0%	[%]
ξ_3 $OREP_{CM}$	20.0%	[%]
ξ_4 $GHG.R_{CM}$	20.0%	[%]
REPIM	**314.0124**	**[$/proj]**

Wind Farm Life-Cycle Production Model

		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	90 107 610	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**90 107 610**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model

		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$w_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model

		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.048925	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	48	[h]
n_{tlh}	100	[h]
AAR	14 679 146	[$M]
AEP_{avail}	90 107 610	[kWh/yr]
$O\&M_{WFCM}$	**0.147200**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$

		Notes
$SC_{O\&M}$	**0.000038**	**[$/kWh]**
Work days	2.0	[d]
Feb/Jun/Nov	6	[d]
Hours required	48.0	[h]
$USC_{O\&M}$	**0.000138**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.0	[per yr]
Repair time	4.0	[h]
Hours required	100.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**148.0**	**[h/yr]**
	0.000176	**[$/kWh/yr]**

Hours Distribution

Hours Distribution		FLH_{wf} [h]	H_{prod} [h]
January		744	740
February (*)		672	648
March		744	736
April		720	712
May		744	736
June (*)		720	696
July		744	736
August		744	736
September		720	712
October		744	736
November (*)		720	696
December		744	736
Total	**[h/yr]**	**8 760**	**8 616**

(*) Period of less hours for production

Exchange rates

		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$

		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Project Financing

		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 898 967	[$]
Debt payments	3 020 512	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 898 967	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$

			Notes
73.1255	yr_1	78.4712	yr_{15}
73.5187	yr_2	77.6515	yr_{15}
73.7873	yr_3	78.1612	yr_{16}
74.1334	yr_4	78.6268	yr_{17}
74.4746	yr_5	79.1175	yr_{18}
74.9273	yr_6	79.6115	yr_{19}
75.2253	yr_7	77.7347	yr_{20}
75.5275	yr_8	78.2446	yr_{21}
76.0152	yr_9	78.7103	yr_{22}
76.4118	yr_{10}	79.0644	yr_{23}
76.7332	yr_{11}	79.4723	yr_{25}
77.2289	yr_{12}	76.8666	Mean
77.6321	yr_{13}	2.0151	SD
78.0589	yr_{14}	-0.4631	ϒ (skewness)
$LCOE_{wso}$	**76.8666**	**US$/MWh**	valid !
	0.076867	**US$/kWh**	

Figure T.2 *I-O system representation* of *$LCOE_{wso}$ algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of *$O\&M_{manag(B)}$* and *E_{pi} (Case $_2$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
UCRF	0.070243	[–]

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diameter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.6%	[%]
Availability	98.2%	[%]
	358	[d/yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{CT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
S&RV	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model		Notes
REI_{CM}	67.4078	[$/kWe]
$LCCCM_{WF}$	1 204.5180	[$/kW]
LRCM	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	20.00%	[%]
n_e	4	[yr]
REP_{CM}	0.00000048	[$/kWeh]
AEP_{avail}/H_{prod}	24 762	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0120	[$/kWeh]
ε_0	0.008498	[$/kWeh]
n_c	14	[yr]
$OREP_{CM}$	103.0468	[$/kWe]
$LCCCM_{WF_{OREGCM}}$	5.0125	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	20.0%	[%]
ifr	2.5%	[%/yr]
n_e	14	[yr]
CR_f	40.0%	[%]
$GHG.R_{CM}$	8 186.2796	[$/tCO₂]
$LCER_{CO_2}$	173.2	[tCO₂/MWeh]
$\sum AEP_{avail}$	212 467	[MWeh]
n_e	25	[yr]
$GHG_{EM_{T\,CO_2}}$	0.00089	[tCO₂/MWeh]
$GHG_{EM_{wecs\,CO_2}}$	0.00008	[tCO₂/MWeh]
ε_c	25.5000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	10.0%	[%]
ξ_2 REP_{CM}	50.0%	[%]
ξ_3 $OREP_{CM}$	20.0%	[%]
ξ_4 $GHG.R_{CM}$	20.0%	[%]
REPIM	**1 664.6060**	**[$/proj]**

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWe/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
$SD_{x_{col}}$	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 943 465	[kWeh/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{exp}}$	25.00%	[%]
$P\&D_{LM\,factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWeh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 943 465**	**[kWeh/yr]**

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWe]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fuel_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041526	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	90	[h]
AAR	29 460 159	[$M]
AEP_{avail}	212 943 465	[kWh/yr]
$O\&M_{WFCM}$	**0.139801**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$		Notes
$SC_{O\&M}$	**0.000024**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000053**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.8	[per yr]
Repair time	2.0	[h]
Hours required	90.0	[h]
$SC_{O\&M}$+$USC_{O\&M}$	**162.0**	**[h/yr]**
	0.000077	**[$/kWh/yr]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February(*)	672	641
March	744	737
April	720	713
May	744	737
June(*)	720	689
July	744	737
August	744	737
September	720	713
October	744	737
November(*)	720	689
December	744	737
Total [h/yr]	**8 760**	**8 600**

(*) Period of less hours for production

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1 = yes and 0 = no	

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 580 865	[$]
Debt payments	2 988 376	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 580 865	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.3448	yr_1	94.4360	yr_{15}
85.0205	yr_2	94.1138	yr_{15}
85.7100	yr_3	94.9205	yr_{16}
86.1734	yr_4	95.8186	yr_{17}
86.8681	yr_5	96.7191	yr_{18}
87.5940	yr_6	97.4969	yr_{19}
88.1682	yr_7	93.9817	yr_{20}
88.8666	yr_8	94.6831	yr_{21}
89.7788	yr_9	95.7335	yr_{22}
90.3684	yr_{10}	96.5076	yr_{23}
91.1898	yr_{11}	97.5244	yr_{25}
91.9082	yr_{12}	91.7691	Mean
92.6296	yr_{13}	4.1987	SD
93.6712	yr_{14}	-0.3338	Υ (skewness)
$LCOE_{wso}$	**91.7691**	**US$/MWh**	valid !
	0.091769	**US$/kWh**	

Figure T.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$ and E_{pi} *(Case $_2$)*. Source: Own elaboration

Table T.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)} + Epi$ ($Case_2$)

Months	v_{wc} (m/s)	ρ (kg/m³)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	641	850 430	6 803 436	3 673 320	6 803 436	779 598	6 803 436	779 598	779 598	4 727 258	6 803 436	6 803 436	779 598	3 673 320	6 803 436	483 758	483 758	3 300 063	4 727 258	7 716 188	1 577 029	1 577 029	7 716 188	6 803 436	4 727 258	4 727 258
March	4.0	1.1671	737	556 507	7 495 900	5 438 155	8 876 568	978 319	7 495 900	978 319	978 319	6 560 068	7 495 900	7 495 900	978 319	5 438 155	8 876 568	896 836	896 836	1 814 186	4 225 724	1 814 186	1 690 536	1 690 536	7 826 555	8 876 568	3 796 335	6 560 068
April	4.7	1.1667	713	867 380	6 344 604	6 344 604	4 086 931	1 635 011	6 344 604	1 635 011	1 635 011	7 249 700	6 344 604	6 344 604	1 754 600	6 344 604	4 086 931	946 187	946 187	1 635 011	6 344 604	1 635 011	3 671 646	946 187	7 249 700	6 344 604	1 754 600	7 249 700
May	6.0	1.1670	737	1 814 119	5 437 953	7 495 621	5 437 953	1 814 119	5 437 953	1 814 119	1 814 119	7 826 264	5 437 953	5 437 953	1 690 473	7 495 621	6 559 824	1 690 473	1 690 473	978 283	8 876 238	978 283	556 486	896 803	6 559 824	4 225 566	1 690 473	7 826 264
June	7.9	1.1686	689	3 955 677	3 955 677	7 326 396	6 140 844	3 553 729	3 955 677	3 553 729	3 553 729	8 309 307	3 955 677	3 955 677	3 553 729	7 326 396	5 090 627	1 698 250	1 698 250	839 524	7 326 396	839 524	839 524	3 553 729	5 090 627	5 090 627	915 799	8 309 307
July	8.6	1.1698	737	5 450 949	3 805 267	8 897 452	1 694 513	4 235 665	3 805 267	4 235 665	4 235 665	557 816	557 816	3 805 267	5 450 949	8 897 452	1 818 455	3 805 267	3 805 267	557 816	7 513 536	557 816	980 621	4 235 665	4 235 665	1 694 513	898 946	557 816
August	9.6	1.1677	737	7 499 787	1 815 127	1 815 127	1 815 127	8 881 171	1 815 127	5 440 975	5 440 975	897 302	897 302	1 815 127	4 227 915	1 815 127	1 691 413	5 440 975	7 830 614	7 830 614	897 302	4 227 915	7 830 614	5 440 975	1 815 127	1 815 127	556 795	897 302
September	10.1	1.1657	713	8 576 955	1 633 475	1 633 475	3 668 197	7 562 383	1 633 475	6 338 644	6 338 644	945 298	945 298	1 633 475	6 338 644	1 633 475	3 668 197	6 338 644	7 242 889	7 242 889	945 298	5 254 599	8 576 955	6 338 644	1 633 475	3 668 197	6 338 644	945 298
October	9.7	1.1645	737	7 809 082	976 135	976 135	555 264	7 479 165	976 135	7 479 165	7 479 165	1 686 762	1 686 762	976 135	8 856 751	976 135	555 264	7 479 165	6 545 422	6 545 422	1 810 136	6 545 422	4 216 289	7 479 165	976 135	976 135	8 856 751	1 686 762
November	9.2	1.1638	689	6 115 594	836 072	836 072	836 072	6 115 594	836 072	7 296 271	7 296 271	1 691 267	1 691 267	836 072	7 296 271	836 072	836 072	7 296 271	5 069 696	5 069 696	1 575 994	6 988 019	6 115 594	7 296 271	836 072	836 072	7 296 271	1 691 267
December	7.6	1.1651	737	3 790 014	555 580	555 580	976 690	5 429 099	555 580	8 861 786	8 861 786	3 790 014	3 790 014	555 580	7 483 417	555 580	976 690	8 861 786	4 218 687	4 218 687	3 790 014	7 813 521	5 429 099	8 861 786	555 580	555 580	7 483 417	3 790 014
Annual	7.4	1.1666	8 600	48 979 624	48 549 424	48 794 102	48 399 005	49 021 215	48 549 424	48 970 644	48 970 644	48 473 266	48 496 226	48 549 424	48 968 028	48 794 102	48 470 887	49 169 824	49 318 276	48 922 388	48 589 860	48 172 649	48 991 802	48 874 151	48 297 112	48 393 836	48 547 502	48 473 266

Table T.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)} + Epi$ ($Case_2$)

Months	v_{wc} (m/s)	ρ (kg/m³)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	740	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408
February	11.5	1.2345	648	12 092 721	4 293 137	12 092 721	12 092 721	12 092 721	3 417 096	12 092 721	12 715 785	1 795 784	3 417 096	12 715 785	1 795 784	9 244 173	12 092 721	6 674 015	12 715 785	4 293 137	5 486 290	3 417 096	2 815 600	12 092 721	2 106 703	6 674 015	12 092 721	12 715 785
March	10.5	1.2329	736	10 486 228	3 193 907	13 717 510	13 717 510	13 717 510	6 223 433	13 717 510	13 717 510	2 389 762	3 193 907	13 717 510	2 389 762	13 717 510	13 717 510	6 223 433	13 717 510	3 876 220	7 570 742	4 869 967	13 717 510	14 424 289	2 037 067	10 486 228	14 424 289	3 193 907
April	9.5	1.2317	712	7 316 597	7 316 597	10 458 483	10 458 483	10 458 483	7 316 597	10 458 483	4 706 485	3 086 689	7 316 597	13 257 022	3 086 689	13 257 022	4 706 485	4 706 485	13 257 022	3 086 689	10 134 212	3 086 689	13 940 075	13 257 022	3 086 689	3 086 689	13 257 022	3 746 098
May	8.2	1.2282	736	4 851 676	10 446 845	10 446 845	10 446 845	6 200 059	10 446 845	10 446 845	10 446 845	3 861 662	6 200 059	10 446 845	3 861 662	14 370 115	10 446 845	3 861 662	10 446 845	2 380 787	13 665 991	6 200 059	2 380 787	10 446 845	3 861 662	14 370 115	10 446 845	4 851 676
June	7.1	1.2224	696	2 994 461	12 860 910	7 097 981	7 097 981	7 097 981	10 145 990	4 565 858	12 860 910	4 565 858	10 145 990	7 097 981	4 565 858	7 097 981	2 240 532	2 994 461	7 097 981	1 909 861	12 860 910	7 097 981	1 909 861	7 097 981	4 565 858	12 860 910	7 097 981	5 834 806
July	6.1	1.2154	736	2 008 118	13 522 571	4 800 760	6 134 992	10 337 209	13 522 571	7 463 154	3 148 518	6 134 992	2 008 118	6 134 992	6 134 992	6 134 992	2 008 118	2 355 801	6 134 992	6 134 992	14 219 306	10 337 209	3 821 135	6 134 992	6 134 992	13 522 571	3 821 135	7 463 154
August	6.4	1.2075	736	2 340 496	10 598 668	3 796 310	3 796 310	3 796 310	13 434 719	6 095 134	3 796 310	7 414 668	2 340 496	4 769 571	7 414 668	4 769 571	10 598 668	1 995 072	4 769 571	13 434 719	1 995 072	13 434 719	4 769 571	4 769 571	7 414 668	4 769 571	3 128 063	10 270 051
September	7.6	1.2064	712	3 669 202	1 928 273	5 891 057	4 609 876	4 609 876	4 609 876	1 928 273	5 891 057	9 926 189	9 926 189	3 669 202	9 926 189	3 669 202	5 891 057	9 926 189	3 669 202	12 984 898	2 262 132	12 984 898	5 891 057	3 669 202	9 926 189	3 669 202	2 262 132	1 928 273
October	8.9	1.2126	736	6 121 079	6 121 079	3 141 378	2 003 564	3 141 378	2 003 564	2 350 459	7 446 229	13 491 905	13 491 905	3 141 378	13 491 905	3 141 378	7 446 229	13 491 905	3 141 378	10 643 782	3 141 378	2 003 564	7 446 229	3 141 378	13 491 905	2 350 459	2 003 564	2 350 459
November	10.6	1.2194	696	10 121 586	3 625 425	2 235 143	2 235 143	2 235 143	2 235 143	2 987 258	2 235 143	12 829 976	4 554 876	2 235 143	12 829 976	2 235 143	2 987 258	12 829 976	2 235 143	9 807 761	3 625 425	2 235 143	9 807 761	2 235 143	12 829 976	1 905 267	5 820 771	12 829 976
December	11.5	1.2237	736	13 614 984	2 371 901	2 021 842	3 170 035	2 021 842	3 170 035	3 847 249	2 021 842	14 316 481	13 614 984	2 021 842	14 316 481	2 021 842	3 847 249	14 316 481	2 021 842	7 514 158	4 833 568	14 316 481	13 614 984	2 021 842	14 316 481	6 176 918	4 833 568	13 614 984
Annual	9.1	1.2222	8 616	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577

Table T.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)} + Epi$ ($Case_2$)

Months	v_{wc} (m/s)	ρ (kg/m³)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	641	24 319 291	14 509 901	6 932 878	26 305 527	14 509 901	14 509 901	26 305 527	26 305 527	6 932 878	14 509 901	14 509 901	7 772 679	26 305 527	6 932 878	17 428 282	6 932 878	6 932 878	6 932 878	6 932 878	22 528 524	26 305 527	26 305 527	29 044 609	7 772 679	17 402 199
March	12.7	1.2495	737	18 273 052	18 273 052	8 918 969	27 905 823	12 408 183	18 273 052	27 905 823	27 905 823	8 918 969	12 408 183	18 273 052	9 997 395	27 905 823	8 918 969	30 184 982	8 918 969	8 918 969	8 918 969	8 918 969	23 050 141	27 905 823	27 905 823	31 495 010	9 997 395	18 969 625
April	12.4	1.2490	713	16 100 080	19 338 295	9 667 330	24 894 425	9 667 330	19 338 295	24 894 425	24 894 425	9 667 330	9 667 330	19 338 295	9 667 330	24 894 425	9 667 330	26 984 508	9 667 330	29 188 421	9 667 330	9 667 330	22 244 176	20 024 605	24 894 425	24 985 682	9 667 330	18 186 892
May	11.2	1.2425	737	12 338 025	25 598 814	9 940 868	19 885 473	9 940 868	25 598 814	19 885 473	19 885 473	9 940 868	9 940 868	25 598 814	12 338 025	19 885 473	9 940 868	25 598 814	9 940 868	27 748 037	9 940 868	9 940 868	21 042 787	19 885 473	19 885 473	19 137 999	12 338 025	16 209 586
June	10.4	1.2351	689	9 237 631	25 785 086	11 465 208	16 884 369	8 241 161	25 785 086	16 884 369	16 884 369	11 465 208	8 241 161	25 785 086	15 384 455	16 884 369	11 465 208	16 884 369	11 465 208	23 787 904	11 465 208	11 465 208	17 001 691	16 884 369	16 884 369	16 806 455	15 384 455	14 990 327
July	10.0	1.2275	737	8 761 837	29 653 191	16 356 443	16 356 443	7 815 162	29 653 191	16 356 443	16 356 443	16 356 443	7 815 162	29 653 191	17 951 122	16 356 443	16 356 443	7 815 162	16 356 443	19 646 221	16 356 443	16 356 443	15 570 355	16 087 422	16 356 443	16 802 962	17 951 122	8 647 175
August	9.7	1.2216	737	7 777 512	12 130 855	17 864 641	12 130 855	17 864 641	12 130 855	12 130 855	12 130 855	17 864 641	17 864 641	12 130 855	19 551 573	12 130 855	17 864 641	8 719 626	17 864 641	17 864 641	17 864 641	17 864 641	12 936 052	15 417 110	12 130 855	12 621 116	19 551 573	7 130 060
September	10.4	1.2234	713	9 469 157	7 534 977	18 941 875	9 469 157	26 431 347	7 534 977	9 469 157	9 469 157	18 941 875	26 431 347	7 534 977	24 384 108	9 469 157	18 941 875	9 469 157	18 941 875	15 770 041	18 941 875	18 941 875	12 353 594	13 310 548	9 469 157	8 865 389	24 384 108	19 080 004
October	13.1	1.2327	737	19 729 237	8 798 861	29 778 493	9 862 764	25 397 690	8 798 861	9 862 764	9 862 764	29 778 493	25 397 690	8 798 861	27 530 026	9 862 764	25 397 690	9 862 764	25 397 690	12 241 087	29 778 493	25 397 690	12 273 661	8 881 296	9 862 764	8 143 371	27 530 026	21 651 123
November	14.3	1.2429	689	23 939 450	9 296 482	25 949 356	8 293 664	28 068 725	9 296 482	8 293 664	8 293 664	25 949 356	28 068 725	9 296 482	28 068 725	8 293 664	25 949 356	11 538 250	25 949 356	9 296 482	25 949 356	25 949 356	7 443 284	8 293 664	8 293 664	8 895 126	28 068 725	22 011 001
December	15.1	1.2528	737	30 263 395	10 023 366	25 811 256	7 975 983	20 050 501	10 023 366	7 975 983	7 975 983	25 811 256	20 050 501	10 023 366	32 581 568	7 975 983	30 263 395	16 693 026	30 263 395	10 023 366	25 811 256	30 263 395	6 366 601	7 975 983	7 975 983	9 187 032	32 581 568	42 583 526
Annual	12.5	1.2404	8 600	212 943 465	213 677 678	214 362 116	212 699 281	213 130 306	213 677 678	212 699 281	212 699 281	214 362 116	213 130 306	213 677 678	213 240 500	212 699 281	214 433 451	213 913 741	214 433 451	214 152 844	214 362 116	214 433 451	213 565 675	213 706 617	212 699 281	214 004 745	213 240 500	213 962 451

Table T.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$ + *Epi* (*Case* $_2$)

Months	v_{wc} (m/s)	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table T.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)}$ + *Epi* (*Case* $_2$)

Months	v_{wc} (m/s)	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table T.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$ + *Epi* (*Case* $_2$)

Months	v_{wc} (m/s)	*Wind speed data series for simulations (m/s)*																								
		yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table T.7 kWh per H_{prod} with sensitivity analysis of $O\&M_{manag(B)} + Epi\ (Case\ _2)$

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 696	5 646	5 674	5 628	5 700	5 646	5 695	5 695	5 637	5 639	5 646	5 694	5 674	5 636	5 718	5 735	5 689	5 650	5 602	5 697	5 683	5 616	5 628	5 645	5 637
Corvo Island (Portugal)	10 458	10 535	10 467	10 475	10 468	10 563	10 497	10 429	10 525	10 527	10 454	10 525	10 507	10 500	10 474	10 454	10 510	10 523	10 545	10 560	10 464	10 520	10 532	10 452	10 407
Cape Saint James (Canada)	24 762	24 848	24 927	24 734	24 784	24 848	24 734	24 734	24 927	24 784	24 848	24 797	24 734	24 936	24 875	24 936	24 903	24 927	24 936	24 835	24 851	24 734	24 886	24 797	24 881

Table T.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)} + Epi\ (Case\ _2)$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	48 979 624	48 549 424	48 794 102	48 399 005	49 021 215	48 549 424	48 970 644	48 970 644	48 473 266	48 496 226	48 549 424	48 968 028	48 794 102	48 470 887	49 169 824	49 318 276	48 922 388	48 589 860	48 172 649	48 991 802	48 874 151	48 297 112	48 393 836	48 547 502	48 473 266
(+) AAR ($M/yr)	-	4 308 015	4 376 931	4 508 965	4 584 266	4 759 280	4 831 313	4 995 061	5 119 937	5 194 634	5 327 022	5 466 187	5 651 151	5 771 856	5 876 963	6 110 750	6 282 430	6 387 799	6 502 991	6 608 332	6 888 721	4 930 788	4 994 386	5 129 498	5 274 431	5 398 025
PPAR	-	4 308 015	4 376 931	4 508 965	4 584 266	4 759 280	4 831 313	4 995 061	5 119 937	5 194 634	5 327 022	5 466 187	5 651 151	5 771 856	5 876 963	6 110 750	6 282 430	6 387 799	6 502 991	6 608 332	6 888 721	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4 930 788	4 994 386	5 129 498	5 274 431	5 398 025
(-) $O\&M_{WFCM}$	-	3 958 388	4 021 593	4 142 789	4 211 857	4 372 535	4 459 642	4 610 143	4 724 747	4 793 035	4 914 544	5 042 290	5 212 260	5 322 943	5 419 232	5 634 158	5 791 793	5 888 285	5 993 824	6 090 278	6 348 036	5 856 505	5 931 402	6 091 221	6 262 682	6 408 790
$O\&M_{fixed}$	-	2 661 279	2 703 850	2 785 412	2 831 928	2 940 042	2 984 539	3 085 692	3 162 833	3 208 975	3 290 756	3 376 724	3 490 983	3 565 547	3 630 475	3 774 895	3 880 948	3 946 038	4 017 195	4 082 268	4 255 476	4 351 387	4 407 510	4 526 744	4 654 645	4 763 714
$O\&M_{variable}$	-	1 297 109	1 317 743	1 357 376	1 379 929	1 432 493	1 475 103	1 524 451	1 561 914	1 584 059	1 623 788	1 665 566	1 721 276	1 757 396	1 788 757	1 859 263	1 910 846	1 942 247	1 976 628	2 008 010	2 092 560	1 505 118	1 523 892	1 564 477	1 608 038	1 645 077
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 458 162	2 519 616	2 582 607	2 647 172	2 713 351	2 781 185	2 850 715	2 921 982	2 995 032	3 069 908	3 146 655	3 225 322	3 305 955	3 388 604	3 473 319	3 560 152	3 649 156	3 740 385	3 833 894	3 929 742	4 027 985	4 128 685	4 231 902	4 337 699	4 446 142
(=) Profit before tax	-	3 671 058	3 759 805	3 855 754	3 949 226	4 052 984	4 129 565	4 236 759	4 343 328	4 448 440	4 560 490	4 675 610	4 796 896	4 915 868	5 036 360	5 169 687	4 050 788	4 148 670	4 249 552	4 351 948	4 470 427	3 102 268	3 191 669	3 270 179	3 349 448	3 435 376
(-) Revenue tax	-	1 292 405	1 313 079	1 352 689	1 375 280	1 427 784	1 449 394	1 498 518	1 535 981	1 558 390	1 598 107	1 639 856	1 695 345	1 731 557	1 763 089	1 833 225	1 884 729	1 916 340	1 950 897	1 982 500	2 066 616	1 479 236	1 498 316	1 538 850	1 582 329	1 619 407
(+) REPIM	270 724	3 747	3 639	3 584	3 485	3 461	3 361	3 326	3 263	3 170	3 113	3 061	3 032	2 968	2 898	458	470	478	487	495	516	528	534	549	564	578
REI_{CM}	33 704	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	3 424	3 311	3 247	3 142	3 105	3 000	2 952	2 880	2 781	2 715	2 651	2 609	2 536	2 458	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	237 020	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	323	328	338	343	356	362	374	383	389	399	409	423	432	440	458	470	478	487	495	516	528	534	549	564	578
(=) Profit after tax w/out interest	-	2 382 400	2 450 364	2 506 649	2 577 432	2 628 660	2 683 532	2 741 567	2 810 610	2 893 220	2 965 496	3 038 814	3 104 583	3 187 280	3 276 169	3 336 919	2 166 530	2 232 809	2 299 141	2 369 944	2 404 326	1 623 560	1 693 887	1 731 878	1 767 683	1 816 546
(-) Debt payments	-	-	3 181 770	3 261 315	3 342 848	3 426 419	3 512 079	3 599 881	3 689 878	3 782 125	3 876 678	3 973 595	4 072 935	4 174 759	4 279 128	4 386 106	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 458 162	2 519 616	2 582 607	2 647 172	2 713 351	2 781 185	2 850 715	2 921 982	2 995 032	3 069 908	3 146 655	3 225 322	3 305 955	3 388 604	3 473 319	3 560 152	3 649 156	3 740 385	3 833 894	3 929 742	4 027 985	4 128 685	4 231 902	4 337 699	4 446 142
(=) Free net cashflow	-59 955 176	7 462 301	4 475 492	4 582 405	4 705 082	4 809 502	4 918 895	5 032 813	5 159 138	5 300 461	5 432 918	5 567 922	5 696 918	5 844 423	5 999 741	6 128 581	9 523 741	9 773 950	10 028 812	10 292 855	10 525 311	9 947 569	10 225 997	10 477 291	10 731 730	11 004 695
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 492 876	-48 017 383	-43 434 978	-38 729 896	-33 920 394	-29 001 500	-23 968 686	-18 809 549	-13 509 088	-8 076 169	-2 508 248	3 188 670	9 033 094	15 032 835	21 161 416	30 685 157	40 459 107	50 487 919	60 780 774	71 306 085	81 253 654	91 479 651	101 956 942	112 688 672	123 693 367
	$LCOE_{wso}$	67.67	67.82	68.03	68.19	68.45	68.63	68.88	69.09	69.27	69.49	69.73	70.01	70.24	70.45	70.78	69.81	70.01	70.21	70.41	70.77	70.38	70.56	70.83	71.11	71.38

Table T.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)} + Epi\ (Case_{2})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577
(+) AAR ($M/yr)	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
PPAR	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
(-) $O\&M_{WFCM}$	-	9 414 550	9 720 704	9 900 012	10 154 527	10 401 931	10 758 472	10 957 897	11 159 028	11 543 192	11 833 646	12 046 185	12 430 378	12 719 232	13 028 853	13 321 057	13 628 511	14 043 351	14 411 633	14 802 558	15 194 336	13 212 815	13 615 294	13 970 912	14 212 144	14 504 416
$O\&M_{fixed}$	-	4 895 943	5 055 217	5 148 526	5 280 948	5 409 674	5 595 159	5 698 935	5 803 599	6 003 456	6 154 579	6 265 179	6 465 057	6 615 352	6 776 449	6 928 488	7 088 460	7 304 288	7 495 901	7 699 294	7 903 132	8 027 381	8 271 977	8 488 105	8 634 738	8 812 382
$O\&M_{variable}$	-	4 518 607	4 665 487	4 751 486	4 873 579	4 992 258	5 163 313	5 258 962	5 355 430	5 539 736	5 679 068	5 781 006	5 965 321	6 103 880	6 252 405	6 392 569	6 540 051	6 739 063	6 915 732	7 103 264	7 291 205	5 185 434	5 343 317	5 482 807	5 577 406	5 692 034
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 451 715	2 513 008	2 575 833	2 640 229	2 706 235	2 773 891	2 843 238	2 914 319	2 987 177	3 061 856	3 138 403	3 216 863	3 297 284	3 379 717	3 464 209	3 550 815	3 639 585	3 730 575	3 823 839	3 919 435	4 017 421	4 117 856	4 220 803	4 326 323	4 434 481
(=) Profit before tax	-	8 946 558	9 212 763	9 405 167	9 644 687	9 882 136	10 187 113	10 400 384	10 617 023	10 945 580	11 220 537	11 451 402	11 787 570	12 069 347	12 366 274	12 655 569	11 706 581	12 043 801	12 355 385	12 682 799	13 013 061	8 073 477	8 297 625	8 509 904	8 689 642	8 887 690
(-) Revenue tax	-	4 513 837	4 660 683	4 746 712	4 868 802	4 987 484	5 158 496	5 254 175	5 350 673	5 534 936	5 674 267	5 776 238	5 960 521	6 099 089	6 247 616	6 387 792	6 535 283	6 734 270	6 910 933	7 098 455	7 286 389	5 180 661	5 338 519	5 478 004	5 572 639	5 687 288
(+) REPIM	427 968	2 591	2 555	2 485	2 435	2 383	2 355	2 293	2 232	2 207	2 164	2 107	2 080	2 036	1 997	1 954	1 915	1 890	1 858	262	269	273	281	288	293	299
REI_{CM}	33 704	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	2 425	2 383	2 310	2 256	2 199	2 165	2 099	2 034	2 003	1 955	1 894	1 860	1 812	1 766	1 719	1 674	1 642	1 604	-	-	-	-	-	-	-
$OREP_{CM}$	394 264	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	166	172	175	179	184	190	194	197	204	209	213	220	225	230	235	241	248	255	262	269	273	281	288	293	299
(=) Profit after tax w/out interest	-	4 435 312	4 554 636	4 660 940	4 778 320	4 897 035	5 030 973	5 148 502	5 268 581	5 412 851	5 548 434	5 677 270	5 829 129	5 972 295	6 120 655	6 269 731	5 173 212	5 311 421	5 446 310	5 584 605	5 726 941	2 893 089	2 959 388	3 032 188	3 117 296	3 200 702
(-) Debt payments	-	-	3 173 426	3 252 761	3 334 080	3 417 432	3 502 868	3 590 440	3 680 201	3 772 206	3 866 511	3 963 174	4 062 253	4 163 810	4 267 905	4 374 602	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 451 715	2 513 008	2 575 833	2 640 229	2 706 235	2 773 891	2 843 238	2 914 319	2 987 177	3 061 856	3 138 403	3 216 863	3 297 284	3 379 717	3 464 209	3 550 815	3 639 585	3 730 575	3 823 839	3 919 435	4 017 421	4 117 856	4 220 803	4 326 323	4 434 481
(=) Free net cashflow	-59 797 933	9 508 766	6 581 500	6 738 476	6 907 795	7 079 747	7 268 252	7 441 713	7 619 123	7 822 156	8 017 972	8 208 547	8 423 687	8 631 717	8 846 563	9 063 787	12 521 086	12 842 992	13 166 170	13 497 462	13 837 619	11 206 534	11 480 669	11 766 502	12 069 968	12 377 190
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 289 167	-43 707 667	-36 969 190	-30 061 395	-22 981 649	-15 713 397	-8 271 683	-652 560	7 169 596	15 187 568	23 396 114	31 819 802	40 451 519	49 298 082	58 361 868	70 882 955	83 725 947	96 892 117	110 389 579	124 227 199	135 433 732	146 914 402	158 680 903	170 750 871	183 128 061
	$LCOE_{wso}$	73.13	73.52	73.79	74.13	74.47	74.93	75.23	75.53	76.02	76.41	76.73	77.23	77.63	78.06	78.47	77.65	78.16	78.63	79.12	79.61	77.73	78.24	78.71	79.06	79.47

Table T.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)} + Epi\ (Case_{2})$

Item	Years																									
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 943 465	213 677 678	214 362 116	212 699 281	213 130 306	213 677 678	212 699 281	212 699 281	214 362 116	213 130 306	213 677 678	213 240 500	212 699 281	214 433 451	213 913 741	214 433 451	214 152 844	214 362 116	214 433 451	213 565 675	213 706 617	212 699 281	214 004 745	213 240 500	213 962 451
(+) AAR ($M/yr)	-	30 196 663	31 058 298	31 936 726	32 481 214	33 360 711	34 282 550	34 978 715	35 853 182	37 036 811	37 744 583	38 787 558	39 675 905	40 564 585	41 917 697	42 861 506	44 039 781	45 081 704	46 253 902	47 426 027	48 414 954	34 760 655	35 461 726	36 571 360	37 351 777	38 415 192
PPAR	-	30 196 663	31 058 298	31 936 726	32 481 214	33 360 711	34 282 550	34 978 715	35 853 182	37 036 811	37 744 583	38 787 558	39 675 905	40 564 585	41 917 697	42 861 506	44 039 781	45 081 704	46 253 902	47 426 027	48 414 954	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34 760 655	35 461 726	36 571 360	37 351 777	38 415 192
(-) $O\&M_{WFCM}$	-	20 633 860	21 222 504	21 822 620	22 194 549	22 795 389	23 425 157	23 900 721	24 498 115	25 306 751	25 790 238	26 502 761	27 109 626	27 716 717	28 641 138	29 285 891	30 090 843	30 802 628	31 603 422	32 404 162	33 079 730	29 459 748	30 053 783	30 994 073	31 655 349	32 556 460
$O\&M_{fixed}$	-	11 570 156	11 900 294	12 236 866	12 445 485	12 782 467	13 135 671	13 402 407	13 737 461	14 190 972	14 462 154	14 861 773	15 202 144	15 542 642	16 061 091	16 422 713	16 874 171	17 273 385	17 722 515	18 171 617	18 550 525	19 026 830	19 410 567	20 017 937	20 445 105	21 027 176
$O\&M_{variable}$	-	9 063 703	9 322 210	9 585 754	9 749 063	10 012 922	10 289 486	10 498 314	10 760 654	11 115 779	11 328 084	11 640 988	11 907 483	12 174 075	12 580 047	12 863 178	13 216 672	13 529 243	13 880 907	14 232 546	14 529 205	10 432 918	10 643 217	10 976 136	11 210 244	11 529 285
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation		2 425 631	2 486 272	2 548 428	2 612 139	2 677 443	2 744 379	2 812 988	2 883 313	2 955 396	3 029 281	3 105 013	3 182 638	3 262 204	3 343 759	3 427 353	3 513 037	3 600 863	3 690 884	3 783 156	3 877 735	3 974 679	4 074 046	4 175 897	4 280 294	4 387 302
(=) Profit before tax	-	12 851 702	13 206 915	13 569 506	13 828 450	14 195 652	14 578 480	14 892 109	15 264 535	15 737 264	16 061 729	16 494 866	16 881 600	17 271 072	17 810 343	18 222 744	17 461 975	17 879 939	18 341 365	18 805 021	19 212 960	9 275 586	9 481 988	9 753 184	9 976 722	10 246 033
(-) Revenue tax	-	9 058 999	9 317 489	9 581 018	9 744 364	10 008 213	10 284 765	10 493 614	10 755 955	11 111 043	11 323 375	11 636 267	11 902 772	12 169 376	12 575 309	12 858 452	13 211 934	13 524 511	13 876 171	14 227 808	14 524 486	10 428 196	10 638 518	10 971 408	11 205 533	11 524 558
(+) REPIM	1 064 171	1 200	1 220	1 240	1 248	1 268	1 290	1 303	1 323	1 355	1 369	1 395	1 416	1 436	1 473	1 288	1 323	1 354	1 390	1 425	1 455	1 492	1 522	1 570	1 603	1 649
REI_{CM}	33 704	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	293	287	281	272	266	260	252	246	242	235	230	224	218	214	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	1 030 468	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	907	933	960	976	1 002	1 030	1 051	1 077	1 113	1 134	1 165	1 192	1 219	1 259	1 288	1 323	1 354	1 390	1 425	1 455	1 492	1 522	1 570	1 603	1 649
(=) Profit after tax w/out interest	-	3 793 903	3 890 646	3 989 728	4 085 333	4 188 706	4 295 005	4 399 798	4 509 904	4 627 576	4 739 723	4 859 994	4 980 244	5 103 133	5 236 507	5 365 580	4 251 364	4 356 782	4 466 584	4 578 638	4 689 928	-1 151 119	-1 155 008	-1 216 655	-1 227 208	-1 276 876
(-) Debt payments	-	-	3 139 663	3 218 154	3 298 608	3 381 074	3 465 600	3 552 240	3 641 046	3 732 073	3 825 374	3 921 009	4 019 034	4 119 510	4 222 498	4 328 060	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation		2 425 631	2 486 272	2 548 428	2 612 139	2 677 443	2 744 379	2 812 988	2 883 313	2 955 396	3 029 281	3 105 013	3 182 638	3 262 204	3 343 759	3 427 353	3 513 037	3 600 863	3 690 884	3 783 156	3 877 735	3 974 679	4 074 046	4 175 897	4 280 294	4 387 302
(=) Free net cashflow	-59 161 729	8 841 273	5 924 537	6 074 467	6 222 190	6 378 984	6 540 040	6 700 959	6 868 594	7 045 233	7 217 822	7 400 045	7 583 796	7 771 774	7 971 865	8 169 321	11 561 460	11 849 631	12 146 754	12 450 812	12 758 907	7 119 584	7 322 463	7 472 753	7 679 435	7 852 433
$\Sigma_{free\ net\ annual\ cashflow}$	-	-50 320 456	-44 395 919	-38 321 453	-32 099 263	-25 720 278	-19 180 238	-12 479 280	-5 610 686	1 434 547	8 652 369	16 052 414	23 636 211	31 407 985	39 379 849	47 549 170	59 110 630	70 960 261	83 107 015	95 557 827	108 316 733	115 436 317	122 758 780	130 231 533	137 910 968	145 763 401
	$LCOE_{wso}$	84.34	85.02	85.71	86.17	86.87	87.59	88.17	88.87	89.78	90.37	91.19	91.91	92.63	93.67	94.44	94.11	94.92	95.82	96.72	97.50	93.98	94.68	95.73	96.51	97.52

APPENDIX U

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

O&M warranty conditions

		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Depreciation

		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Revenues

		Notes
Power Purchase Agreement Rate	0.08581	[$/kWh]
Expected Market Price	0.06007	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Financial Indexes

		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Project Information

		Notes
Project Name	Firestar Wind Farm	
Project Location	Aracati (Brazil)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m^2]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (a)	0.14	[–]
Betz Limit`s coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	11.2%	[%]
Availability	98.2%	[%]
	358	[d/yr]

Levelized Replacement Cost Model

		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inst}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{Y_{RC}}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm Removal Cost Model

		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m^2/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Renewable Energy Public Incentive Model

		Notes
REI_{CM}	65.7637	[$/kW$_e$]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
ψ_{total}	15.00%	[%]
n_{ψ}	3	[yr]
REP_{CM}	0.00000594	[$/kW$_e$h]
AEP_{avail}/H_{prod}	5 696	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0339	[$/kW$_e$h]
ε_0	0.023377	[$/kW$_e$h]
n_{ε}	15	[yr]
$OREP_{CM}$	21.6787	[$/kW$_e$]
$LCCCM_{WF_{OREGCM}}$	4.5846	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
ψ_{total}	15.0%	[%]
ifr	2.5%	[%/yr]
n_{ψ}	15	[yr]
CR_f	25.0%	[%]
$GHG.R_{CM}$	3 868.4070	[$/tCO$_2$]
$LCER_{CO_2}$	56.2	[tCO$_2$/MW$_e$h]
$\sum AEP_{avail\ yr_1+...+yr_n}$	48 856	[MW$_e$h]
n_{ψ}	25	[yr]
$GHG_{EM_{ff\ co_2}}$	0.00123	[tCO$_2$/MW$_e$h]
$GHG_{EM_{wecs\ co_2}}$	0.00008	[tCO$_2$/MW$_e$h]
ε_c	37.1056	[$/tCO$_2$]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	0.0%	[%]
ξ_2 REP_{CM}	0.0%	[%]
ξ_3 $OREP_{CM}$	50.0%	[%]
ξ_4 $GHG.R_{CM}$	50.0%	[%]
REPIM	**1 945.0428**	**[$/proj]**

Wind Farm Life-Cycle Production Model

		Notes
WF_{CM}	50 000	[kW$_e$/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	48 979 624	[kW$_e$h/yr]
η_{wecs}	20.98%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.839325	[–]
N_{WT}	25	[–]
A	6 361.7	[m^2]
AEP_{rated}	438 000 000	[kW$_e$h/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	0.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**48 979 624**	**[kW$_e$h/yr]**

Wind Farm Life-Cycle Capital Cost Model

		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kW$_e$]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m^2/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m^2]
Bld_{area}	300.0	[m^2]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
$W_{F_{CM}}$	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

Wind Farm O&M Cost Model

		Notes
$O\&M_{fixed_{CM}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.025839	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	90	[h]
AAR	4 202 942	[$M]
AEP_{avail}	48 979 624	[kWh/yr]
$O\&M_{WFCM}$	**0.124114**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$

		Notes
$SC_{O\&M}$	**0.000105**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000229**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.8	[per yr]
Repair time	2.0	[h]
Hours required	90.0	[h]
$SC_{O\&M}$+$USC_{O\&M}$	**162.0**	**[h/yr]**
	0.000334	**[$/kWh/yr]**

Exchange rates

		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Project Financing

		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 841 967	[$]
Debt payments	3 014 754	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 841 967	[$]
Discount rate	9.00%	[%/yr]

Hours Distribution

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February[(*)]	672	641
March	744	737
April	720	713
May	744	737
June[(*)]	720	689
July	744	737
August	744	737
September	720	713
October	744	737
November[(*)]	720	689
December	744	737
Total [h/yr]	**8 760**	**8 600**

[(*)] Period of less hours for production

Conditions for $LCOE_{wso}$

		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
ξ_1 REI_{CM}	1	**[1/0]**
ξ_2 REP_{CM}	1	**[1/0]**
ξ_3 $OREP_{CM}$	1	**[1/0]**
ξ_4 $GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	0	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Initial Results Summary of $LCOE_{wso}$

			Notes
67.6693	yr_1	70.7843	yr_{15}
67.8196	yr_2	69.8148	yr_{15}
68.0301	yr_3	70.0062	yr_{16}
68.1907	yr_4	70.2090	yr_{17}
68.4452	yr_5	70.4052	yr_{18}
68.6285	yr_6	70.7652	yr_{19}
68.8776	yr_7	70.3784	yr_{20}
69.0932	yr_8	70.5607	yr_{21}
69.2651	yr_9	70.8306	yr_{22}
69.4927	yr_{10}	71.1149	yr_{23}
69.7293	yr_{11}	71.3767	yr_{25}
70.0108	yr_{12}	69.6873	Mean
70.2358	yr_{13}	1.0827	SD
70.4493	yr_{14}	-0.4490	Υ (skewness)
$LCOE_{wso}$	**69.6873**	**US$/MWh**	valid !
	0.069687	**US$/kWh**	

Figure U.1 *I-O representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)}$ and E_{pi} *(Case $_3$)*. Source: Own elaboration

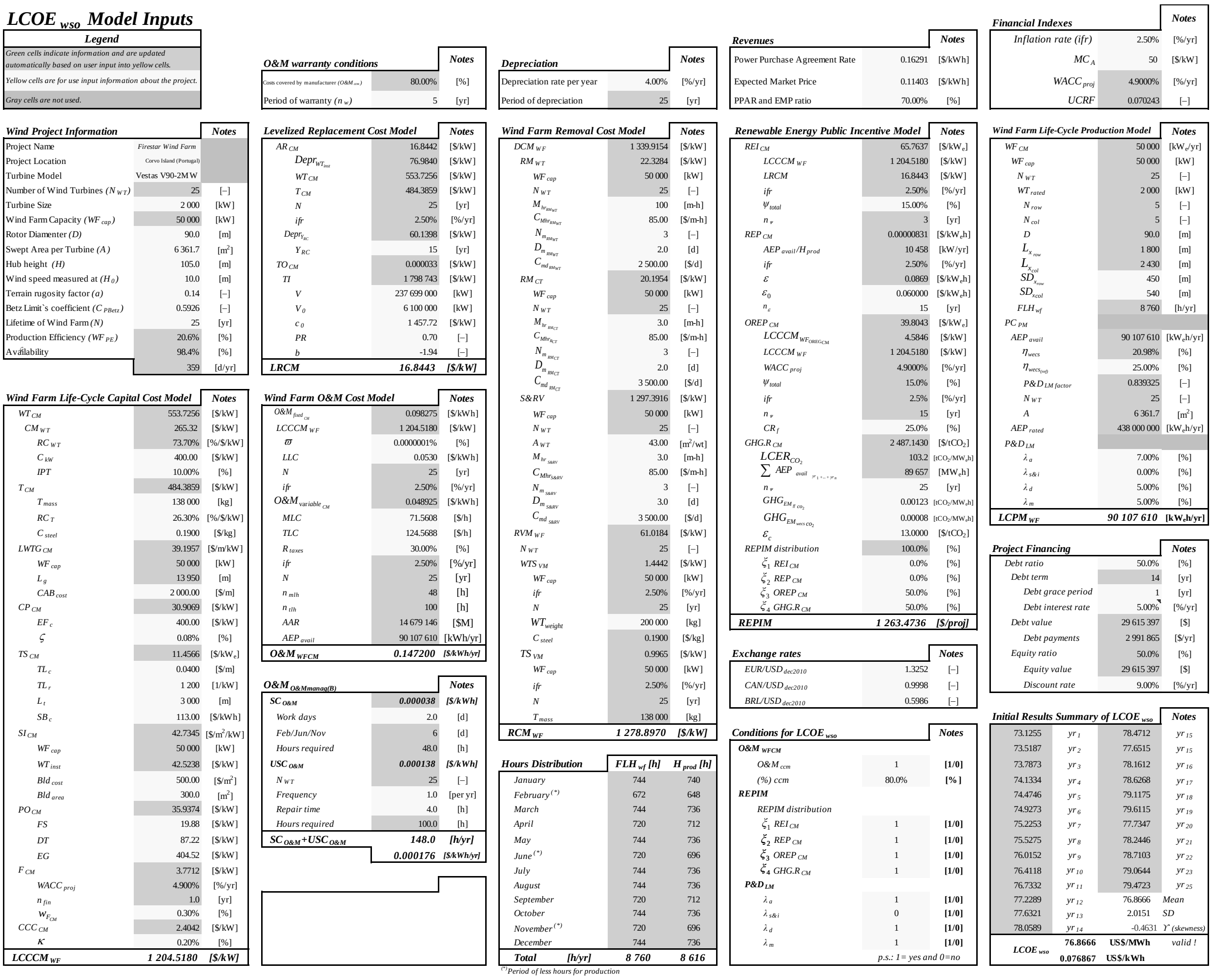

Figure U.2 *I-O system representation* of *LCOE$_{wso}$ algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Corvo Island (Portugal) with sensitivity analysis of *O&M$_{manag(B)}$* and *E$_{pi}$ (Case $_3$)*. Source: Own elaboration

$LCOE_{wso}$ Model Inputs

Legend
Green cells indicate information and are updated automatically based on user input into yellow cells.
Yellow cells are for use input information about the project.
Gray cells are not used.

Wind Project Information		Notes
Project Name	Firestar Wind Farm	
Project Location	Cape Saint James (Canada)	
Turbine Model	Vestas V90-2MW	
Number of Wind Turbines (N_{WT})	25	[–]
Turbine Size	2 000	[kW]
Wind Farm Capacity (WF_{cap})	50 000	[kW]
Rotor Diamenter (D)	90.0	[m]
Swept Area per Turbine (A)	6 361.7	[m²]
Hub height (H)	105.0	[m]
Wind speed measured at (H_0)	10.0	[m]
Terrain rugosity factor (α)	0.14	[–]
Betz Limit's coefficient (C_{PBetz})	0.5926	[–]
Lifetime of Wind Farm (N)	25	[yr]
Production Efficiency (WF_{PE})	48.6%	[%]
Availability	98.2%	[%]
	358	[d/yr]

Wind Farm Life-Cycle Capital Cost Model		Notes
WT_{CM}	553.7256	[$/kW]
CM_{WT}	265.32	[$/kW]
RC_{WT}	73.70%	[%/$/kW]
C_{kW}	400.00	[$/kW]
IPT	10.00%	[%]
T_{CM}	484.3859	[$/kW]
T_{mass}	138 000	[kg]
RC_T	26.30%	[%/$/kW]
C_{steel}	0.1900	[$/kg]
$LWTG_{CM}$	39.1957	[$/m/kW]
WF_{cap}	50 000	[kW]
L_g	13 950	[m]
CAB_{cost}	2 000.00	[$/m]
CP_{CM}	30.9069	[$/kW]
EF_c	400.00	[$/kW]
ς	0.08%	[%]
TS_{CM}	11.4566	[$/kWe]
TL_c	0.0400	[$/m]
TL_r	1 200	[1/kW]
L_t	3 000	[m]
SB_c	113.00	[$/kWh]
SI_{CM}	42.7345	[$/m²/kW]
WF_{cap}	50 000	[kW]
WT_{inst}	42.5238	[$/kW]
Bld_{cost}	500.00	[$/m²]
Bld_{area}	300.0	[m²]
PO_{CM}	35.9374	[$/kW]
FS	19.88	[$/kW]
DT	87.22	[$/kW]
EG	404.52	[$/kW]
F_{CM}	3.7712	[$/kW]
$WACC_{proj}$	4.900%	[%/yr]
n_{fin}	1.0	[yr]
W_{FCost}	0.30%	[%]
CCC_{CM}	2.4042	[$/kW]
κ	0.20%	[%]
$LCCCM_{WF}$	**1 204.5180**	**[$/kW]**

O&M warranty conditions		Notes
Costs covered by manufacturer ($O\&M_{ccm}$)	80.00%	[%]
Period of warranty (n_w)	5	[yr]

Levelized Replacement Cost Model		Notes
AR_{CM}	16.8442	[$/kW]
$Depr_{WT_{inv}}$	76.9840	[$/kW]
WT_{CM}	553.7256	[$/kW]
T_{CM}	484.3859	[$/kW]
N	25	[yr]
ifr	2.50%	[%/yr]
$Depr_{TLC}$	60.1398	[$/kW]
Y_{RC}	15	[yr]
TO_{CM}	0.000033	[$/kW]
TI	1 798 743	[$/kW]
V	237 699 000	[kW]
V_0	6 100 000	[kW]
c_0	1 457.72	[$/kW]
PR	0.70	[–]
b	-1.94	[–]
LRCM	**16.8443**	**[$/kW]**

Wind Farm O&M Cost Model		Notes
$O\&M_{fixed_{cw}}$	0.098275	[$/kWh]
$LCCCM_{WF}$	1 204.5180	[$/kW]
ϖ	0.0000001%	[%]
LLC	0.0530	[$/kWh]
N	25	[yr]
ifr	2.50%	[%/yr]
$O\&M_{variable_{CM}}$	0.041526	[$/kWh]
MLC	71.5608	[$/h]
TLC	124.5688	[$/h]
R_{taxes}	30.00%	[%]
ifr	2.50%	[%/yr]
N	25	[yr]
n_{mlh}	72	[h]
n_{tlh}	90	[h]
AAR	29 460 159	[$M]
AEP_{avail}	212 943 465	[kWh/yr]
$O\&M_{WFCM}$	**0.139801**	**[$/kWh/yr]**

$O\&M_{O\&Mmanag(B)}$		Notes
$SC_{O\&M}$	**0.000024**	**[$/kWh]**
Work days	3.0	[d]
Feb/Jun/Nov	9	[d]
Hours required	72.0	[h]
$USC_{O\&M}$	**0.000053**	**[$/kWh]**
N_{WT}	25	[–]
Frequency	1.8	[per yr]
Repair time	2.0	[h]
Hours required	90.0	[h]
$SC_{O\&M}+USC_{O\&M}$	**162.0**	**[h/yr]**
	0.000077	**[$/kWh/yr]**

Depreciation		Notes
Depreciation rate per year	4.00%	[%/yr]
Period of depreciation	25	[yr]

Wind Farm Removal Cost Model		Notes
DCM_{WF}	1 339.9154	[$/kW]
RM_{WT}	22.3284	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMWT}}$	100	[m-h]
$C_{Mhr_{RMWT}}$	85.00	[$/m-h]
$N_{m_{RMWT}}$	3	[–]
$D_{m_{RMWT}}$	2.0	[d]
$C_{md_{RMWT}}$	2 500.00	[$/d]
RM_{CT}	20.1954	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
$M_{hr_{RMCT}}$	3.0	[m-h]
$C_{Mhr_{RCT}}$	85.00	[$/m-h]
$N_{m_{RMCT}}$	3	[–]
$D_{m_{RMCT}}$	2.0	[d]
$C_{md_{RMCT}}$	3 500.00	[$/d]
$S\&RV$	1 297.3916	[$/kW]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
A_{WT}	43.00	[m²/wt]
$M_{hr_{S\&RV}}$	3.0	[m-h]
$C_{Mhr_{S\&RV}}$	85.00	[$/m-h]
$N_{m_{S\&RV}}$	3	[–]
$D_{m_{S\&RV}}$	3.0	[d]
$C_{md_{S\&RV}}$	3 500.00	[$/d]
RVM_{WF}	61.0184	[$/kW]
N_{WT}	25	[–]
WTS_{VM}	1.4442	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
WT_{weight}	200 000	[kg]
C_{steel}	0.1900	[$/kg]
TS_{VM}	0.9965	[$/kW]
WF_{cap}	50 000	[kW]
ifr	2.50%	[%/yr]
N	25	[yr]
T_{mass}	138 000	[kg]
RCM_{WF}	**1 278.8970**	**[$/kW]**

Hours Distribution	FLH_{wf} [h]	H_{prod} [h]
January	744	738
February (*)	672	641
March	744	737
April	720	713
May	744	737
June (*)	720	689
July	744	737
August	744	737
September	720	713
October	744	737
November (*)	720	689
December	744	737
Total [h/yr]	**8 760**	**8 600**

(*) Period of less hours for production

Revenues		Notes
Power Purchase Agreement Rate	0.13835	[$/kWh]
Expected Market Price	0.09684	[$/kWh]
PPAR and EMP ratio	70.00%	[%]

Renewable Energy Public Incentive Model		Notes
REI_{CM}	65.7637	[$/kWe]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$LRCM$	16.8443	[$/kW]
ifr	2.50%	[%/yr]
Ψ_{total}	15.00%	[%]
n_{Ψ}	3	[yr]
REP_{CM}	0.00000053	[$/kWeh]
AEP_{avail}/H_{prod}	24 762	[kW/yr]
ifr	2.50%	[%/yr]
ε	0.0131	[$/kWeh]
ε_0	0.007998	[$/kWeh]
n_{ε}	20	[yr]
$OREP_{CM}$	83.3033	[$/kWe]
$LCCCM_{WF_{OREGCM}}$	4.0521	[$/kW]
$LCCCM_{WF}$	1 204.5180	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
Ψ_{total}	15.0%	[%]
ifr	2.5%	[%/yr]
n_{Ψ}	20	[yr]
CR_f	25.0%	[%]
$GHG.R_{CM}$	10 881.1639	[$/tCO₂]
$LCER_{CO_2}$	244.5	[tCO₂/MWeh]
$\sum AEP_{avail_{yr_1+...+yr_n}}$	212 467	[MWeh]
n_{Ψ}	25	[yr]
$GHG_{EM_{ff\ CO_2}}$	0.00123	[tCO₂/MWeh]
$GHG_{EM_{wecs\ CO_2}}$	0.00008	[tCO₂/MWeh]
ε_c	24.0000	[$/tCO₂]
REPIM distribution	100.0%	[%]
ξ_1 REI_{CM}	0.0%	[%]
ξ_2 REP_{CM}	0.0%	[%]
ξ_3 $OREP_{CM}$	50.0%	[%]
ξ_4 $GHG.R_{CM}$	50.0%	[%]
REPIM	**5 482.2336**	**[$/proj]**

Exchange rates		Notes
$EUR/USD_{dec2010}$	1.3252	[–]
$CAN/USD_{dec2010}$	0.9998	[–]
$BRL/USD_{dec2010}$	0.5986	[–]

Conditions for $LCOE_{wso}$		Notes
$O\&M_{WFCM}$		
$O\&M_{ccm}$	1	**[1/0]**
(%) ccm	80.0%	**[%]**
REPIM		
REPIM distribution		
REI_{CM}	1	**[1/0]**
REP_{CM}	1	**[1/0]**
$OREP_{CM}$	1	**[1/0]**
$GHG.R_{CM}$	1	**[1/0]**
$P\&D_{LM}$		
λ_a	1	**[1/0]**
$\lambda_{s\&i}$	1	**[1/0]**
λ_d	1	**[1/0]**
λ_m	1	**[1/0]**
	p.s.: 1= yes and 0=no	

Financial Indexes		Notes
Inflation rate (ifr)	2.50%	[%/yr]
MC_A	50	[$/kW]
$WACC_{proj}$	4.9000%	[%/yr]
$UCRF$	0.070243	[–]

Wind Farm Life-Cycle Production Model		Notes
WF_{CM}	50 000	[kWe/yr]
WF_{cap}	50 000	[kW]
N_{WT}	25	[–]
WT_{rated}	2 000	[kW]
N_{row}	5	[–]
N_{col}	5	[–]
D	90.0	[m]
$L_{x_{row}}$	1 800	[m]
$L_{x_{col}}$	2 430	[m]
$SD_{x_{row}}$	450	[m]
SD_{xcol}	540	[m]
FLH_{wf}	8 760	[h/yr]
PC_{PM}		
AEP_{avail}	212 943 465	[kWeh/yr]
η_{wecs}	20.35%	[%]
$\eta_{wecs_{(ref)}}$	25.00%	[%]
$P\&D_{LM\ factor}$	0.814145	[–]
N_{WT}	25	[–]
A	6 361.7	[m²]
AEP_{rated}	438 000 000	[kWeh/yr]
$P\&D_{LM}$		
λ_a	7.00%	[%]
$\lambda_{s\&i}$	3.00%	[%]
λ_d	5.00%	[%]
λ_m	5.00%	[%]
$LCPM_{WF}$	**212 943 465**	**[kWeh/yr]**

Project Financing		Notes
Debt ratio	50.0%	[%]
Debt term	14	[yr]
Debt grace period	1	[yr]
Debt interest rate	5.00%	[%/yr]
Debt value	29 071 659	[$]
Debt payments	2 936 934	[$/yr]
Equity ratio	50.0%	[%]
Equity value	29 071 659	[$]
Discount rate	9.00%	[%/yr]

Initial Results Summary of $LCOE_{wso}$			Notes
84.3448	yr_1	94.4360	yr_{15}
85.0205	yr_2	94.1138	yr_{15}
85.7100	yr_3	94.9205	yr_{16}
86.1734	yr_4	95.8186	yr_{17}
86.8681	yr_5	96.7191	yr_{18}
87.5940	yr_6	97.4969	yr_{19}
88.1682	yr_7	93.9817	yr_{20}
88.8666	yr_8	94.6831	yr_{21}
89.7788	yr_9	95.7335	yr_{22}
90.3684	yr_{10}	96.5076	yr_{23}
91.1898	yr_{11}	97.5244	yr_{25}
91.9082	yr_{12}	91.7691	Mean
92.6296	yr_{13}	4.1987	SD
93.6712	yr_{14}	-0.3338	ϒ (skewness)
$LCOE_{wso}$	**91.7691**	**US$/MWh**	valid !
	0.091769	**US$/kWh**	

Figure U.3 *I-O system representation* of $LCOE_{wso}$ *algorithm* calculations for the hypothetical 50MW$_e$ wind farm in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)}$ and E_{pi} *(Case $_3$)*. Source: Own elaboration

Table U.1 Energy production (AEP_{avail}) map of the wind farm for Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ (Case 3)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	1.1665	738	1 693 132	8 890 198	3 802 165	7 507 410	557 361	8 890 198	557 361	557 361	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	4 232 212	8 890 198	8 890 198	557 361	3 802 165	7 507 410	557 361	3 802 165	7 507 410	4 232 212	4 232 212
February	4.9	1.1666	641	850 430	6 803 436	3 673 320	6 803 436	779 598	6 803 436	779 598	779 598	4 727 258	6 803 436	6 803 436	779 598	3 673 320	6 803 436	483 758	483 758	3 300 063	4 727 258	7 716 188	1 577 029	1 577 029	7 716 188	6 803 436	4 727 258	4 727 258
March	4.0	1.1671	737	556 507	7 495 900	5 438 155	8 876 568	978 319	7 495 900	978 319	978 319	6 560 068	7 495 900	7 495 900	978 319	5 438 155	8 876 568	896 836	896 836	1 814 186	4 225 724	1 814 186	1 690 536	1 690 536	7 826 555	8 876 568	3 796 335	6 560 068
April	4.7	1.1667	713	867 380	6 344 604	6 344 604	4 086 931	1 635 011	6 344 604	1 635 011	1 635 011	7 249 700	6 344 604	6 344 604	1 754 600	6 344 604	4 086 931	946 187	946 187	1 635 011	6 344 604	1 635 011	3 671 646	946 187	7 249 700	6 344 604	1 754 600	7 249 700
May	6.0	1.1670	737	1 814 119	5 437 953	7 495 621	5 437 953	1 814 119	5 437 953	1 814 119	1 814 119	7 826 264	5 437 953	5 437 953	1 690 473	7 495 621	6 559 824	1 690 473	1 690 473	978 283	8 876 238	978 283	556 486	896 803	6 559 824	4 225 566	1 690 473	7 826 264
June	7.9	1.1686	689	3 955 677	3 955 677	7 326 396	6 140 844	3 553 729	3 955 677	3 553 729	3 553 729	8 309 307	3 955 677	3 955 677	3 553 729	7 326 396	5 090 627	1 698 250	1 698 250	839 524	7 326 396	839 524	839 524	3 553 729	5 090 627	5 090 627	915 799	8 309 307
July	8.6	1.1698	737	5 450 949	3 805 267	8 897 452	1 694 513	4 235 665	3 805 267	4 235 665	4 235 665	557 816	557 816	3 805 267	5 450 949	8 897 452	1 818 455	3 805 267	3 805 267	557 816	7 513 536	557 816	980 621	4 235 665	4 235 665	1 694 513	898 946	557 816
August	9.6	1.1677	737	7 499 787	1 815 127	1 815 127	1 815 127	8 881 171	1 815 127	5 440 975	5 440 975	897 302	897 302	1 815 127	4 227 915	1 815 127	1 691 413	5 440 975	7 830 614	7 830 614	897 302	4 227 915	7 830 614	5 440 975	1 815 127	1 815 127	556 795	897 302
September	10.1	1.1657	713	8 576 955	1 633 475	1 633 475	3 668 197	7 562 383	1 633 475	6 338 644	6 338 644	945 298	945 298	1 633 475	6 338 644	1 633 475	3 668 197	6 338 644	7 242 889	7 242 889	945 298	5 254 599	8 576 955	6 338 644	1 633 475	3 668 197	6 338 644	945 298
October	9.7	1.1645	737	7 809 082	976 135	976 135	555 264	7 479 165	976 135	7 479 165	7 479 165	1 686 762	1 686 762	976 135	8 856 751	976 135	555 264	7 479 165	6 545 422	6 545 422	1 810 136	6 545 422	4 216 289	7 479 165	976 135	976 135	8 856 751	1 686 762
November	9.2	1.1638	689	6 115 594	836 072	836 072	836 072	6 115 594	836 072	7 296 271	7 296 271	1 691 267	1 691 267	836 072	7 296 271	836 072	836 072	7 296 271	5 069 696	5 069 696	1 575 994	6 988 019	6 115 594	7 296 271	836 072	836 072	7 296 271	1 691 267
December	7.6	1.1651	737	3 790 014	555 580	555 580	976 690	5 429 099	555 580	8 861 786	8 861 786	3 790 014	3 790 014	555 580	7 483 417	555 580	976 690	8 861 786	4 218 687	4 218 687	3 790 014	7 813 521	5 429 099	8 861 786	555 580	555 580	7 483 417	3 790 014
Annual	7.4	1.1666	8 600	48 979 624	48 549 424	48 794 102	48 399 005	49 021 215	48 549 424	48 970 644	48 970 644	48 473 266	48 496 226	48 549 424	48 968 028	48 794 102	48 470 887	49 169 824	49 318 276	48 922 388	48 589 860	48 172 649	48 991 802	48 874 151	48 297 112	48 393 836	48 547 502	48 473 266

Table U.2 Energy production map of the wind farm for Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ (Case 3)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	1.2313	740	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	14 490 462	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408	10 871 408
February	11.5	1.2345	648	12 092 721	4 293 137	12 092 721	12 092 721	12 092 721	3 417 096	12 092 721	12 715 785	1 795 784	3 417 096	12 715 785	1 795 784	9 244 173	12 092 721	6 674 015	12 715 785	4 293 137	5 486 290	3 417 096	2 815 600	12 092 721	2 106 703	6 674 015	12 092 721	12 715 785
March	10.5	1.2329	736	10 486 228	3 193 907	13 717 510	13 717 510	13 717 510	6 223 433	13 717 510	13 717 510	2 389 762	3 193 907	13 717 510	2 389 762	13 717 510	13 717 510	6 223 433	13 717 510	3 876 220	7 570 742	4 869 967	13 717 510	14 424 289	2 037 067	10 486 228	14 424 289	3 193 907
April	9.5	1.2317	712	7 316 597	7 316 597	10 458 483	10 458 483	10 458 483	7 316 597	10 458 483	4 706 485	3 086 689	7 316 597	13 257 022	3 086 689	13 257 022	4 706 485	4 706 485	13 257 022	3 086 689	10 134 212	3 086 689	13 940 075	13 257 022	3 086 689	3 086 689	13 257 022	3 746 098
May	8.2	1.2282	736	4 851 676	10 446 845	10 446 845	10 446 845	6 200 059	10 446 845	10 446 845	10 446 845	3 861 662	6 200 059	10 446 845	3 861 662	14 370 115	10 446 845	3 861 662	10 446 845	2 380 787	13 665 991	6 200 059	2 380 787	10 446 845	3 861 662	14 370 115	10 446 845	4 851 676
June	7.1	1.2224	696	2 994 461	12 860 910	7 097 981	7 097 981	7 097 981	10 145 990	4 565 858	12 860 910	4 565 858	10 145 990	7 097 981	4 565 858	7 097 981	2 240 532	2 994 461	7 097 981	1 909 861	12 860 910	7 097 981	1 909 861	7 097 981	4 565 858	12 860 910	7 097 981	5 834 806
July	6.1	1.2154	736	2 008 118	13 522 571	4 800 760	6 134 992	10 337 209	13 522 571	7 463 154	3 148 518	6 134 992	2 008 118	6 134 992	6 134 992	6 134 992	2 008 118	2 355 801	6 134 992	6 134 992	14 219 306	10 337 209	3 821 135	6 134 992	6 134 992	13 522 571	3 821 135	7 463 154
August	6.4	1.2075	736	2 340 496	10 598 668	3 796 310	3 796 310	3 796 310	13 434 719	6 095 134	3 796 310	7 414 668	2 340 496	4 769 571	7 414 668	4 769 571	10 598 668	1 995 072	4 769 571	13 434 719	1 995 072	13 434 719	4 769 571	4 769 571	7 414 668	4 769 571	3 128 063	10 270 051
September	7.6	1.2064	712	3 669 202	1 928 273	5 891 057	4 609 876	4 609 876	4 609 876	1 928 273	5 891 057	9 926 189	9 926 189	3 669 202	9 926 189	3 669 202	5 891 057	9 926 189	3 669 202	12 984 898	2 262 132	12 984 898	5 891 057	3 669 202	9 926 189	3 669 202	2 262 132	1 928 273
October	8.9	1.2126	736	6 121 079	6 121 079	3 141 378	2 003 564	3 141 378	2 003 564	2 350 459	7 446 229	13 491 905	13 491 905	3 141 378	13 491 905	3 141 378	7 446 229	13 491 905	3 141 378	10 643 782	3 141 378	2 003 564	7 446 229	3 141 378	13 491 905	2 350 459	2 003 564	2 350 459
November	10.6	1.2194	696	10 121 586	3 625 425	2 235 143	2 235 143	2 235 143	2 235 143	2 987 258	2 235 143	12 829 976	4 554 876	2 235 143	12 829 976	2 235 143	2 987 258	12 829 976	2 235 143	9 807 761	3 625 425	2 235 143	9 807 761	2 235 143	12 829 976	1 905 267	5 820 771	12 829 976
December	11.5	1.2237	736	13 614 984	2 371 901	2 021 842	3 170 035	2 021 842	3 170 035	3 847 249	2 021 842	14 316 481	13 614 984	2 021 842	14 316 481	2 021 842	3 847 249	14 316 481	2 021 842	7 514 158	4 833 568	14 316 481	13 614 984	2 021 842	14 316 481	6 176 918	4 833 568	13 614 984
Annual	9.1	1.2222	8 616	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577

Table U.3 Energy production map of the wind farm for Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ (Case 3)

Months	v_{wc} (m/s)	(kg/m^3)	H_{prod} (h)	AEP_{avail}(kWh) yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	1.2561	738	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	8 013 494	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	32 734 798	40 754 809	32 734 798	32 734 798	28 019 994	8 013 494	7 100 933
February	14.7	1.2522	641	24 319 291	14 509 901	6 932 878	26 305 527	14 509 901	14 509 901	26 305 527	26 305 527	6 932 878	14 509 901	14 509 901	7 772 679	26 305 527	6 932 878	17 428 282	6 932 878	6 932 878	6 932 878	6 932 878	22 528 524	26 305 527	26 305 527	29 044 609	7 772 679	17 402 199
March	12.7	1.2495	737	18 273 052	18 273 052	8 918 969	27 905 823	12 408 183	18 273 052	27 905 823	27 905 823	8 918 969	12 408 183	18 273 052	9 997 395	27 905 823	8 918 969	30 184 982	8 918 969	8 918 969	8 918 969	8 918 969	23 050 141	27 905 823	27 905 823	31 495 010	9 997 395	18 969 625
April	12.4	1.2490	713	16 100 080	19 338 295	9 667 330	24 894 425	9 667 330	19 338 295	24 894 425	24 894 425	9 667 330	9 667 330	19 338 295	9 667 330	24 894 425	9 667 330	26 984 508	9 667 330	29 188 421	9 667 330	9 667 330	22 244 176	20 024 605	24 894 425	24 985 682	9 667 330	18 186 892
May	11.2	1.2425	737	12 338 025	25 598 814	9 940 868	19 885 473	9 940 868	25 598 814	19 885 473	19 885 473	9 940 868	9 940 868	25 598 814	12 338 025	19 885 473	9 940 868	25 598 814	9 940 868	27 748 037	9 940 868	9 940 868	21 042 787	19 885 473	19 885 473	19 137 999	12 338 025	16 209 586
June	10.4	1.2351	689	9 237 631	25 785 086	11 465 208	16 884 369	8 241 161	25 785 086	16 884 369	16 884 369	11 465 208	8 241 161	25 785 086	15 384 455	16 884 369	11 465 208	16 884 369	11 465 208	23 787 904	11 465 208	11 465 208	17 001 691	16 884 369	16 884 369	16 806 455	15 384 455	14 990 327
July	10.0	1.2275	737	8 761 837	29 653 191	16 356 443	16 356 443	7 815 162	29 653 191	16 356 443	16 356 443	16 356 443	7 815 162	29 653 191	17 951 122	16 356 443	16 356 443	7 815 162	16 356 443	19 646 221	16 356 443	16 356 443	15 570 355	16 087 422	16 356 443	16 802 962	17 951 122	8 647 175
August	9.7	1.2216	737	7 777 512	12 130 855	17 864 641	12 130 855	17 864 641	12 130 855	12 130 855	12 130 855	17 864 641	17 864 641	12 130 855	19 551 573	12 130 855	17 864 641	8 719 626	17 864 641	17 864 641	17 864 641	17 864 641	12 936 052	15 417 110	12 130 855	12 621 116	19 551 573	7 130 060
September	10.4	1.2234	713	9 469 157	7 534 977	18 941 875	9 469 157	26 431 347	7 534 977	9 469 157	9 469 157	18 941 875	26 431 347	7 534 977	24 384 108	9 469 157	18 941 875	9 469 157	18 941 875	15 770 041	18 941 875	18 941 875	12 353 594	13 310 548	9 469 157	8 865 389	24 384 108	19 080 004
October	13.1	1.2327	737	19 729 237	8 798 861	29 778 493	9 862 764	25 397 690	8 798 861	9 862 764	9 862 764	29 778 493	25 397 690	8 798 861	27 530 026	9 862 764	25 397 690	9 862 764	25 397 690	12 241 087	29 778 493	25 397 690	12 273 661	8 881 296	9 862 764	8 143 371	27 530 026	21 651 123
November	14.3	1.2429	689	23 939 450	9 296 482	25 949 356	8 293 664	28 068 725	9 296 482	8 293 664	8 293 664	25 949 356	28 068 725	9 296 482	28 068 725	8 293 664	25 949 356	11 538 250	25 949 356	9 296 482	25 949 356	25 949 356	7 443 284	8 293 664	8 293 664	8 895 126	28 068 725	22 011 001
December	15.1	1.2528	737	30 263 395	10 023 366	25 811 256	7 975 983	20 050 501	10 023 366	7 975 983	7 975 983	25 811 256	20 050 501	10 023 366	32 581 568	7 975 983	30 263 395	16 693 026	30 263 395	10 023 366	25 811 256	30 263 395	6 366 601	7 975 983	7 975 983	9 187 032	32 581 568	42 583 526
Annual	12.5	1.2404	8 600	212 943 465	213 677 678	214 362 116	212 699 281	213 130 306	213 677 678	212 699 281	212 699 281	214 362 116	213 130 306	213 677 678	213 240 500	212 699 281	214 433 451	213 913 741	214 433 451	214 152 844	214 362 116	214 433 451	213 565 675	213 706 617	212 699 281	214 004 745	213 240 500	213 962 451

Table U.4 Wind speed series simulations for AEP_{avail} in Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ (Case 3)

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	5.8	5.8	10.1	7.6	9.6	4.0	10.1	4.0	4.0	7.9	10.1	10.1	4.0	7.6	9.6	7.9	10.1	10.1	4.0	7.6	9.6	4.0	7.6	9.6	7.9	7.9
February	4.9	4.9	9.7	7.9	9.7	4.7	9.7	4.7	4.7	8.6	9.7	9.7	4.7	7.9	9.7	4.0	4.0	7.6	8.6	10.1	6.0	6.0	10.1	9.7	8.6	8.6
March	4.0	4.0	9.6	8.6	10.1	4.9	9.6	4.9	4.9	9.2	9.6	9.6	4.9	8.6	10.1	4.7	4.7	6.0	7.9	6.0	5.8	5.8	9.7	10.1	7.6	9.2
April	4.7	4.7	9.2	9.2	7.9	5.8	9.2	5.8	5.8	9.6	9.2	9.2	6.0	9.2	7.9	4.9	4.9	5.8	9.2	5.8	7.6	4.9	9.6	9.2	6.0	9.6
May	6.0	6.0	8.6	9.6	8.6	6.0	8.6	6.0	6.0	9.7	8.6	8.6	5.8	9.6	9.2	5.8	5.8	4.9	10.1	4.9	4.0	4.7	9.2	7.9	5.8	9.7
June	7.9	7.9	7.9	9.7	9.2	7.6	7.9	7.6	7.6	10.1	7.9	7.9	7.6	9.7	8.6	6.0	6.0	4.7	9.7	4.7	4.7	7.6	8.6	8.6	4.9	10.1
July	8.6	8.6	7.6	10.1	5.8	7.9	7.6	7.9	7.9	4.0	4.0	7.6	8.6	10.1	6.0	7.6	7.6	4.0	9.6	4.0	4.9	7.9	7.9	5.8	4.7	4.0
August	9.6	9.6	6.0	6.0	6.0	10.1	6.0	8.6	8.6	4.7	4.7	6.0	7.9	6.0	5.8	8.6	9.7	9.7	4.7	7.9	9.7	8.6	6.0	6.0	4.0	4.7
September	10.1	10.1	5.8	5.8	7.6	9.7	5.8	9.2	9.2	4.9	4.9	5.8	9.2	5.8	7.6	9.2	9.6	9.6	4.9	8.6	10.1	9.2	5.8	7.6	9.2	4.9
October	9.7	9.7	4.9	4.9	4.0	9.6	4.9	9.6	9.6	5.8	5.8	4.9	10.1	4.9	4.0	9.6	9.2	9.2	6.0	9.2	7.9	9.6	4.9	4.9	10.1	5.8
November	9.2	9.2	4.7	4.7	4.7	9.2	4.7	9.7	9.7	6.0	6.0	4.7	9.7	4.7	4.7	9.7	8.6	8.6	5.8	9.6	9.2	9.7	4.7	4.7	9.7	6.0
December	7.6	7.6	4.0	4.0	4.9	8.6	4.0	10.1	10.1	7.6	7.6	4.0	9.6	4.0	4.9	10.1	7.9	7.9	7.6	9.7	8.6	10.1	4.0	4.0	9.6	7.6
Annual	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4

Table U.5 Wind speed series simulations for AEP_{avail} in Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ (Case 3)

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7	10.6	10.6	11.7	10.6	10.6	10.6	11.7	10.6	10.6	11.7	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
February	11.5	11.5	8.2	11.5	11.5	11.5	7.6	11.5	11.7	6.1	7.6	11.7	6.1	10.5	11.5	9.5	11.7	8.2	8.9	7.6	7.1	11.5	6.4	9.5	11.5	11.7
March	10.5	10.5	7.1	11.5	11.5	11.5	8.9	11.5	11.5	6.4	7.1	11.5	6.4	11.5	11.5	8.9	11.5	7.6	9.5	8.2	11.5	11.7	6.1	10.5	11.7	7.1
April	9.5	9.5	9.5	10.6	10.6	10.6	9.5	10.6	8.2	7.1	9.5	11.5	7.1	11.5	8.2	8.2	11.5	7.1	10.5	7.1	11.7	11.5	7.1	7.1	11.5	7.6
May	8.2	8.2	10.5	10.5	10.5	8.9	10.5	10.5	10.5	7.6	8.9	10.5	7.6	11.7	10.5	7.6	10.5	6.4	11.5	8.9	6.4	10.5	7.6	11.7	10.5	8.2
June	7.1	7.1	11.5	9.5	9.5	9.5	10.6	8.2	11.5	8.2	10.6	9.5	8.2	9.5	6.4	7.1	9.5	6.1	11.5	9.5	6.1	9.5	8.2	11.5	9.5	8.9
July	6.1	6.1	11.5	8.2	8.9	10.5	11.5	9.5	7.1	8.9	6.1	8.9	8.9	8.9	6.1	6.4	8.9	8.9	11.7	10.5	7.6	8.9	8.9	11.5	7.6	9.5
August	6.4	6.4	10.6	7.6	7.6	7.6	11.5	8.9	7.6	9.5	6.4	8.2	9.5	8.2	10.6	6.1	8.2	11.5	6.1	11.5	8.2	8.2	9.5	8.2	7.1	10.5
September	7.6	7.6	6.1	8.9	8.2	8.2	8.2	6.1	8.9	10.5	10.5	7.6	10.5	7.6	8.9	10.5	7.6	11.5	6.4	11.5	8.9	7.6	10.5	7.6	6.4	6.1
October	8.9	8.9	8.9	7.1	6.1	7.1	6.1	6.4	9.5	11.5	11.5	7.1	11.5	7.1	9.5	11.5	7.1	10.6	7.1	6.1	9.5	7.1	11.5	6.4	6.1	6.4
November	10.6	10.6	7.6	6.4	6.4	6.4	6.4	7.1	6.4	11.5	8.2	6.4	11.5	6.4	7.1	11.5	6.4	10.5	7.6	6.4	10.5	6.4	11.5	6.1	8.9	11.5
December	11.5	11.5	6.4	6.1	7.1	6.1	7.1	7.6	6.1	11.7	11.5	6.1	11.7	6.1	7.6	11.7	6.1	9.5	8.2	11.7	11.5	6.1	11.7	8.9	8.2	11.5
Annual	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1

Table U.6 Wind speed series simulations for AEP_{avail} in Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ (Case 3)

Months	v_{wc}	Wind speed data series for simulations (m/s)																								
	(m/s)	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
January	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	9.7	15.4	15.4	15.4	15.4	15.4	15.4	15.4	16.6	15.4	15.4	14.7	9.7	9.3
February	14.7	14.7	12.4	9.7	15.1	12.4	12.4	15.1	15.1	9.7	12.4	12.4	10.0	15.1	9.7	13.1	9.7	9.7	9.7	9.7	14.3	15.1	15.1	15.6	10.0	13.1
March	12.7	12.7	12.7	10.0	14.7	11.2	12.7	14.7	14.7	10.0	11.2	12.7	10.4	14.7	10.0	15.1	10.0	10.0	10.0	10.0	13.8	14.7	14.7	15.3	10.4	12.9
April	12.4	12.4	13.1	10.4	14.3	10.4	13.1	14.3	14.3	10.4	10.4	13.1	10.4	14.3	10.4	14.7	10.4	15.1	10.4	10.4	13.8	13.3	14.3	14.3	10.4	12.9
May	11.2	11.2	14.3	10.4	13.1	10.4	14.3	13.1	13.1	10.4	10.4	14.3	11.2	13.1	10.4	14.3	10.4	14.7	10.4	10.4	13.4	13.1	13.1	13.0	11.2	12.3
June	10.4	10.4	14.7	11.2	12.7	10.0	14.7	12.7	12.7	11.2	10.0	14.7	12.4	12.7	11.2	12.7	11.2	14.3	11.2	11.2	12.8	12.7	12.7	12.7	12.4	12.2
July	10.0	10.0	15.1	12.4	12.4	9.7	15.1	12.4	12.4	12.4	9.7	15.1	12.7	12.4	12.4	9.7	12.4	13.1	12.4	12.4	12.2	12.3	12.4	12.5	12.7	10.0
August	9.7	9.7	11.2	12.7	11.2	12.7	11.2	11.2	11.2	12.7	12.7	11.2	13.1	11.2	12.7	10.0	12.7	12.7	12.7	12.7	11.4	12.1	11.2	11.4	13.1	9.4
September	10.4	10.4	9.7	13.1	10.4	14.7	9.7	10.4	10.4	13.1	14.7	9.7	14.3	10.4	13.1	10.4	13.1	12.4	13.1	13.1	11.4	11.7	10.4	10.2	14.3	13.2
October	13.1	13.1	10.0	15.1	10.4	14.3	10.0	10.4	10.4	15.1	14.3	10.0	14.7	10.4	14.3	10.4	14.3	11.2	15.1	14.3	11.2	10.1	10.4	9.8	14.7	13.5
November	14.3	14.3	10.4	14.7	10.0	15.1	10.4	10.0	10.0	14.7	15.1	10.4	15.1	10.0	14.7	11.2	14.7	10.4	14.7	14.7	9.7	10.0	10.0	10.3	15.1	13.9
December	15.1	15.1	10.4	14.3	9.7	13.1	10.4	9.7	9.7	14.3	13.1	10.4	15.4	9.7	15.1	12.4	15.1	10.4	14.3	15.1	9.0	9.7	9.7	10.1	15.4	16.9
Annual	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

Table U.7 kWh per H_{prod} with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ *(Case 3)*

Sites	kW/yr																								
	yr_1	yr_2	yr_3	yr_4	yr_5	yr_6	yr_7	yr_8	yr_9	yr_{10}	yr_{11}	yr_{12}	yr_{13}	yr_{14}	yr_{15}	yr_{16}	yr_{17}	yr_{18}	yr_{19}	yr_{20}	yr_{21}	yr_{22}	yr_{23}	yr_{24}	yr_{25}
Aracari (Brazil)	5 696	5 646	5 674	5 628	5 700	5 646	5 695	5 695	5 637	5 639	5 646	5 694	5 674	5 636	5 718	5 735	5 689	5 650	5 602	5 697	5 683	5 616	5 628	5 645	5 637
Corvo Island (Portugal)	10 458	10 535	10 467	10 475	10 468	10 563	10 497	10 429	10 525	10 527	10 454	10 525	10 507	10 500	10 474	10 454	10 510	10 523	10 545	10 560	10 464	10 520	10 532	10 452	10 407
Cape Saint James (Canada)	24 762	24 848	24 927	24 734	24 784	24 848	24 734	24 734	24 927	24 784	24 848	24 797	24 734	24 936	24 875	24 936	24 903	24 927	24 936	24 835	24 851	24 734	24 886	24 797	24 881

Table U.8 Cashflow for 25 years of the wind farm project 50 000 kW Aracati (Brazil) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ *(Case 3)*

Item	Years 0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ *(kWh/yr)*	-	48 979 624	48 549 424	48 794 102	48 399 005	49 021 215	48 549 424	48 970 644	48 970 644	48 473 266	48 496 226	48 549 424	48 968 028
(+) AAR ($M/yr)	-	4 308 015	4 376 931	4 508 965	4 584 266	4 759 280	4 831 313	4 995 061	5 119 937	5 194 634	5 327 022	5 466 187	5 651 151
PPAR	-	4 308 015	4 376 931	4 508 965	4 584 266	4 759 280	4 831 313	4 995 061	5 119 937	5 194 634	5 327 022	5 466 187	5 651 151
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	3 958 388	4 021 593	4 142 789	4 211 857	4 372 535	4 459 642	4 610 143	4 724 747	4 793 035	4 914 544	5 042 290	5 212 260
$O\&M_{fixed}$	-	2 661 279	2 703 850	2 785 412	2 831 928	2 940 042	2 984 539	3 085 692	3 162 833	3 208 975	3 290 756	3 376 724	3 490 983
$O\&M_{variable}$	-	1 297 109	1 317 743	1 357 376	1 379 929	1 432 493	1 475 103	1 524 451	1 561 914	1 584 059	1 623 788	1 665 566	1 721 276
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 447 041	2 508 217	2 570 923	2 635 196	2 701 076	2 768 603	2 837 818	2 908 763	2 981 482	3 056 019	3 132 420	3 210 730
(=) Profit before tax	-	3 659 937	3 748 406	3 844 070	3 937 250	4 040 708	4 116 983	4 223 862	4 330 109	4 434 890	4 546 601	4 661 374	4 782 304
(-) Revenue tax	-	1 292 405	1 313 079	1 352 689	1 375 280	1 427 784	1 449 394	1 498 518	1 535 981	1 558 390	1 598 107	1 639 856	1 695 345
(+) REPIM	541 967	1 072	1 089	1 122	1 141	1 184	1 202	1 243	1 274	1 293	1 326	1 360	1 406
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	541 967	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	1 072	1 089	1 122	1 141	1 184	1 202	1 243	1 274	1 293	1 326	1 360	1 406
(=) Profit after tax w/out interest	-	2 368 604	2 436 416	2 492 503	2 563 111	2 614 108	2 668 791	2 726 587	2 795 401	2 877 793	2 949 820	3 022 878	3 088 365
(-) Debt payments	-	-	3 167 376	3 246 560	3 327 724	3 410 917	3 496 190	3 583 595	3 673 185	3 765 015	3 859 140	3 955 618	4 054 509
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 447 041	2 508 217	2 570 923	2 635 196	2 701 076	2 768 603	2 837 818	2 908 763	2 981 482	3 056 019	3 132 420	3 210 730
(=) Free net cashflow	-59 683 934	7 437 385	4 464 539	4 571 330	4 693 909	4 798 176	4 907 460	5 021 223	5 147 403	5 288 594	5 420 892	5 555 727	5 684 535
$\Sigma_{free\ net\ annual\ cashflow}$	-	-52 246 549	-47 782 010	-43 210 680	-38 516 771	-33 718 595	-28 811 135	-23 789 912	-18 642 509	-13 353 915	-7 933 023	-2 377 296	3 307 239
$LCOE_{wso}$		67.67	67.82	68.03	68.19	68.45	68.63	68.88	69.09	69.27	69.49	69.73	70.01

Item	Years 13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ *(kWh/yr)*	48 794 102	48 470 887	49 169 824	49 318 276	48 922 388	48 589 860	48 172 649	48 991 802	48 874 151	48 297 112	48 393 836	48 547 502	48 473 266
(+) AAR ($M/yr)	5 771 856	5 876 963	6 110 750	6 282 430	6 387 799	6 502 991	6 608 332	6 888 721	4 930 788	4 994 386	5 129 498	5 274 431	5 398 025
PPAR	5 771 856	5 876 963	6 110 750	6 282 430	6 387 799	6 502 991	6 608 332	6 888 721	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	4 930 788	4 994 386	5 129 498	5 274 431	5 398 025
(-) $O\&M_{WFCM}$	5 322 943	5 419 232	5 634 158	5 791 793	5 888 285	5 993 824	6 090 278	6 348 036	5 856 505	5 931 402	6 091 221	6 262 682	6 408 790
$O\&M_{fixed}$	3 565 547	3 630 475	3 774 895	3 880 948	3 946 038	4 017 195	4 082 268	4 255 476	4 351 387	4 407 510	4 526 744	4 654 645	4 763 714
$O\&M_{variable}$	1 757 396	1 788 757	1 859 263	1 910 846	1 942 247	1 976 628	2 008 010	2 092 560	1 505 118	1 523 892	1 564 477	1 608 038	1 645 077
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 290 998	3 373 273	3 457 605	3 544 045	3 632 647	3 723 463	3 816 549	3 911 963	4 009 762	4 110 006	4 212 756	4 318 075	4 426 027
(=) Profit before tax	4 900 912	5 021 030	5 153 973	4 034 682	4 132 161	4 232 630	4 334 603	4 452 648	3 084 045	3 172 990	3 251 034	3 329 824	3 415 261
(-) Revenue tax	1 731 557	1 763 089	1 833 225	1 884 729	1 916 340	1 950 897	1 982 500	2 066 616	1 479 236	1 498 316	1 538 850	1 582 329	1 619 407
(+) REPIM	1 436	1 463	1 521	1 563	1 590	1 618	1 645	1 714	1 753	1 776	1 824	1 875	1 919
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	1 436	1 463	1 521	1 563	1 590	1 618	1 645	1 714	1 753	1 776	1 824	1 875	1 919
(=) Profit after tax w/out interest	3 170 791	3 259 403	3 322 269	2 151 516	2 217 411	2 283 351	2 353 748	2 387 746	1 606 562	1 676 450	1 714 008	1 749 369	1 797 773
(-) Debt payments	4 155 872	4 259 768	4 366 263	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 290 998	3 373 273	3 457 605	3 544 045	3 632 647	3 723 463	3 816 549	3 911 963	4 009 762	4 110 006	4 212 756	4 318 075	4 426 027
(=) Free net cashflow	5 831 865	5 987 004	6 118 060	9 492 621	9 742 043	9 996 099	10 259 315	10 490 952	9 912 348	10 189 881	10 440 275	10 693 793	10 965 807
$\Sigma_{free\ net\ annual\ cashflow}$	9 139 104	15 126 109	21 244 168	30 736 789	40 478 833	50 474 932	60 734 247	71 225 200	81 137 548	91 327 429	101 767 703	112 461 496	123 427 304
$LCOE_{wso}$	70.24	70.45	70.78	69.81	70.01	70.21	70.41	70.77	70.38	70.56	70.83	71.11	71.38

Table U.9 Cashflow for 25 years of the wind farm project 50 000 kW Corvo Island (Portugal) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ *(Case 3)*

Years 0–12:

Item	0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	90 107 610	90 769 774	90 190 491	90 253 921	90 198 973	91 016 328	90 443 405	89 858 042	90 685 374	90 700 678	90 078 677	90 685 374
(+) AAR ($M/yr)	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402
PPAR	-	15 046 124	15 535 609	15 822 374	16 229 340	16 624 945	17 194 985	17 513 916	17 835 578	18 449 787	18 914 223	19 254 127	19 868 402
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	9 414 550	9 720 704	9 900 012	10 154 527	10 401 931	10 758 472	10 957 897	11 159 028	11 543 192	11 833 646	12 046 185	12 430 378
$O\&M_{fixed}$	-	4 895 943	5 055 217	5 148 526	5 280 948	5 409 674	5 595 159	5 698 935	5 803 599	6 003 456	6 154 579	6 265 179	6 465 057
$O\&M_{variable}$	-	4 518 607	4 665 487	4 751 486	4 873 579	4 992 258	5 163 313	5 258 962	5 355 430	5 539 736	5 679 068	5 781 006	5 965 321
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 428 463	2 489 174	2 551 403	2 615 189	2 680 568	2 747 582	2 816 272	2 886 679	2 958 846	3 032 817	3 108 637	3 186 353
(=) Profit before tax	-	8 923 305	9 188 929	9 380 737	9 619 647	9 856 469	10 160 805	10 373 418	10 589 383	10 917 249	11 191 497	11 421 636	11 757 060
(-) Revenue tax	-	4 513 837	4 660 683	4 746 712	4 868 802	4 987 484	5 158 496	5 254 175	5 350 673	5 534 936	5 674 267	5 776 238	5 960 521
(+) REPIM	995 107	691	713	727	745	764	790	804	819	847	869	884	912
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	995 107	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	691	713	727	745	764	790	804	819	847	869	884	912
(=) Profit after tax w/out interest	-	4 410 159	4 528 960	4 634 751	4 751 590	4 869 749	5 003 099	5 120 048	5 239 529	5 383 160	5 518 099	5 646 282	5 797 452
(-) Debt payments	-	-	3 143 328	3 221 911	3 302 459	3 385 021	3 469 646	3 556 387	3 645 297	3 736 429	3 829 840	3 925 586	4 023 726
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 428 463	2 489 174	2 551 403	2 615 189	2 680 568	2 747 582	2 816 272	2 886 679	2 958 846	3 032 817	3 108 637	3 186 353
(=) Free net cashflow	-59 230 794	9 460 360	6 562 088	6 718 708	6 887 646	7 059 206	7 247 292	7 420 346	7 597 334	7 799 911	7 995 269	8 185 381	8 400 028
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 770 434	-43 208 345	-36 489 638	-29 601 992	-22 542 786	-15 295 494	-7 875 149	-277 814	7 522 096	15 517 365	23 702 746	32 102 774
$LCOE_{wso}$		*73.13*	*73.52*	*73.79*	*74.13*	*74.47*	*74.93*	*75.23*	*75.53*	*76.02*	*76.41*	*76.73*	*77.23*

Years 13–25:

Item	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	90 530 336	90 473 134	90 246 888	90 078 677	90 557 464	90 666 434	90 855 213	90 985 978	90 162 393	90 643 598	90 743 354	90 059 500	89 670 577
(+) AAR ($M/yr)	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
PPAR	20 330 295	20 825 386	21 292 641	21 784 277	22 447 567	23 036 443	23 661 518	24 287 963	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	17 268 871	17 795 063	18 260 013	18 575 463	18 957 626
(-) $O\&M_{WFCM}$	12 719 232	13 028 853	13 321 057	13 628 511	14 043 351	14 411 633	14 802 558	15 194 336	13 212 815	13 615 294	13 970 912	14 212 144	14 504 416
$O\&M_{fixed}$	6 615 352	6 776 449	6 928 488	7 088 460	7 304 288	7 495 901	7 699 294	7 903 132	8 027 381	8 271 977	8 488 105	8 634 738	8 812 382
$O\&M_{variable}$	6 103 880	6 252 405	6 392 569	6 540 051	6 739 063	6 915 732	7 103 264	7 291 205	5 185 434	5 343 317	5 482 807	5 577 406	5 692 034
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 266 012	3 347 662	3 431 354	3 517 138	3 605 066	3 695 193	3 787 573	3 882 262	3 979 319	4 078 802	4 180 772	4 285 291	4 392 423
(=) Profit before tax	12 038 075	12 334 220	12 622 714	11 672 904	12 009 282	12 320 003	12 646 533	12 975 888	8 035 375	8 258 571	8 469 873	8 648 610	8 845 633
(-) Revenue tax	6 099 089	6 247 616	6 387 792	6 535 283	6 734 270	6 910 933	7 098 455	7 286 389	5 180 661	5 338 519	5 478 004	5 572 639	5 687 288
(+) REPIM	934	956	978	1 000	1 031	1 058	1 087	1 115	1 133	1 167	1 198	1 219	1 244
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	934	956	978	1 000	1 031	1 058	1 087	1 115	1 133	1 167	1 198	1 219	1 244
(=) Profit after tax w/out interest	5 939 920	6 087 561	6 235 899	5 138 621	5 276 043	5 410 128	5 549 164	5 690 615	2 855 846	2 921 219	2 993 067	3 077 190	3 159 589
(-) Debt payments	4 124 319	4 227 427	4 333 113	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 266 012	3 347 662	3 431 354	3 517 138	3 605 066	3 695 193	3 787 573	3 882 262	3 979 319	4 078 802	4 180 772	4 285 291	4 392 423
(=) Free net cashflow	8 607 561	8 821 892	9 038 589	12 452 818	12 773 095	13 094 606	13 425 755	13 764 120	11 131 189	11 403 446	11 687 349	11 988 829	12 294 019
$\Sigma_{free\ net\ annual\ cashflow}$	40 710 335	49 532 227	58 570 816	71 023 635	83 796 730	96 891 337	110 317 091	124 081 212	135 212 401	146 615 847	158 303 196	170 292 025	182 586 044
$LCOE_{wso}$	*77.63*	*78.06*	*78.47*	*77.65*	*78.16*	*78.63*	*79.12*	*79.61*	*77.73*	*78.24*	*78.71*	*79.06*	*79.47*

Table U.10 Cashflow for 25 years of the wind farm project 50 000 kW Cape Saint James (Canada) with sensitivity analysis of $O\&M_{manag(B)} + E_{pi}$ *(Case 3)*

Years 0–12:

Item	0	1	2	3	4	5	6	7	8	9	10	11	12
(-) $LCCCM_{WF}$	60 225 901	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	27 686 278	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	24 219 295	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	1 959 783	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	1 545 346	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	572 832	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	2 136 726	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	1 796 870	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	188 559	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	120 211	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	-	212 943 465	213 677 678	214 362 116	212 699 281	213 130 306	213 677 678	212 699 281	212 699 281	214 362 116	213 130 306	213 677 678	213 240 500
(+) AAR ($M/yr)	-	30 196 663	31 058 298	31 936 726	32 481 214	33 360 711	34 282 550	34 978 715	35 853 182	37 036 811	37 744 583	38 787 558	39 675 905
PPAR	-	30 196 663	31 058 298	31 936 726	32 481 214	33 360 711	34 282 550	34 978 715	35 853 182	37 036 811	37 744 583	38 787 558	39 675 905
EMP	-	-	-	-	-	-	-	-	-	-	-	-	-
(-) $O\&M_{WFCM}$	-	20 633 860	21 222 504	21 822 620	22 194 549	22 795 389	23 425 157	23 900 721	24 498 115	25 306 751	25 790 238	26 502 761	27 109 626
$O\&M_{fixed}$	-	11 570 156	11 900 294	12 236 866	12 445 485	12 782 467	13 135 671	13 402 407	13 737 461	14 190 972	14 462 154	14 861 773	15 202 144
$O\&M_{variable}$	-	9 063 703	9 322 210	9 585 754	9 749 063	10 012 922	10 289 486	10 498 314	10 760 654	11 115 779	11 328 084	11 640 988	11 907 483
(+) LRCM	-	863 268	884 850	906 971	929 646	952 887	976 709	1 001 127	1 026 155	1 051 809	1 078 104	1 105 057	1 132 683
(+) Depreciation		2 383 876	2 443 473	2 504 560	2 567 174	2 631 353	2 697 137	2 764 565	2 833 679	2 904 521	2 977 134	3 051 563	3 127 852
(=) Profit before tax	-	12 809 947	13 164 117	13 525 637	13 783 484	14 149 562	14 531 238	14 843 686	15 214 902	15 686 390	16 009 583	16 441 417	16 826 813
(-) Revenue tax	-	9 058 999	9 317 489	9 581 018	9 744 364	10 008 213	10 284 765	10 493 614	10 755 955	11 111 043	11 323 375	11 636 267	11 902 772
(+) REPIM	2 082 583	3 015	3 101	3 188	3 243	3 331	3 423	3 492	3 579	3 698	3 768	3 872	3 961
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	2 082 583	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	-	3 015	3 101	3 188	3 243	3 331	3 423	3 492	3 579	3 698	3 768	3 872	3 961
(=) Profit after tax w/out interest	-	3 753 963	3 849 728	3 947 808	4 042 363	4 144 679	4 249 896	4 353 564	4 462 527	4 579 044	4 689 977	4 809 021	4 928 003
(-) Debt payments	-	-	3 085 617	3 162 757	3 241 826	3 322 872	3 405 943	3 491 092	3 578 369	3 667 829	3 759 524	3 853 512	3 949 850
(+) RCM_{WF}	-	2 621 739	2 687 282	2 754 464	2 823 326	2 893 909	2 966 257	3 040 413	3 116 424	3 194 334	3 274 193	3 356 047	3 439 949
(+) Depreciation		2 383 876	2 443 473	2 504 560	2 567 174	2 631 353	2 697 137	2 764 565	2 833 679	2 904 521	2 977 134	3 051 563	3 127 852
(=) Free net cashflow	-58 143 317	8 759 578	5 894 866	6 044 075	6 191 037	6 347 070	6 507 346	6 667 450	6 834 260	7 010 071	7 181 779	7 363 119	7 545 953
$\Sigma_{free\ net\ annual\ cashflow}$	-	-49 383 739	-43 488 873	-37 444 798	-31 253 761	-24 906 692	-18 399 345	-11 731 895	-4 897 634	2 112 437	9 294 216	16 657 336	24 203 289
$LCOE_{wso}$		*84.34*	*85.02*	*85.71*	*86.17*	*86.87*	*87.59*	*88.17*	*88.87*	*89.78*	*90.37*	*91.19*	*91.91*

Years 13–25:

Item	13	14	15	16	17	18	19	20	21	22	23	24	25
(-) $LCCCM_{WF}$	-	-	-	-	-	-	-	-	-	-	-	-	-
WT_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
T_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LWTG_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
CP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
TS_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
SI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
PO_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
F_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
CCC_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$LCPM_{WF}$ (kWh/yr)	212 699 281	214 433 451	213 913 741	214 433 451	214 152 844	214 362 116	214 433 451	213 565 675	213 706 617	212 699 281	214 004 745	213 240 500	213 962 451
(+) AAR ($M/yr)	40 564 585	41 917 697	42 861 506	44 039 781	45 081 704	46 253 902	47 426 027	48 414 954	34 760 655	35 461 726	36 571 360	37 351 777	38 415 192
PPAR	40 564 585	41 917 697	42 861 506	44 039 781	45 081 704	46 253 902	47 426 027	48 414 954	-	-	-	-	-
EMP	-	-	-	-	-	-	-	-	34 760 655	35 461 726	36 571 360	37 351 777	38 415 192
(-) $O\&M_{WFCM}$	27 716 717	28 641 138	29 285 891	30 090 843	30 802 628	31 603 422	32 404 162	33 079 730	29 459 748	30 053 783	30 994 073	31 655 349	32 556 460
$O\&M_{fixed}$	15 542 642	16 061 091	16 422 713	16 874 171	17 273 385	17 722 515	18 171 617	18 550 525	19 026 830	19 410 567	20 017 937	20 445 105	21 027 176
$O\&M_{variable}$	12 174 075	12 580 047	12 863 178	13 216 672	13 529 243	13 880 907	14 232 546	14 529 205	10 432 918	10 643 217	10 976 136	11 210 244	11 529 285
(+) LRCM	1 161 000	1 190 025	1 219 776	-	-	-	-	-	-	-	-	-	-
(+) Depreciation	3 206 048	3 286 199	3 368 354	3 452 563	3 538 877	3 627 349	3 718 033	3 810 984	3 906 258	4 003 915	4 104 013	4 206 613	4 311 778
(=) Profit before tax	17 214 916	17 752 784	18 163 746	17 401 501	17 817 953	18 277 830	18 739 898	19 146 209	9 207 165	9 411 857	9 681 300	9 903 041	10 170 510
(-) Revenue tax	12 169 376	12 575 309	12 858 452	13 211 934	13 524 511	13 876 171	14 227 808	14 524 486	10 428 196	10 638 518	10 971 408	11 205 533	11 524 558
(+) REPIM	4 050	4 185	4 279	4 397	4 501	4 618	4 735	4 834	4 958	5 058	5 216	5 327	5 479
REI_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
REP_{CM}	-	-	-	-	-	-	-	-	-	-	-	-	-
$OREP_{CM}$	-	-	-	-	-	-	-	-	-	-	-	-	-
$GHG.R_{CM}$	4 050	4 185	4 279	4 397	4 501	4 618	4 735	4 834	4 958	5 058	5 216	5 327	5 479
(=) Profit after tax w/out interest	5 049 591	5 181 659	5 309 573	4 193 964	4 297 943	4 406 277	4 516 824	4 626 556	-1 216 073	-1 221 603	-1 284 892	-1 297 165	-1 348 569
(-) Debt payments	4 048 596	4 149 811	4 253 557	-	-	-	-	-	-	-	-	-	-
(+) RCM_{WF}	3 525 947	3 614 096	3 704 448	3 797 060	3 891 986	3 989 286	4 089 018	4 191 243	4 296 024	4 403 425	4 513 511	4 626 348	4 742 007
(+) Depreciation	3 206 048	3 286 199	3 368 354	3 452 563	3 538 877	3 627 349	3 718 033	3 810 984	3 906 258	4 003 915	4 104 013	4 206 613	4 311 778
(=) Free net cashflow	7 732 990	7 932 143	8 128 819	11 443 586	11 728 806	12 022 912	12 323 875	12 628 783	6 986 209	7 185 737	7 332 631	7 535 797	7 705 217
$\Sigma_{free\ net\ annual\ cashflow}$	31 936 278	39 868 422	47 997 241	59 440 827	71 169 633	83 192 545	95 516 420	108 145 203	115 131 412	122 317 149	129 649 780	137 185 577	144 890 793
$LCOE_{wso}$	*92.63*	*93.67*	*94.44*	*94.11*	*94.92*	*95.82*	*96.72*	*97.50*	*93.98*	*94.68*	*95.73*	*96.51*	*97.52*

APPENDIX V

Table V.1 Relation v_{wc} and $LCOE_{wso}$

Variables	Aracati (Brazil)	Corvo Island (Portugal)	Cape Saint James (Canada)
$LCOE_{wso}$	*69.6991*	*76.8666*	*91.8264*
v_{wc} *(m/s)*	*7.4*	*9.1*	*12.5*

Source: Own elaboration. Note: Correlation Coeff.= *0.9996*

Variations:	*24.2%*	*36.4%*
	10.3%	*19.5%*

Table V.2 Impact of O&M programs on $LCOE_{wso}$

	Aracati (Brazil)	Corvo Island (Portugal)	Cape Saint James (Canada)
$O\&M_{manag(STD)}$	*69.6792*	*76.8138*	*91.7081*
$O\&M_{manag(A)}$	*69.6991*	*76.8666*	*91.8264*
$O\&M_{managb(B)}$	*69.6873*	*76.8666*	*91.7691*

Source: Own elaboration

Variations:	0.03%	0.07%	0.13%
	0.01%	0.07%	0.07%

Table V.3 Impact of O&M programs on *wind farm availability*

O&M programs	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
$O\&M_{managing(STD)}$	*0.9793*	*0.9793*	*0.9793*
$O\&M_{managing(A)}$	*0.9836*	*0.9836*	*0.9836*
$O\&M_{managing(B)}$	*0.9817*	*0.9836*	*0.9817*

Source: Own elaboration

	0.44%	0.44%	0.44%
Variations:	0.24%	0.44%	0.24%

Table V.4 Impact of L_{wt} on $LCOE_{wso}$

Layouts (L_{wt})	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
5D4D	*69.6792*	*76.8138*	*91.7081*
5D7D	*69.8318*	*76.9663*	*91.8606*
5D10D	*69.9843*	*77.1188*	*92.0131*
6D12D	*70.3401*	*77.4747*	*92.3690*

Source: Own elaboration

Variations:	0.22% 0.44% 0.95%	0.20% 0.40% 0.86%	0.17% 0.33% 0.72%

Table V.5 Impact of E_{pi} on $LCCCM_{WF}$

	Item	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
$LCCCM_{WF}$	*Base-case*	*1 196.8218*	*1 194.7880*	*1 185.8714*
	Case $_1$	*1 182.0575*	*1 178.8311*	*1 164.6862*
	Case $_2$	*1 199.1041*	*1 195.9638*	*1 183.2312*
	Case $_3$	*1 193.6800*	*1 184.6289*	*1 162.8596*

Source: Own elaboration

Variations:	*-1.23%* *0.19%* *-0.26%*	*-1.34%* *0.10%* *-0.85%*	*-1.79%* *-0.22%* *-1.94%*

Table V.6 Impact of L_{wt} on $LCCCM_{WF}$

	Variables	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
$LCCCM_{WF}$	*5D4D*	*1 204.5180*	*1 204.5180*	*1 204.5180*
	5D7D	*1 207.5681*	*1 207.5681*	*1 207.5681*
	5D10D	*1 210.6183*	*1 210.6183*	*1 210.6183*
	6D12D	*1 217.7353*	*1 217.7353*	*1 217.7353*

Source: Own elaboration

Variations:	0.25% 0.51% 1.10%	0.25% 0.51% 1.10%	0.25% 0.51% 1.10%

Table V.7 Relation among $LCOE_{wso}$, $O\&M_{MANAG(A)}$ and E_{pi}

	Item	Aracati (Brazil)	Corvo Island (Portugal)	Cape Saint James (Canada)
		$O\&M_{manag(A)}$		
$LCOE_{wso}$	*Reference*	*69.6792*	*76.8138*	*91.7081*
	Case $_1$	*69.6991*	*76.8666*	*91.8264*
	Case $_2$	*69.6991*	*76.8666*	*91.8264*
	Case $_3$	*69.6991*	*76.8666*	*91.8264*

Source: Own elaboration

	0.03%	0.07%	0.13%
Variations:	0.03%	0.07%	0.13%
	0.03%	0.07%	0.13%

Table V.8 Relation among $LCOE_{wso}$, $O\&M_{MANAG(B)}$ and E_{pi}

	Item	Aracati (Brazil)	Corvo Island (Portugal)	Cape Saint James (Canada)
		$O\&M_{manag(B)}$		
$LCOE_{wso}$	*Reference*	*69.6792*	*76.8138*	*91.7081*
	Case $_1$	*69.6873*	*76.8666*	*91.7691*
	Case $_2$	*69.6873*	*76.8666*	*91.7691*
	Case $_3$	*69.6873*	*76.8666*	*91.7691*

Source: Own elaboration

	0.01%	0.07%	0.07%
Variations:	0.01%	0.07%	0.07%
	0.01%	0.07%	0.07%

Table V.9 Impact of E_{pi} on $LCOE_{wso}$

	Item	Aracati (Brazil)	Corvo Island (Portugal)	Cape Saint James (Canada)
$LCOE_{wso}$	*Base-case*	*69.6792*	*76.8138*	*91.7081*
	Case $_1$	*69.6792*	*76.8138*	*91.7081*
	Case $_2$	*76.8138*	*76.8138*	*91.7081*
	Case $_3$	*69.6792*	*76.8138*	*91.7081*

Source: Own elaboration

0.00%	0.00%	0.00%
10.24%	0.00%	0.00%
0.00%	0.00%	0.00%

Table V.10 Relation between $LCCCM_{WF}$ and $LCOE_{wso}$

Items	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
$LCCCM_{WF}$	*1 204.52*	*1 204.52*	*1 204.52*
$LCOE_{wso}$	*69.68*	*76.81*	*91.71*

Source: Own elaboration

Table V.11 Relation between v_{wc} and L_{wt}

Variables	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
v_{wc} *(m/s)*	*7.4*	*9.1*	*12.5*
5D7D	*69.8318*	*76.9663*	*91.8606*
5D10D	*69.9843*	*77.1188*	*92.0131*
6D12D	*70.3401*	*77.4747*	*92.3690*

Source: Own elaboration

Table V.12 Percentual variations of v_{wc}, L_{wt}, $O\&M_{manag}$ and E_{pi}

Variables	*Aracati (Brazil)*	*Corvo Island (Portugal)*	*Cape Saint James (Canada)*
Simple variable	*7.4 m/s*	*9.1m/s*	*12.5m/s*
v_{wc}	*100.00%*	*100.00%*	*100.00%*
L_{wt}			
5D7D	*0.00%*	*0.00%*	*0.00%*
5D10D	*0.00%*	*0.00%*	*0.00%*
6D12D	*0.00%*	*0.00%*	*0.00%*
$O\&M_{manag}$			
$O\&M_{manag(A)}$	*0.45%*	*0.43%*	*0.44%*
$O\&M_{manag(B)}$	*0.24%*	*0.43%*	*0.23%*
Epi			
Case 1	*0.00%*	*0.00%*	*0.00%*
Case 2	*0.00%*	*0.00%*	*0.00%*
Case 3	*0.00%*	*0.00%*	*0.00%*
Multiples variables			
$O\&M_{manag(A)}$+ Case $_1$	*0.45%*	*0.43%*	*0.44%*
$O\&M_{manag(A)}$+ Case $_2$	*0.45%*	*0.43%*	*0.44%*
$O\&M_{manag(A)}$+ Case $_3$	*0.45%*	*0.43%*	*0.44%*
$O\&M_{manag(B)}$+ Case $_1$	*0.24%*	*0.43%*	*0.23%*
$O\&M_{manag(B)}$+ Case $_2$	*0.24%*	*0.43%*	*0.23%*
$O\&M_{manag(B)}$+ Case $_3$	*0.24%*	*0.43%*	*0.23%*

Source: Own elaboration