Universidade de Aveiro Departamento de Ambiente e Ordenamento

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Martha Demertzi

Environmental Product Declaration – a study of construction materials

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Dissertation submitted to the University of Aveiro to meet the requirements for the degree of Master in Environmental Studies, held under the scientific supervision of Doctor Victor Miguel Carneiro de Sousa Ferreira, Professor at the Department of Civil Engineering in Universidade de Aveiro (UA), co-supervision of Ana Cláudia Dias, Post-doctoral fellow at he Department of Environment and Planning in Universidade de Aveiro (UA) and co-supervision of Jordi Oliver i Solà, Post-doctoral associated researcher at the Department of Environment (ICTA) in Universitat Autònoma de Barcelona (UAB).

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Abstract

Nowadays, the protection of the environment is getting more and more important both for the manufacturers and the consumers. There is a strong awareness in terms of environmental issues, discussions on this subject, questions about the role of citizens in this context and a turn towards a more aware way of consumption and a preference to environmental friendly products manufactured and marketed.

This means that purchasing decisions have to be influenced by increasing environmental awareness and sustainable consumption by consumers. That also encourages companies to adopt an environmental orientation in their business strategies.

As part of this growing environmental awareness, there is the need for clarification of concepts and the establishment of objective criteria, data collection, calculation methodology and objectives to justify the choice of materials used in the construction sector in order to optimize and to increase the sense of responsibility.

The first part of the thesis presents and explains several concepts, methodologies and regulations that historically evolved and led to the present documents needed for the proof of the environmental impact of a product. These documents are called Environmental Product Declarations (EPDs). In this work is highlighted the importance of the EPDs, the standardization of criteria, the whole process of organization of an EPD to the stage of evaluation and publication and indicates all regulatory framework.

After the explanation of the basic concepts, a case study on ceramic tiles is presented. In this part, the objective is to analyze the information that EPDs provide, how the values they provide can be read, the differences in the procedures used and finally the way that EPDs could help the construction industry. For this purpose, two official EPDs from different EPD systems (Catalonia and Germany) and one Portuguese study (unofficial EPD) are analyzed.

At the end of this work it is concluded that EPDs are an essential tool of a product's environmental information, which comes in response to environmental demands that the market gradually has imposed. Each organization must comply with regulatory procedures and establish procedures for the manufacturing of a product and its whole life cycle that are responsible and environmental friendly.

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1. INTRODUCTION

1.1. Preface

Nowadays, it is noticed an increased environmental awareness and consciousness that will hopefully influence not only the producers but also the consumers being more careful and responsible while choosing the products to be used. This choice should be made based on their evaluation for different criteria, such as quality, durability, environmental impact, etc.

As it will be presented in the continuation, the building construction process not only consumes the most energy of all sectors and creates the most carbon dioxide (CO_2) emissions, but also creates the most waste, uses the most non-energy related resources and is responsible for the most environmental pollution **[1]**. Because of that there should be given great attention to the materials used for this purpose. As part of a global environmental awareness, there is a need for the establishment of objective criteria and data for the selection of building materials in order to optimize the construction sustainability.

Indeed, there has been an increase of European regulation that addresses the sustainability of construction materials such as the new European Construction Products Regulation (305/2011/EU - CPR), approved in 2011, replacing the Construction Products Directive (89/106/EEC - CPD) is laying down harmonized conditions for the marketing of construction products **[2]**. In that sense the measure of the environmental impact of these products stands as an important issue where life cycle assessment (LCA) is an objective important tool. A new European standard (EN 15804:2012) has also been launched that is concerned with this matter, the buildup of Environmental Products Declaration (EPD), specifically for construction products. The overall goal of an EPD is to provide relevant, verified and comparable information about the environmental impact and can become an important tool to assess a material or product sustainability.

1.2. Objectives

This thesis will focus on the environmental impact of construction materials looking into the buildup, advantages and limitations of an EPD through the use of a case study on ceramic tiles. Two official EPD documents from different EPD systems (Catalonia and Germany) and one Portuguese study (unofficial EPD) will be analyzed.

The main objective is the explanation of EPDs and their importance, the information they provide, the way to evaluate it and compare it to others. Through the comparison it will be possible to understand the whole procedure followed for the manufacturing of the same product in different cases and see what is the most efficient and less harmful.

1.3. Motivation

The reason why this work will focus on the construction industry is due to the fact that this is one of the largest and most important industries and in the same time this is a sector with great environmental impact. Because of that, there is no time to wait until the goals of sustainable development have been identified and until the tools to achieve those goals have been proved practically.

The aim of this work is to raise environmental awareness to the risks that come from the construction sector and present ways to protect the environment by agents involved in the construction area. Having been mainly developed by the agents involved, the EPDs now constitute an efficient and effective tool, based on objective criteria, which is an encouraging recognition and use of this type of documentation.

1.4. Thesis outline

The first five sections of the thesis belong to a more theoretical part and the last one presents the case study. Each one of these sections has its own role and significance for the understanding of EPDs and also the case study in which will be presented and compared different EPDs of ceramic tiles in different systems existing in European Union (EU).

Section 1 is introductory and explains the general background of the chosen topic and the reasons why it was selected, the main objectives of this work and its structure. Section 2 focuses on the sustainability in construction and explains the background of this concept and also of sustainable development and construction and finally it mentions the EU measures taken for the promotion of this concept. Section 3 moves on to eco-labelling and presents its historical evolution, explains the basic definitions and objectives linked to it and clarifies its importance in markets. In Section 4, the main focus is the LCA and is presented its whole historical evolution, its concept and finally its main principles and the whole methodology. In the final theoretical section and after explaining some important definitions on which EPDs are based, in Section 5 are finally presented the EPDs, their concept, how they are made and why, where and how they can be used and the regulatory framework to which they obey.

Once all the theoretical concepts and definitions are clarified, follows the Section 6 that presents the case study. Throughout this section, different cases of EPDs for the same product (ceramic tiles) are presented and explained so that it can be seen if different systems will have different results and why for the same product.

At the end of this work, in Section 7, it is summarized the whole work, the main conclusions and suggestions for continuation of this topic.

2. SUSTAINABILITY IN CONSTRUCTION

2.1. Background

The sustainability of the energy sources used for different purposes has been gaining a lot of attention because of the climate change debate, where is believed that emissions from fossil fuel based industries are basically responsible for the greenhouse effect, which has as a result a change in the global weather pattern. Because of that, many industries including the building industry have started adopting energy efficiency measures in order to try and control the resources used. The greatest consumer of energy worldwide is the building industry and because of that any measures taken in this sector to improve energy efficiency in buildings will have a desirable effect in the environmental impact of the materials used and in the reduction of carbon emissions into air **[3]**.

According to the European Commission, 44% of the total energy consumed in the EU is used in industrial, domestic or tertiary buildings (*Figure 1*) **[4]**.

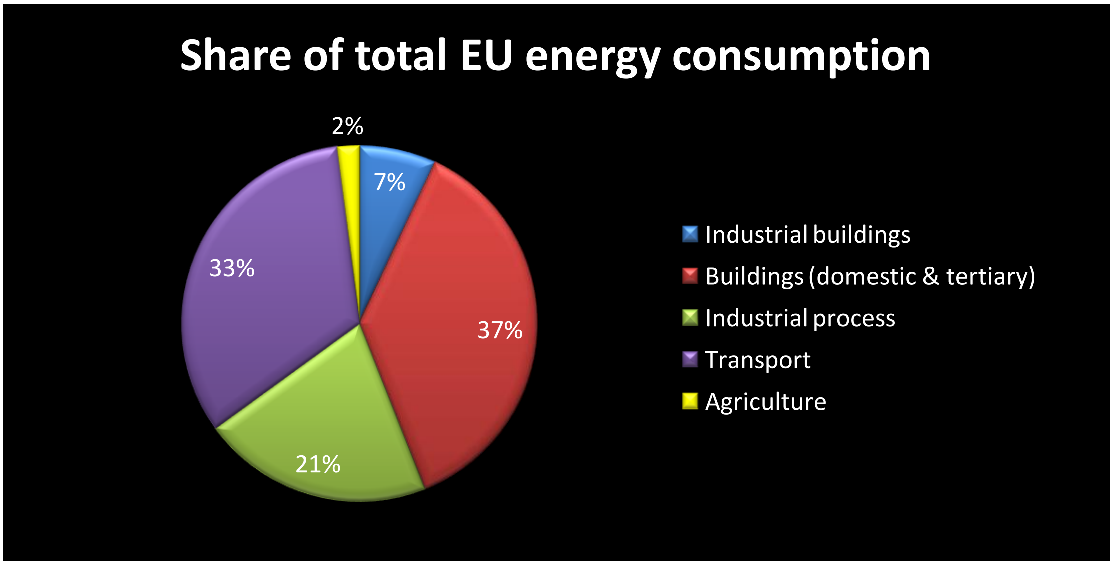

Figure 1: Share of total EU energy consumption ***[4]***

By trying to make new and existing buildings more energy efficient can therefore make a significant contribution to reducing CO_2 emissions and in the same time conserve valuable energy resources. It is a fact that a great number of buildings occupied today were constructed during a period when energy efficiency was not such a major concern. This has as a result great amounts of energy to be used for heating, cooling and lighting. In Europe, the existing buildings are replaced at a low rate (about 1% per year) and because of that a greater emphasis through policies should be given on the existing building stock. Nowadays, the technology and know-how to reduce energy consumption from buildings already exists. Currently, the legal framework is being adapted and the recast EU Energy Performance of Buildings Directive, if properly implemented in the Member States, will make it mandatory to use energy-efficient, cost-optimal solutions each time a building component is replaced.

2.2. Sustainable development

In general, sustainable development refers to a pattern of growth in which the resources used aim to meet human needs while in the same time preserve the environment so that these needs can be met not only in the present, but also in the future for generations to come **[5]**. The concept of sustainable development brings together the concern for the carrying capacity of natural systems and the social challenges facing humanity. It can be conceptually broken into three different parts: environmental sustainability, economic sustainability and sociopolitical sustainability (*Figure 2*) and these parts could be considered as the pillars of the sustainable development **[6]**.

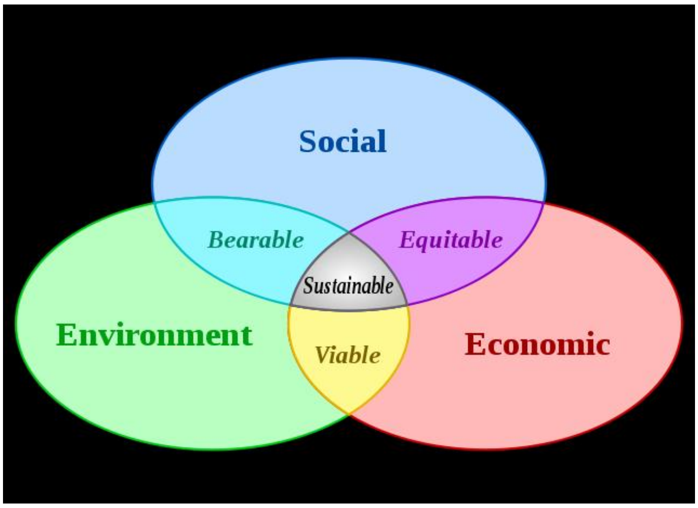

*Figure 2: Scheme of sustainable development at the confluence of three constituent parts **[7]***

The first time that the definition of sustainable development was widely introduced, was at the Brundtland Report (or Our Common Future), that was published in 1987 from the United Nations World Commission on Environment and Development (WCED) **[8]**. The main targets were multilateralism and also interdependence of nations in the search of a sustainable development path. In that report was included what is now a very widely recognized definition:

'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

This definition contains within it two basic concepts:

- The concept of 'needs', particularly the needs of the world's poor, to which should be given priority.
- The idea of limitations imposed by the technological state and the social organization on the environment's ability meeting present and future needs

The attention on sustainability peaked worldwide at the United Nations (UN) 'Conference on Environment and Development', in Rio de Janeiro in 1992. This Conference was the largest-ever meeting of world leaders since brought together 179 governments. It resulted in the following documents **[9]**:

- *Rio Declaration on Environment and Development*: consisted of 27 principles that intended to guide future sustainable development around the world.
- *Agenda 21*: a blueprint of action to be taken globally, nationally and locally by organizations, governments and major groups of the UN in every area where humans directly affect the environment.
- *Forest Principles*: a document (non-legally binding) with several recommendations for forestry.

Moreover, two important legally binding agreements were opened for signature:

- *Convention on Biological Diversity*: having as objective the development of national strategies for the conservation and sustainable use of biological diversity.
- *Framework Convention on Climate Change (UNFCCC)*: having as objective the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

At European level, in 1997 the Amsterdam Treaty pointed out sustainable development as a central item of European policy. Later at the Gothenburg Summit in June 2001, European Union leaders started the first EU strategy for sustainable development based on a proposal from the European Commission. This strategy had two main parts **[10]**:

In the first one were proposed objectives and policy measures to resolve a number of important unsustainable trends and the second one focused on new approach to policy-making that ensured that the EU's environmental, economic and social policies mutually reinforced each other. Basically, the Gothenburg declaration formed the basis of the EU's policies towards sustainable development.

The 6th European Environment Action Program (6EAP) established the environmental objectives for the years 2001 to 2010 and the action to be taken in order to achieve them (Decision 1600/2002). The 6EAP had four priority issues **[11]**:

1. Climate change
2. Nature and biodiversity.
3. Environment and health.
4. Sustainable management of natural resources

2.3. Sustainable construction

Issues like sustainable construction, green building, reduction of carbon footprint and others, have been very important for stakeholders of the construction industry value chain. Sustainable construction, because of the attention given to the environment through efficient ways of reducing carbon footprints, can be considered the future while thinking of posterity and utilization the natural resources, reduction of the greenhouse gas emissions and on-site waste, use of sustainable materials and increase of skills in the workforce **[12]**.
In sustainable construction there are six main principles **[13]**:

1. Minimize resource consumption
2. Maximize resource reuse
3. Use renewable and recyclable resources
4. Protect the natural environment
5. Create a healthy and non-toxic environment
6. Pursue quality in creating the built environment

In order to realize the above mentioned principles of sustainable construction, there are three basic ways in which the construction industry can act:

1. Create a built environment for a better quality of life
2. Restore damaged and/or polluted environments
3. Improve dry environments

Moreover, in order to achieve sustainability in construction there should be given some priorities. More specifically the attention should be given to the following **[14]**:

- Water should be used as a limited resource.

- Resources should be used at the speed at which they are naturally renewed and should be retained at the speed at which can be absorbed by local ecosystems.
- Locations and systems chosen should optimize employee commuting and costumer transportation option and also minimize the use of single-occupancy vehicles. Alternative work modes might include use of telecommuting and teleconferencing.
- Material and energy resources should be understood as part of a balanced nature/human cycle. Waste must occur to the extent that is incorporated back into the cycle and can be used for the generation of more resources.
- Operation and maintenance systems must support waste reduction and recycling.
- Site planning should use resources naturally available on the site i.e. natural shading and drainage, solar and wind energy.
- The design should help maximizing occupant's health and productivity.
- Resource efficient materials have to be used in the construction of the building and also in the furnishing in order to lessen the impact locally as well as globally.
- Material and design strategies should aim the production of excellent total indoor environmental quality especially of indoor air quality.
- Both energy and material waste have to be minimized throughout the building's life cycle (from design through reuse or demolition).
- The building's shell should be designed aiming energy efficiency

2.4. Measures in EU

As it was mentioned previously (Section 2.2.), EU has sustainability as a central item of policy and it was briefly presented the historical evolution of this focus. In this section are presented more specifically the measures taken by EU concerning a) buildings, b) the life cycle approach concerning environmental issues and c) the construction products.

a) _Legislative framework on buildings_ **[15]** *:*

- Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.
- Directive 2005/32/EC of the European Parliament and the Council of 6 July 2005 establishing a framework for the development of specifications for the design of environmentally friendly products that consume energy (EuP).
- COM 2008 311 final – Proposal for a Regulation of the European Parliament and of the Council. Laying down harmonized conditions for the marketing of the construction products (Construction Product Regulation, CPR).

- Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

b) *Legislative framework and the life cycle approach on environmental issues* **[16]:**

- SEC (2007) 1729 - Action Plan of the Lead Market Initiative in the Area of Sustainable Construction.
- COM (2008) 397 final - Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan (SCP).
- Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives – Waste Framework Directive.
- COM (2008) 400 - Public Procurement For A Better Environment (GPP)
- Regulation (EC) No 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Eco-label.
- CEN TC/350 – Sustainability of construction works.
- CEN TC/351 – Construction products – assessment of the release of dangerous substances

c) *Legislative framework on construction materials* **[17]:**

- Construction Products Regulation, CPR 305/2011/EU. This regulation wants to ensure reliable information on construction products in relation to their performances. This is achieved by providing a 'common technical language' (to be used by manufacturers, the authorities of Member States and their users) offering uniform assessment methods of the performance of construction products. Moreover, it intends to bring clarification of the basic concepts, simplification of the procedures, so as to reduce the costs incurred by enterprises and finally increased credibility for the whole system.
- BS EN 15804:2012 Sustainability of construction works, environmental product declarations, core rules for the product category of construction products. This standard provides core product category rules for all construction products and services. Moreover, it provides a structure to ensure that all EPDs of construction products, construction services and construction processes are derived, verified and presented in a harmonized way

A more detailed explanation of the EPDs and their regulations will be given in the continuation (Section 5).

2.5. Sustainability assessment

A construction can be seen as sustainable only when all the different sustainability dimensions (environmental, social, economic and cultural) are taken into consideration and are dealt with. Except for the various sustainability issues it is also very important the interaction of a building with its surroundings. The environmental issues share common concerns which generally involve the reduction of emissions, wastes, pollutants and the use of non-renewable materials and water. Some of the goals that can be found in building sustainability assessment methods are the following: use of environmental friendly materials and products, minimization of energy consumed, optimization of site potential, a healthy and comfortable indoor climate quality, preservation of both regional and cultural identity, protection and conservation of water resources, and finally optimization of the operational and maintenance practices.

Sustainability assessment has as a purpose to gather and also report information for decision-making throughout different phases of the construction, design and use of a construction. Using various indicators, the sustainability of a construction can be scored and the relevant phenomena can be identified, valued and analyzed. At the moment two trends can be recognized: firstly the complexity and diversity of different indicators from different operators and secondly, the evolution towards better usability through a common understanding and simplicity **[18]**.

Lists of environmental issues and of relevant indicators have been and are being developed by many different organizations. This kind of indicators can be organized within the pressure-state-response framework into a matrix of indicators (*Table 1*).

Both the development of convenient assessment methods and respective tools could be considered a challenge not only theoretically but also in practice. A very important issue is the one of managing the flows of information and knowledge between the levels of indicator systems. Nowadays, there is a wide range of sustainability assessment tools in the construction market and they are broadly used in EPDs, for example LEED in the United States and BREEAM in the United Kingdom.

A different way to approach sustainable assessment is by using Life-cycle assessment (LCA)-based tools that are developed in order to address the building as whole, for example

EcoEffect (Sweden), Eco-Quantum (Netherlands), ATHENA (Canada), ENVEST (United Kingdom.), BEES (United States), LCA House (Finland) **[19]**.

Table 1: Indicators organized within the pressure-state-response framework **[20]**

Environmental Index	**Pressure Index**	**State Index**	**Response Index**
Climate change	Emissions(GHG)	Concentrations	Energy intensity, environmental measures
Ozone depletion	Emissions (Halocarbon), concentrations	(Chlorine) concentrations, O_3 column	Protocol signature, CFC recovery, fund contribution
Eutrophication	Emissions (N, P Water, soil)	(N, P, BOD) concentrations	Treatment, investment/costs
Acidification	Emissions (SOx, NOx, NH_3)	Deposition, concentrations	Investments, Signed agreements
Toxic contamination	Emissions (POC, heavy metal)	(POC, heavy metal) concentrations	Recovery hazardous waste, investments/ costs
Urban environmental quality	Emissions (VOC, NOx, SOx)	(VOC, NOx, SOx) concentrations	Expenditures, Transport policy
Biodiversity	Land conversion, land fragmentation	Species abundance to virgin area	Protected areas
Waste	Waste generation (municipal, individual, agricultural)	Soil/groundwater quality	Collection rate, recycling, investments/cost
Water resources	Demand/use intensity (municipal, agricultural)	Demand/supply ratio, quality	Expenditures, water pricing, savings policy
Forest resources	Use intensity	Use/sustainable growth ratio	Protected area, forest, sustainable logging
Fish resources	Fish catches	Sustainable stocks	Quotas
Soil degradation	Land use changes	Top soil loss	Rehabilitation/ protection
Oceans/ coastal zones	Emissions, oil spills, depositions	Water quality	Coastal zone management, ocean protection

Even though the majority of the tools are designed to consider a building as a whole (including energy demand, etc.), they are developed based on a bottom-up approach (where a combination of construction materials and components sums up to a building).

Finally, there have also been developed (in research communities) tools supporting decision-making, according to the principles of performance-based design (the focus of all decisions is on demand requirements and on required performance in use) **[21]**.

However, the assessment tools, both environmental and performance-based are under a continuous evolution in order to overcome possible limitations. At the moment, the main goal is to enroot and implement a systematic methodology that will be able to support the design process of a building construction. What is important is this methodology to contribute to the balance between the different sustainability dimensions and in the same time being practical, transparent and flexible enough. Moreover, this method should be easy to adapt to different types of buildings and to the constant development of technology **[18]**.

3. ENVIRONMENTAL LABELLING

3.1. Background

The more grows the interest in the environment, the more grows the demand for information that enables consumers making informed choices. Because of that organizations either directly on products or indirectly by using promotional literature, make environmental claims. However, some companies might provide useful information to the consumers while others make claims that cannot be affirmed. Recently, there have been taken initiatives, to develop labelling schemes that could provide accurate guidance and information. Environmental labelling (or eco-labelling) covers all different types of products and services and is recognized and used in many international countries. In this section of the thesis are going to be presented more definitions, objectives and programs of eco-labelling used globally.

3.2. Eco-labels evolution

World's first eco-labeling program was created in 1977 in Germany, with the name Blue Angel (Blaue Engel) having as a goal the promotion of environmentally friendly products. This label nowadays covers over 4,000 products that have positive environmental features. The mark is entirely voluntary and has increased environmental awareness of both producers and consumers. The criteria for awarding the Blue Angel include: efficient use of fossil fuels, alternative products with less climatic impact, reduction of greenhouse gas emissions and conservation of resources.

In 1992 the European Ecolabel was established. This is a voluntary scheme aiming the encouragement of businesses to market products and services that have lower impact to the environment. The EU Ecolabel covers a wide range of products and services and is a rapidly growing brand with more groups being continuously added. The criteria for awarding the Ecolabel are not based on one single factor but on studies that analyze the impact of the product or service on the environment using its life-cycle, starting from raw material extraction in the pre-production stage, through to production, distribution and disposal **[22].**

By the late 1980s and early 1990s over 15 independent national and multi-national eco-labelling programs were established (*Table 2*).

Table 2: Eco-labelling programs **[23]**.

Country/ Group	Program's Name	Year
Germany	Blue Angel	1977
Canada	Environmental Choice Program	1988
Japan	Eco Mark	1989
Nordic Countries	White Swan	1989
United States	Green Seal	1989
Sweden	Good Environmental Choice	1990
New Zealand	Environmental Choice	1990
India	Ecomark	1991
Austria	Austrian Eco-Label	1991
Republic of Korea	Eco Mark	1992
Singapore	Green Label Singapore	1992
France	NF- Environment	1992
Netherlands	Stichting Milieukeur	1992
European Union	European Flower	1992
Croatia	Environmentally Friendly	1993

Nowadays, most countries, developed and developing, have established eco-labelling programs in many different forms (at local, national, regional and international levels). In the official site of European commission 'Ecolabel Index' is suggested as the largest global director of eco-labels (tracking 431 eco-labels in 246 countries and 26 industry sectors). It provides an extensive list of certified eco-labels from around the world and up to date relevant news and press coverage regarding different eco-labels **[24]**.

3.3. Definitions and objectives

According to the Global Eco-labelling Network (GEN), an eco-label is 'a label which identifies overall environmental preference of a product (such as good or service) within a product category based on life cycle considerations' **[25]**. The products or services with eco-label are expected to cause no, or an acceptable level of, harm to the environment through their production, use, distribution or disposal while other similar products or services without eco-label can pose an unacceptable level of damage to the environment. There is a specific procedure that has to be followed for the development of an eco-label (*Figure 3*) and there are also specific standards describing the whole procedure.

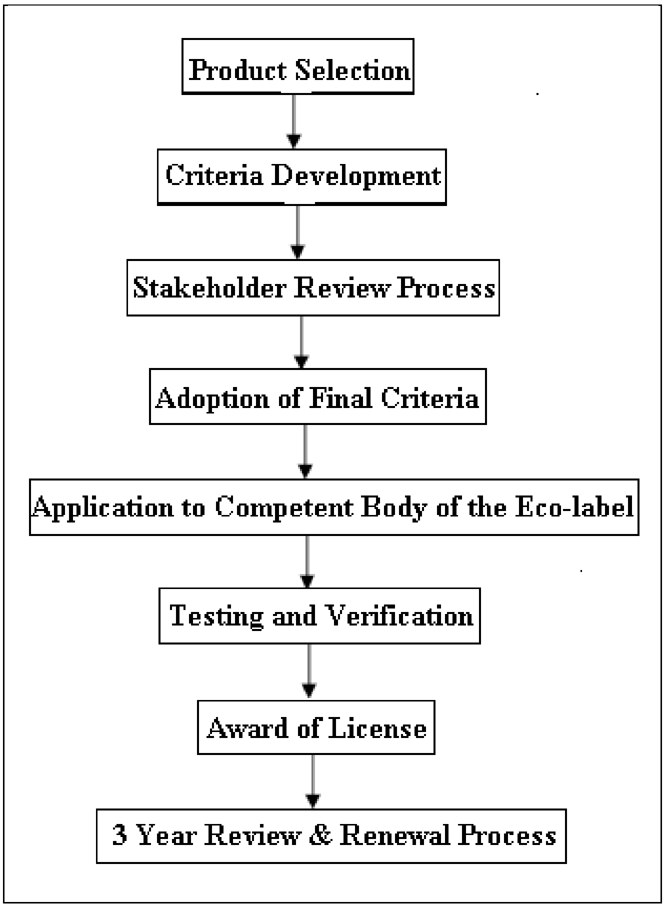

Figure 3: Eco-label development procedure ***[26]*****.**

The ISO 14000 series approaches a range of environmental issues and defines acceptable standards that help to lessen environmental pollution. From these series, more important to mention is the ISO 14020 group that consists of different standards, decided by the International Standards Organization, to specifically rule environmental labelling. The principles of ISO 14020 include assurance, accuracy, life-cycle approach, use of scientific methodology, avoidance of unnecessary trade barriers, participatory and open consultation with any interested parties, posing of minimal administrative burden, allowance of innovation and also supply of information of products **[27]**.

The ISO 14020 group includes the following three labelling schemes:

I. *Type I Environmental labelling- Eco-labelling (ISO 14024, 1999):* presents rules for a voluntary third-party certification system that fulfills specific set up criteria, i.e. scientific methods covering the whole product life. This leads to the use of life-cycle analysis to check the environmental impact of the product **[28].** The application of life-cycle analysis means the compilation and evaluation of the inputs, outputs and the possible environmental impact of the product system during its life cycle **[29]**. It should be mentioned that because of the fact that the development and the definition of the product's criteria are done through a third-party certification process are ensured both the transparency and credibility and are also reduced the efforts of the producers to just convince the consumers of the product's environmental friendliness **[30]**. Type I environmental labelling is the only labelling program that is enforced to employ the services of an eco-labelling body and because of that only this type labels qualify to be called eco-labels **[31]**.

II. *Type II Environmental labelling (ISO 14021, 1999):* is a self-declaration labelling type and environmental claiming system where manufacturers, distributors, importers and other stakeholders can directly claim the environmental friendliness of their products without the certification of a third-party **[28].** ISO 14021 defines the requirements for self-declared environmental claims in regard of the products. Moreover, it describes terms commonly used in environmental claims and qualifies their use. This standard also includes the methodology for general evaluation and verification for self-declared environmental claims **[30].** This kind of claims can be in the form of symbols, graphics or statements on a product's package labels or in other forms, i.e. advertising, technical bulletins and product literature. However, in this case predetermined and accepted criteria are not used and usually only covers single attributes where are defined terms like 'recycled material', 'energy efficient', 'biodegradable' and others **[31].**

III. *Type III Environmental declaration (ISO 14025, 2006):* this standard aims at providing guidance on technical, formatting and administrative issues and also provides quantified environmental data based on independent verification using present indices or predetermined parameters **[32]**. In this respect, a third-party certification agency or an independent body can use a number of environmental performance indicators (such as air emissions, energy consumption, etc.) to achieve an environmental score which can be used as criterion for each product group. This way the consumers are supposed to compare different goods and then choose the one with the highest score. However, there is questioning whether the consumers have enough time and will to go through all these tasks before choosing a product **[33]**. Basically, Type III labels can give a list of the impacts that a product may pose to the environment during its whole life and they could be considered similar to the nutrition labels of food that give information about the sugar, fat and vitamin content. Type III environmental declarations are more convenient in business-to-business communication even though they can be used in the business-to-consumer communication as well **[34].**

Table 3 summarizes some characteristics of each type of labelling scheme:

Table 3: Basic features of eco-label programs ***[26]***

	Eco-label	**Self-declaration claim**	**Environmental product declaration**
Features	Type I ISO 14024:1999	Type II ISO 14021:1999	Type III ISO 14025:2006
Party involved	Third-party, often quasi-government, and second-party initiative of industry association on behalf of members	First-party company initiative	Third-party organization independent of producers, distributors and retailers
Basis	Seal of approval, product specific, life-cycle analysis based	Product or company specific	Single attribute, product and production progress specific, life-cycle analysis based
Criteria	Internal or third-party industry, specific certification based on multiple criteria	Single criteria environmental claims and attributes of product or company performance	Qualified product information based on pre-set categories of parameters set by third-party impartial verification body
Requirement	Voluntary industry standard	Voluntary (marketing tool)	Voluntary or mandatory

3.4. Importance of eco-labelling

Nowadays, voluntary eco-labelling schemes have already become a fact for a wide range of products. However, the degree to which labels have gotten market share depends on the product in question. Moreover, the data concerning the market impact of eco-labelled products is very difficult to access. Likewise, hard data relating to the actual environmental impact of eco-labelling programs are short **[35]**.

Basically, the environmental impact of eco-labelling relies upon the relevance and significance of the criteria and also the market share of the eco-labelled products, which in turn depends on the preferences of the consumers for eco-labelled products and the responsiveness of producers and suppliers **[36]**.

In some cases (i.e. household cleaning products) eco-labels have established a history of promoting the use of more environment-friendly production processes and product characteristics while in the same time have achieved the increase of consumer awareness about environmental issues. Up to now, the results are comparatively more limited in the case of natural resource based products, i.e. organic and forestry products, because eco-labelling schemes apply to small share of production and are still young to provide clear data. However, the label is supplementary to regulatory requirements, so labelling by itself cannot be identified as the primary cause of the high market share **[37]**.

Nevertheless there are strong indicators of the possible benefits to industries that participate in eco-labelling schemes. The real importance of eco-labelling schemes comes not so much from present sales or market share but from the possible future growth. For example, the market for eco-labelled organic products in Europe and North America is expanding more rapidly than supplies and the average prices are significantly higher than for 'non-organic' products. The possible future impact for producers can be great as non-eco-labelled products could start losing real or relative market share **[38]**.

Partially, the industrial interest in eco-labelling comes from economic interests.

Firstly, 'greening' one's images is one of the most important strategies for product differentiation, profit and market share in Organization for Economic Co-operation and Development (OECD) markets. Even though, there is no doubt that there will continue to exist large markets for non-labelled products, eco-labelled products could capture significant shares of the better-priced markets in the future.

Secondly, the awareness of consumers for the environmental impact of the different products might turn the companies to the adoption of eco-labelling schemes. By using eco-labels, the companies can help relieving the concerns among environment-conscious consumers about possible negative environmental impacts of their product choices and also to retain market share and sustain demand of their products in countries where consumers are highly responsive to environmental issues such as Germany, U.K., U.S., and Scandinavian countries **[39].**

In general, the probable benefits for industry from eco-labelling schemes can include: more efficient use of the resources, a common understanding of management practices and outcomes and because of that a reduced friction in international trade (with the assumption that the schemes are accepted internationally), greater market acceptance and improved public relations **[40]**.

4. LIFE-CYCLE ASSESSMENT

4.1. Background

Life-cycle assessment or life-cycle analysis (LCA) is a technique used in order to assess environmental impacts linked to the different stages of a product's life from-cradle-to-grave. Those stages include the raw material extraction through materials processing, distribution, manufacturing, repairing and maintenance, use and also disposal or recycling. LCAs can help avoiding a narrow outlook on environmental concerns by **[41]**:

- Compiling an inventory of relevant energy and material inputs and environmental releases
- Evaluating the potential impacts associated with identified inputs and releases
- Interpreting the results and help making a more informed decision

This section of the thesis presents and explains information about this technique such as the historical evolution, the basic principles and the methodology.

4.2. Historical evolution

The first studies considering the life cycle aspects of products and materials were published during the late sixties and early seventies when concerns over the limitations of raw materials and energy resources gave interest in finding ways to account for energy use and to project future resource supplies and use. The focus of these studies was on issues such as energy efficiency, the consumption of raw materials and to some extent, waste disposal. In the beginning, the use of energy was considered a higher priority than waste and outputs and because of that there was little distinction, at the time, between inventory development (resources going into a product and emissions to the air) and the interpretation of total associated impacts. However, after the oil crisis (1973), energy issues declined in projection. Even though interest in LCA continued, thinking proceeded a bit slower. It was during the mid eighties and early nineties that interest in LCA conquered a wider range of industries, design establishments and retailers **[42]**.

The fast growth of interest in 'cradle-to-grave' assessments of materials and products through the late 1980s and early 1990s had as a result the general belief that LCA methodologies were among the most promising new tools for many different environmental management tasks. The most comprehensive international LCA survey was 'The LCA

Sourcebook', published in 1993. By that time, LCA had gained limited interest. The Sourcebook noted, 'their work escaped from the laboratory and into the real world' **[43]**.

While the field continued to progress, the pace has been sporadic. The basic problem to greater progress in the LCA field was the low level of experience with LCA, combined with very high expectations and over-advertisement. These had as a result a period of disillusionment with LCA, while there was a strong feeling that many were using LCA to support existing positions, rather than to fully understand and respond to the real issues **[44]**.

Around mid-nineties, pressure was growing from a number of environmental organizations to standardize LCA methodology. This finally led to the development of the LCA standards in the International Standards Organization, ISO 14000 series (1997 through 2006). In 2002, the United Nations Environment Program (UNEP) worked with the Society of Environmental Toxicology and Chemistry (SETAC) to launch the Life Cycle Initiative as an international partnership. The Initiative has three programs, aiming to put life cycle thinking into practice and improve the supporting tools through better data and indicators **[45]**:

- *Life Cycle Management (LCM) program*: creates awareness and improves skills of decision-makers by producing information materials, establishing forums for sharing best practice and carrying out training programs around the world.
- *Life Cycle Inventory (LCI) program:* improves global access to transparent, high quality life cycle data by hosting and facilitating expert groups whose work results in web-based information systems.
- *Life Cycle Impact Assessment (LCIA) program*: increases the quality and global reach of life cycle indicators by promoting the exchange of views among experts whose work results in a set of widely accepted recommendations

4.3. LCA methodology

As it is mentioned above, an LCA of a product includes all the production processes and services linked to the product during its whole life cycle, from the extraction of raw materials through production of the materials which are used in the manufacture of the product, over the use of the product, to its recycling and/or final disposal. Transportation, storage, retail and other activities between the life cycle stages might be included where relevant. This life cycle of a product is identical to the complete supply-chain of the product plus its use and end-of-life treatment **[46]**.

LCA considers different 'Inputs' and 'Outputs'. For example, the use of resources, raw materials, energy carriers, etc. are the 'Inputs'. Emissions to air, water and land, waste and by-products are the 'Outputs' (*Figure 4*). For products in the 'Inputs' coming from the techno-sphere (not natural) their 'environmental history' should be included in the calculations by including their indirect upstream activities. In the case of wastes, the future treatment processes that will be used have to be included accordingly.

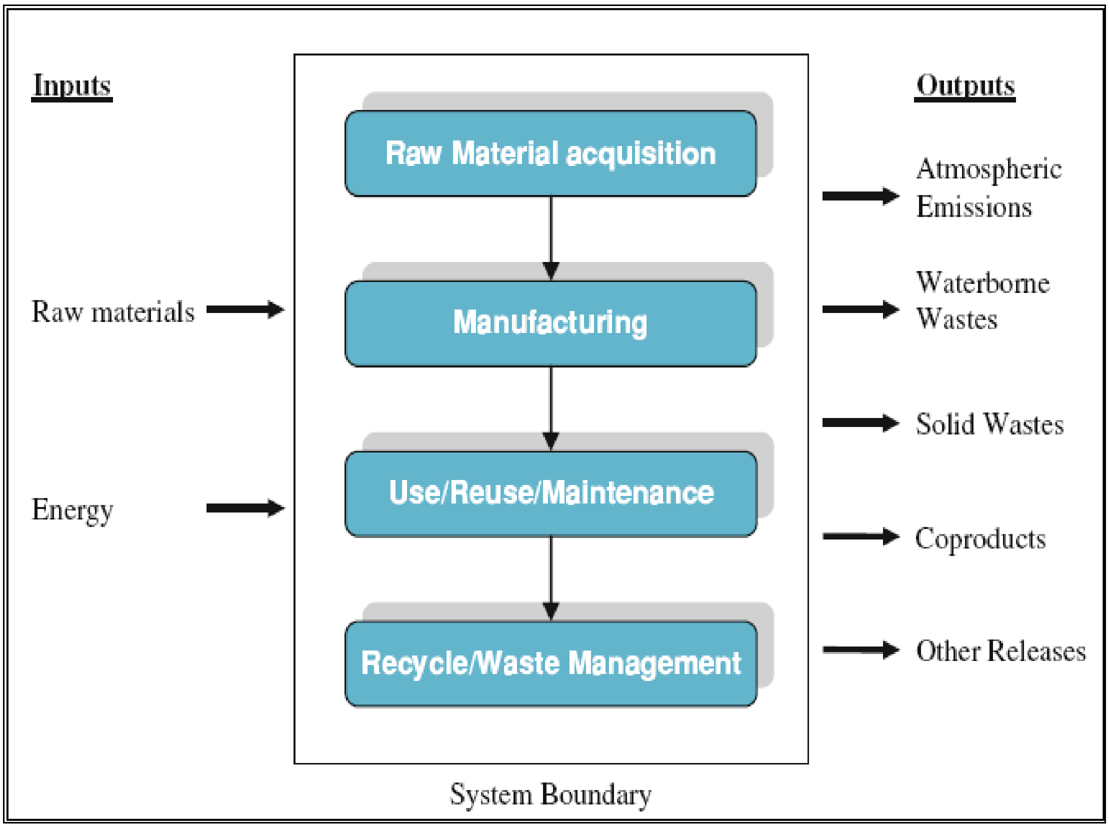

Figure 4: Life-cycle stages ***[47]***

The total inputs from, and outputs to, the nature is the basis for a later analysis and potential assessment, named Life Cycle Impact Assessment (*Figure 5*), of the environmental effects related to the product or process.

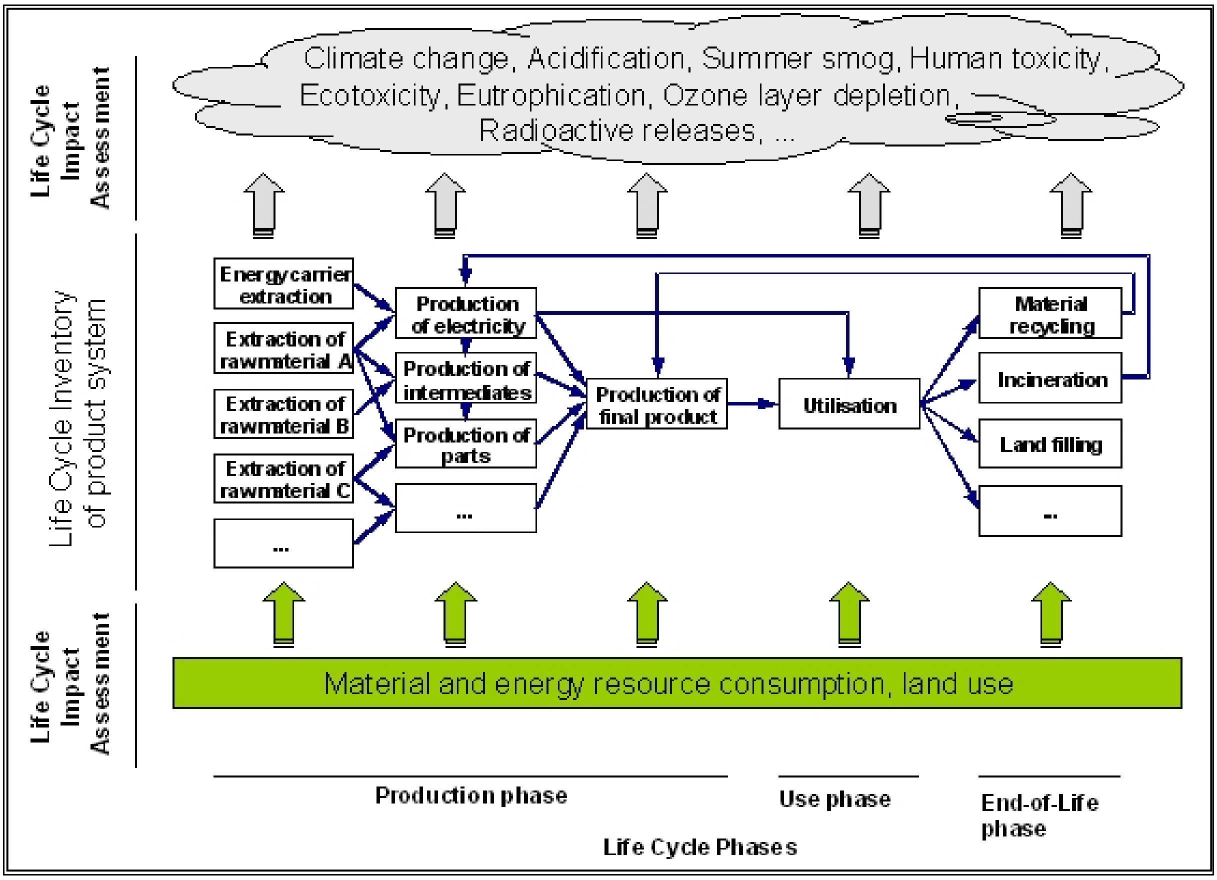

Figure 5: Scheme of a product system's life cycle with data collection of product and waste flows (blue lines) and resources (green) and emissions (grey arrows) followed by the impact assessment of the emissions and resource consumption **[48]**

The principles, procedures and methods of LCA are presented in two international standards declared by the ISO **[49]**:

- ISO International Standard 14040, 2006: Environmental management -- Life cycle assessment -- Principles and framework
- ISO International Standard 14044, 2006: Environmental management -- Life cycle assessment -- Requirements and guidelines

While using LCA, the following can be achieved **[50]**:

- Quantification of environmental releases into the air, water and land related to each lifecycle stage and/or major contributing process.
- Comparison of health and ecological impacts of different products and processes.
- Systematical evaluation of the environmental consequences connected to a given product or process.
- Identification of impacts linked to specific environmental areas of concern.

- Analyzing of the environmental trade-offs affiliated with one or more specific products/processes in order to help gain stakeholder acceptance for a planned action.
- Assessment of the human and ecological effects of material as well as energy consumption and environmental releases to the local community, region and world

In general, LCA includes four main stages (*Figure 6*): goal and scope definition of the study, inventory analysis, impact assessment and finally interpretation.

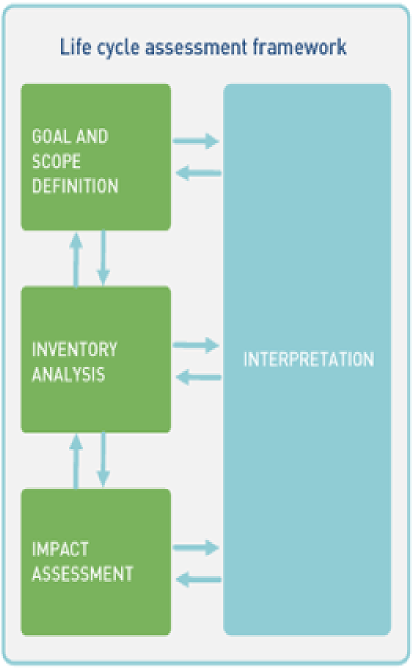

Figure 6: Stages of LCA and their interactions ***[51].***

A. *__Definition of goal and scope__*: This phase determines the depth and direction that the study will have. The purpose of the study is defined by stating the reason for which the assessment is conducted and the way in which the results will be used. The scope of the LCA defines basically: system, boundaries, data requirements, functional unit, environmental effects to be reviewed, assumptions and limitations.

B. *__Life cycle inventory (LCI) analysis__*: In this phase, the unit processes of the system are analyzed in order to identify and also quantify energy, water, materials use and environmental releases (i.e. air emissions, solid waste disposal and wastewater discharge). This description can be represented in process flow charts and also mass balance equations can be used to calculate the inputs and outputs of the system. As a result, this analysis has a long list of resources being used and emissions released to the environment. The data used should be detailed and consistent with the purpose and scope of the study, including uncertainties, variability and gaps.

C. *Life-cycle impact assessment*: This phase is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the LCI. Impact assessment should address ecological and human health effects, as well as resource depletion. A life cycle impact assessment attempts to establish a linkage between the product or process and its potential environmental impacts.

D. *Interpretation:* In this phase, the results of the inventory analysis and the impact assessment are evaluated and tested in order to check their validity before making and reporting conclusions, with a clear understanding of the assumptions used to generate the results **[52], [53].**

Originally, LCA methodologies were developed for the creation of decision supporting tools for categorizing products, product systems or services in environmental terms. However, with the evolution of LCA, a number of related applications arose such as: governmental policy making in the areas of eco-labelling waste management opportunities and green procurement; internal strategic planning and policy decision supporting in industry; internal industrial use in product developing and improvement; external industrial use for marketing purposes. These just indicate a wide variation of LCA applications. Except for the variety of applications there is also variety in the sophistication level and methodology applied in each case. Some more LCA applications are the following: environmental design, product development, strategic planning, product improvement, environmental claims and also for EPDs **[54]**.

Basically, LCA can be considered a tool designed for the evaluation of the impacts of the production, use and waste management of goods. Moreover, an LCA can be performed for the purpose of **[55]**:

- Decisions involved in product and process development
- Decisions on buying
- Structuring and building up information
- Eco-labelling
- Decisions on regulations

5. ENVIRONMENTAL PRODUCT DECLARATION OF CONSTRUCTION MATERIALS

5.1. Definitions and objectives

EPDs are communication tools that provide environmental data on products and services by using predetermined parameters and additional environmental information, when needed. During the last decade the EPD system has gained considerable importance in several countries and they are continuously becoming more known and functional on the market **[56]**. EPDs are defined in ISO TR 14025 and give the possibility to communicate objective, credible and comparable information in relation to the environmental performance of different products or services and they are developed by using LCA **[34].**

The EPDs are applicable to all products, no matter their use or position in the production sequence. They are used to classify them in well-defined groups and this classification helps making comparisons among functionally equivalent products. In general, the main objectives of EPDs are:

- Communication of verifiable and detailed information in environmental terms.
- Encouragement of the supply and the demand of environmental preferable products.
- Stimulation of the continuous environmental improvement potential.

EPDs can be helpful to producers because they provide the opportunity of giving a verified and quantitative description of the environmental performance of a product or a service in an understanding life cycle perspective. On the other hand, consumers can also use EPDs as a source of information in finding and purchasing products and services with a lower environmental impact **[57]**. More specifically, for producers, specific elements of importance are **[58]**:

- *Objective*, because of the requirement that scientifically accepted and validated methods are used for LCA according to the standards ISO 14040/14044 for the identification and focus on the environmental work on the most important environmental aspects, leading towards continuous improvement.
- *Flexible*, because of the fact that the content of an EPD can be changed while necessary and when required by the company/organization after external review and verification.

- *Neutral*, because there are no valuations and predetermined environmental performance levels that should be met.

For consumers, specific elements of importance are:

- *Credible,* because of the requirements on review, approval, inspection and follow-up by a third-party that is independent, accredited and competent.
- *Comparable*, because information in EPDs is being collected and calculated depending on common product-specific requirements.
- *Continuously updated*, because of the requirements on routines for documentation as well as the follow-up procedures.
- The fact that EPDs are neutral enables communication on a wide international scale

5.2. Regulatory framework

As it is described in Section 3, the International Organization for Standardization (ISO) has developed ISO 14025:2006 and ISO 21930:2007 (Sustainability in building construction, Environmental declaration of building products) **[59]** on the Type III environmental declarations which set the rules for issuing an EPD for construction products. Moreover, the European Commission of Standardization (CEN) has developed and published a technical report CEN/TR 15941:2010 concerning the methodology for selecting and processing information for the development of an EPD. Also, one year later, in October 2011, was approved EN 15942:2011 **[60]** that defines the rules for each category of products for the development of an EPD **[61]**.

In 2011, the Regulation 305/2011 'Construction Products Regulation' (CPR) **[62]** was approved by the European Parliament and replaced Construction Products Directive 89/106/EEC (CPD) **[63]** of 21 December 1988. Before CPD's inception, there were differing standards and technical approvals in the EU members. The significance of the CPD was to remove the technical barriers for the EU construction industry **[64]**. The objective of the CPD and the CPR as well is not to define the safety of construction products but to ensure that reliable information is presented in relation to their performance **[65]**.

The CPD provided the following four main elements: a system of harmonized technical specifications, an agreed system of observance confirmation for each product family, a framework of notified bodies and the CE (European Conformity) marking of products **[66]**.The CPR includes a new approach to the basic requirements for the construction, giving priority to the principles of sustainability, including the requirements related to hygiene, health and environment in sustainable use of natural resources. To evaluate the sustainable use of natural resources and the impact of construction on the environment, the CPR recommends the use of EPDs where available **[67]**.

5.3. Product category rules (PCR)

In order to be able to fulfill the expectations of the high market for a number of practical applications, EPDs should meet and comply with specific and strict methodological prerequisites. To ensure that similar procedures are used for the creation of EPDs, common and harmonized calculation rules have to be established. However, groups of products usually have different environmental performance than others and because of that they require specific rules for their product group. Those rules are called Product Category Rules (PCR). The PCR documents should be regarded as complementary to general requirements of EPD programs **[68].**

The most recent standard of the EU, for the category of construction products, is the EN 15804:2012 **[69]**, Core rules. This standard basically provides core PCR for Type III environmental declarations (mentioned in Section 3) for any construction product and service. PCRs are very important for the future development of the EPDs (*Figure 7*). The core PCR **[61]**:

- Describes the stages of a product's life cycle that are included in the EPD and which processes are to be considered in the life cycle stages.
- Defines the characteristics to be declared and also the way in which they are grouped and reported.
- Defines the conditions under which construction products could be compared based on the information provided by EPD.
- Defines rules for the development of different scenarios.
- Includes the rules for calculating the Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA) underlying the EPD and specifies of the data quality to be applied.
- Includes the rules for reporting predetermined, environmental and health information that is not covered by LCA for a product, service or construction process where necessary.

(For the EPD of construction services the same rules and requirements apply as for the EPD of construction products).

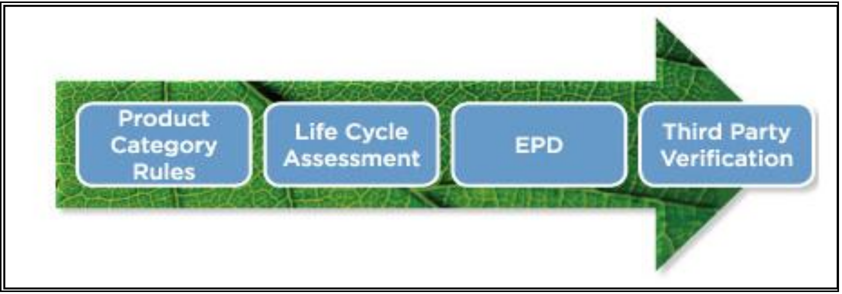

Figure7: Steps followed for the creation of an EPD ***[70]***.

5.3.1. The steps for the preparation of PCR

According to the Environment and Development Foundation (EDF), the steps for the preparation of a PCR are the following **[71]**:

A. *Check an existing PCR*: The first step in order to prepare a Type III environmental declaration is finding out whether already exists a PCR in the same product category or a related PCR to the selected product.
B. *If a PCR already exists*: it should be taken as reference for the LCA calculation and the available PCR documents could be used. If there are reasons for which developing new PCR documents is needed, they should be justified (based on the principle to achieving harmonization of the Type III environmental declaration program).
C. *If there is no existing PCR*: there should be a new one developed. The procedure is described in the continuation (Section 5.3.3.).

5.3.2. Contents of PCR

According to ISO 14025, a PCR document should include the following **[72]**:

- Product category definition and description:
  - Functional unit.
  - Description of data.
  - System boundaries.
  - Criteria for the addition of inputs and outputs.
  - Data quality requirements.
  - Units.
- Inventory analysis:
  - Data collection.

- Calculation procedures.
- Allocation of material and energy flows and releases.

- When applied, selection of impact category and calculation rules.
- Predetermined criteria for reporting LCA data.
- Requirements for supply of additional environmental information or methodological requirements.
- Materials and substances to be declared.
- Instructions for the data required to develop the declaration.
- Instructions on the format and content of the Type III environmental declaration.
- Information on stages that are not considered (if the declaration does not include all life cycle stages).
- Period of validity.

5.3.3. Development and maintenance procedure of PCR

According to the EDF, there is a specific procedure to be followed for the development and the maintenance of a PCR **[73]**:

A. *Define product category*: Product categories are determined through a transparent procedure. If products have functions and applications very much alike, then the criteria for including a group of products to a specific product category should be that the same functional unit could be applied.

B. *Collect and/or produce LCA*: In this step should be determined the life cycle stages that will be included, the parameters that will be covered and the way in which the parameters will be collected and reported through LCA.

C. *Draft PCR*: In this step a draft version of PCR should be developed in the established consultation process, while interested parties are involved. When the draft is completed it should be submitted to PCR review. During the review, the review members will give comments and recommendations for the PCR.

D. *Publish PCR*: After the PCR review and when the new PCR is approved, it should be applied for LCA calculation. (The detail of the actual PCR preparation procedure must be defined by the program operator).

E. *Maintenance of PCR:* The approved PCR should be revised when there are changes in procedures and documents related to the PCR. (The detail of the maintenance procedure should be defined by the program operator).

5.3.4. General guidelines for EPD by EN 15804:2012

An important and recent development by CEN is the publication of EN 15804 (2012) that is a standard providing the core rules for the production of EPDs for construction products. This standard basically provides the common rules for type III environmental declarations that can be used by EPD schemes across Europe. The guidelines of this standard provide the core environmental information on construction products that can be used with data for other products in order to evaluate the building. This new standard wants to ensure that comparable environmental information is generated for a product manufactured or used and that this core information can be transferred from scheme to scheme across Europe, having as a result the minimization of trading barriers **[74].**

Even though EN 15804:2012 lays out the information that should be provided by an EPD, it does not indicate a specific layout. This means that EPDs from different schemes will most probably look different from one another. However, EN 15804 ensures that all EPD will now on use the same environmental indicators, which currently are different between different schemes and that they will be consistently laid out in tables using the same life cycle modules (*Figure 10*).

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Next Product System
Raw material supply	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use / application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport to EoL	Waste processing for reuse, recovery or recycling	Disposal	Reuse, recovery or recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Figure 8: System's boundaries according to EN 15804 **[75]**

According to EN 15804:2012, an EPD should include 24 specific environmental indicators **[74]**, **[76]**:

- Seven are environmental impact categories:

    1. Global Warming Potential (GWP)
    2. Ozone Depletion Potential (ODP)
    3. Acidification potential (AP)
    4. Eutrophication potential (EP)
    5. Photochemical ozone creation potential (POCP)
    6. Abiotic depletion potential for non fossil resources (ADP-elements)
    7. Abiotic depletion potential for fossil resources (ADP-fossil fuels)

- Ten are resource use indicators (showing the amount of resource consumed throughout the life cycle):

    1. Use of renewable primary energy excluding renewable primary energy resources used as raw materials
    2. Use of renewable primary energy resources used as raw materials
    3. Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)
    4. Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials
    5. Use of non renewable primary energy resources used as raw materials
    6. Total use of non renewable primary energy resources (primary energy and primary energy resources used as raw materials)
    7. Use of secondary material
    8. Use of renewable secondary fuels
    9. Use of non renewable secondary fuels
    10. Use of net fresh water

- Three are waste indicators (showing the amount of waste produced throughout the life cycle):

    1. Hazardous waste disposed
    2. Non hazardous waste disposed
    3. Radioactive waste disposed

- Four are output flow indicators (showing the amount of material leaving the system boundary to be used in another product system, through reuse, recycling or recovery):

    1. Components for reuse
    2. Materials for recycling
    3. Materials for energy recovery
    4. Exported energy.

5.4. EPD content

According to ISO 14025, all EPDs should have the same format and also include the same parameters. In general, an EPD has three main parts:

- *Description of the company and product*: this part includes a description of the manufacturer and the product, the functional unit (which is the unit to which all calculations are referred).
- *Environmental performance*: this part is basically the core of the EPD. It is based on the LCA of the product, so all processes from extraction of resources, refining of raw materials, transport and production are included. In most EPDs, important air and water emissions are expressed both as inventory data and as potential influence on different environmental impact categories. All results of calculations are presented per functional unit (that was mentioned in the previous part). EPDs could also include a presentation of environmental impact from a typical transport to customer.
- *Information about the company and the accredited certification body*: in this part should be mentioned the name and address of the company's contact person and the certification body, period of validity of the certification and references are given in this part. An EPD certified by a third party is valid for three years.

More specifically, the format of an EPD is the following **[77]**:

- Organization description. Name and address of manufacturer(s).
- Product description. Name (including e.g. production code) and a simple visual representation of the product for which the EPD is developed.
- Description of the product's use and the unit of the product (functional or declared) to which the data relates.
- Description of the application of the products.

- General specification for the composition of the product.
- Identification of PCR.
- Date of the declaration issue and validity period.
- Additional environmental information (e.g. specific manufacturing processes).
- Statement of whether the declaration is complete (all life stages) or modular (specific life stages).
- Statement that environmental declarations from different programs (ISO 14025) cannot be comparable.
- In case the EPD declares an average performance for a number of products should be stated and the standard deviation of the products' performance with respect to the average should be stated as well.
- The site(s), manufacturer or group of manufacturers or those representing them for whom the results of the LCA are representative.
- Information on where explanatory material can be obtained.
- PCR verification.
- Diagram of the life cycle stages included in the LCA subdivided into product stage, building stage and end of life stage, and also the system's boundaries. (The stages may be further subdivided, according to ISO 21930 and EN 15804:2012).

5.5. Update of an EPD

A responsible body of an EPD might need to correct or change something in the environmental communication of a product/service. Because of the fact that an EPD should include the latest data and information, if there have been done changes the EPD should be updated.

The updated EPD should be examined by an independent entity to verify the new information emerged. The change notification of the declaration should be issued to the operator of the program along with a statement of compliance with the relevant requirements of the tester **[78]**.

5.6. Verification of an EPD

The EPD verification work involves bodies (internal or external) checking the competence requirements of verifiers/organizations, creating EPDs. The verification should cover four main areas:

- The data collected and used for the LCA calculations.
- The way the LCA-based calculations have been done to agree with the calculation rules described in the PCR.
- The presentation of environmental performance included in the EPD.
- Additional environmental information included in the declaration (if existent).

The verification procedure could be seen as being divided into two separate parts **[79]:**

- *The documental review:* focuses on the analysis of all documents that are justifying input data and information included in the EPD (LCA study and documents with environmental information). The objectives of this phase are: 1) the assessment of compliance of the LCA and the EPD with the general program instructions and the reference PCR, 2) verification of the procedures established for the update of the information in the LCA and EPD, and 3) verification of the procedures established for an assessment of the conformity to all relevant process and product related environmental laws (if appropriate).
- *The validation phase:* focuses on the assessment of the validity of data and information included in the LCA study and the EPD. This phase is concluded by sampling activities focusing, mainly, on those processes and activities having important influence on results the overall environmental impact. The main objectives of this phase are: 1) the assessment of how accurate is the information contained in the LCA study and the EPD, 2) the assessment of the application of documented procedures established for updating the information in the LCA and EPD, and 3) the assessment of the compliance with relevant process and product related environmental laws (if relevant).

5.7. EPD (and PCR) registration and publication

The EPD program operator should publish a list of approved PCRs, with complementary information about the parties involved in the development of the PCR and contact details of the PCR moderator (on a so-called PCR Data Sheet). All information should be available to all interested parties. During the gradual build-up of PCR modules of general use based on the Central Product Classification system (CPC), the Secretariat of the program operator should inform about the status of these modules and the way they can be used as already accepted inputs to PCR documents for specific products.

Moreover, the Secretariat should also keep a list of EPDs withdrawn from the official EPD register (not publicly available). Withdrawn EPDs can be made available upon request, and after the organization's concordance **[78]**.

5.8. International programs for EPD registration

As mentioned above, there are specific criteria for the creation of an EPD and specific procedures. Moreover, there are particular associations worldwide for the registration of EPDs. Global Type III Environmental Product Declarations Network (GEDnet) is an international non-profit association of type III environmental declaration organizations and practitioners with members around the world (some of which presented in *Table 4*).

Table 4: Construction material EPD registration programs **[80]**.

Program	Co-ordinator	Country	Website
INIES	CSTB Département Energie, Santé et Environnement	France	*www.inies.fr*
IBU	IBU: Institut fur Bautechnik Undwelt	Germany, Austria and Switzerland	*bau.umwelt.de*
Environdec Green Yard Stick	SEMC : Swedish Environment Management Council	International consortium, coordinated by Sweden.	*www.environdec.com*
DAPc	CAATEEB – Collegi d'aparelladors, arquitectes técnics I Enginyers d'Edificació de Barcelona	Catalonia, Spain	*es.csostenible.net/dapc/certificarse-en-dapc*
BRE environmental profiles	BREEAM (BRE Environmental Assessment Method)	United Kingdom	*www.bre.co.uk*
RTS	Developed in partnership by the companies, confederation, etc.	Finland	*www.rts.fi*
ByOg Byg	Ministry of Economic and Business Affairs	Denmark	*http://en.sbi.dk*
MRPI	Dutch Association Building Supply	Netherlands	*http://www.mrpi.nl*
NHO Program	Norwegian EPD foundation	Norway	*www.epd-norge.no*

After the completion of the procedure for the creation and publication of an EPD, the product after manufacturing receives a label depending on the system where it belongs. Some examples are given in F*igure 9*:

Figure 9: A-Logo of the German EPD system (IBU),
B- Logo of the Swedish EPD system (Environdec)

5.9. European EPD registration systems for construction materials

INIES is a French reference database for EPDs of building products. It was created in 2004 under the administration of the 'Centre Scientifique et Technique du Bâtiment' (CSTB). The database is public, free and the only requirement for admission is the conformation to EN 15804. The main goal of INIES is to help improving the environmental performance of building through monitoring the construction materials. According to the INIES website (http://www.inies.fr/), on their database can be found 718 EPDs under 10 different categories: 1) Ceiling products, 167 EPDs, 2) Covering products, 19 EPDs, 3) Sanitary and bathroom equipment, 5 EPDs, 4) Facades products, 19 EPDs, 5) Insulation materials, 180 EPDs, 6) Interior and exterior joints/closures, 13 EPDs, 7) Product preparation and implementation, 111 EPDs, 8) Floor and walls/ paint/ decorating products, 121 EPDs, 9) Structure/ Masonry/ shell/ frame, 67 EPDs, 10) Flex networks, 16 EPDs **[81].**

IBU was created in Germany, in 1998, out of an initiative of manufacturers of construction products who decided to support the demand for more sustainability in the construction sector. The coordinator of the organization is the Institut fur Bautechnik Undwelt and the focus is on convincing everyone that sustainability is the right choice. According to the official website (http://bau-umwelt.de) there 24 different categories for the existing 235 EPDs: 1) Bathrooms, sanitary installations, 4 EPDs, 2) Floor coverings, 28 EPDs, 3) Building fasteners, 4 EPDs, 4) Coating, 7 EPDs, 5) Metals for buildings, 17 EPDs, 6) Roofing and facades, 16 EPDs, 7) Roofing and waterproofing membranes, 3 EPDs, 8) Insulating materials, 24 EPDs, 9) Floor covering adhesives, 7 EPDs, 10) Fiber glass mesh, 2 EPDs, 11) Raw materials and intermediate products, 4 EPDs, 12) Wooden materials, 11 EPDs, 13) Air-conditioning & refrigeration engineering, 1 EPD, 14) Ceramic tiles, 1 EPD, 15) Luminaries & lamps, 3 EPDs, 16) Masonry, 16 EPDs, 17) Plaster & mortar, 48 EPDs, 18) Laminated plastics, 1 EPD, 19) Timber, 2 EPDs, 20) Locks and fittings, 11 EPDs, 21) Dry construction, 2 EPDs, 22) Solid wood, 2 EPDs, 23) Walls and ceiling coverings, 2 EPDs, 24) Exterior insulation finishing system, 19 EPDs. IBU registers EPDs from companies in Germany, Austria and Switzerland **[82].**

Environdec has the ambition to help and support organizations to communicate the environmental performance of their products (goods and services) in a credible and understandable way. It was created in Sweden in 1996 under the coordination of the Swedish Environment Management Council (SEMC). This program includes EPDs from many different sectors and not only from the construction sector. According to the official website (http://www.environdec.com) there are 11 different categories, one of which is the Constructions, construction products and construction services including 35 EPDs. In this group participate countries from around the world but the coordination is done by Sweden **[83].**

The DAPc System is a program that helps manufacturers of construction products and materials that have a commitment to sustainability and the environment, and want to advance in the analysis of the environmental impacts of their products. The program begun in 2008 in Catalonia, Spain with the coordinated by the College of surveyors, architects, technicians and engineers of buildings of Barcelona (CAATEEB). Even though it is a fairly new program there are already many members from all Spain. On the official website of the program (http://csostenible.net) are available all the verified and published EPDs, 12 in total **[84].**

Environmental Profiles (BRE): has the goal to help clients create better, safer and more sustainable products, buildings, communities and businesses and to support the innovation needed to achieve this. The BRE certification was created in 1999 in the United Kingdom under the coordination of BRE Environmental Assessment Method (BREEAM). This program is used for the registration of EPDs for construction. However, on the official website (http://www.bre.co.uk), the number and names of the EPDs are not provided in detail **[85]**.

The Building Information Foundation RTS was established in 2004 in Finland coordinated by a total of 50 background organizations and partners in cooperation with the Board of Directors. These organizations are representing the entire construction branch in Finland. The Building Information Foundation RTS is a private, non-profit Foundation whose task is to foster both good planning and building methods and good property management practices. The Foundation and its activities are directed by a Board and an Assembly that represents the entire building and construction industry through 50 associations and organizations. On the official website of the organization (http://www.rts.fi) are available the EPD documents of 4 different construction products (plywood, fiber panels, natural fiber-based insulation, ceramic tiles) **[86].**

Environmental Relevant Product Information (MRPI): is an initiative of the Dutch Association Building Supply (NVTB) and the former Ministry of Housing. MRPI is a tool for producers and was established in Finland in 1999. MRPI Foundation establishes the rules for the preparation and testing of environmentally relevant product information. These are truthful product information on which clients, architects and contractors, in addition to price and performance, construction that will have to choose. The official website (http://www.mrpi.nl/) provides the EPD documents available. There are 8 different categories with a total of 45 EPDs: 1) Walls, 21 EPDs, 2) Façade openings, 3 EPDs, 4) Floor, 3 EPDs, 5) Flat roofs, 3 EPDs, 6) Pitched roofs, 5 EPDs, 7) Roof openings, 8 EPDs, 8) Doors, 2 EPDs **[87].**

The Norwegian EPD Foundation was established in 2002 by the Confederation of Norwegian Enterprise (NHO) and the Federation of Norwegian Building Industries (BNL). The reason for its establishment was an expressed desire from the Norwegian corporate sector relating to the development of credible, standardized and internationally valid Environmental Product Declarations for products and services. The official website (http://www.epd-norge.no) provides the EPDs for construction materials. There are 10 different categories, with a total of 69 EPDs: 1) Mechanical Equipment for Buildings, 5 EPDs, 2) Concrete, 13 EPDs, 3) Building Products, 6 EPDs, 4) Cement, 5 EPDs, 5) Roofing Membrane, 4 EPDs, 6) Steel as Construction Material, 4 EPDs, 7) Solid Wood Products, 9 EPDs, 8) Chemical-technical Construction Products, 2 EPDs, 9) Building Boards, 18 EPDs, 10) Insulation Materials, 3 EPDs **[88].**

The EPDs under development for a product, depending on the EPD system and PCR used, might cause some differences in the final document. One of those differences can be the system boundaries used for the LCA of the product. In general, there are three basic types of system boundaries (Figure 10). The life cycle of a construction product can be referred as cradle to gate, cradle to site or cradle to grave. This distinction will be important for the better understanding of the case study (*Section 6*).

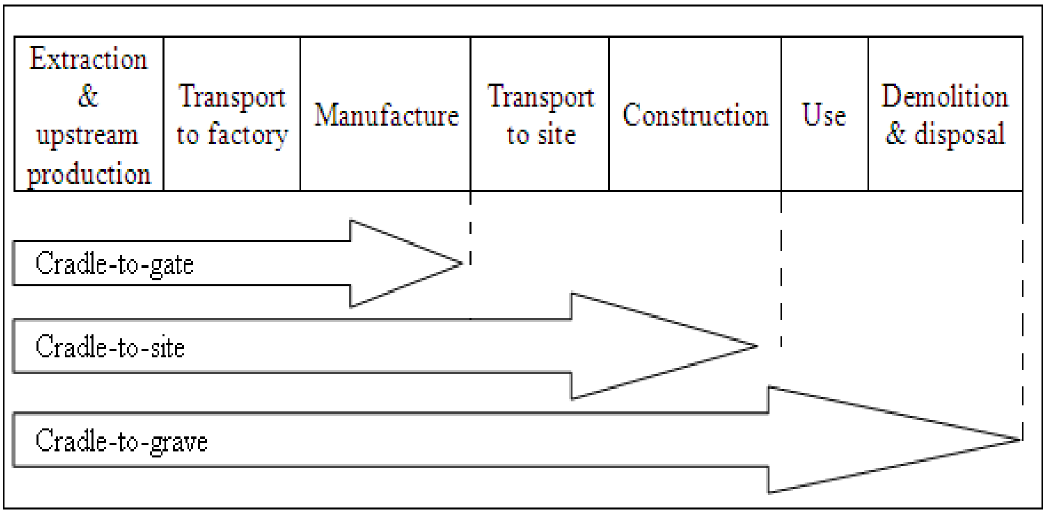

Figure 10: Life cycle stages included in each LCA case **[89]**

6. CASE STUDY – CERAMIC TILES

6.1. Framework of the case study

In this section of the thesis the aim is to better present and understand the use of EPDs. In order to do that a comparison of different EPD documents from different EPD systems will be presented. The goal of this EPD comparison is to see if there is a difference in the results of the same product in three different systems and if so what is the reason. Moreover, the results will be commented in order to see the environmental impact and the driving forces in each case.

The product chosen was the ceramic tiles for several reasons. Firstly, in order to allow a correct comparison the functional unit used in each case should be the same. In the case study the functional unit used in all the cases is $1m^2$ of ceramic tiles. Apart from that, a difficulty faced while looking for official EPD documents was the language in which the EPD was published. In the case of the ceramic tile, all the documents were in English. Finally, another reason for which this specific product was chosen was the fact that more than one European EPD systems had it registered.

The systems in which the EPDs used for this comparison were registered are the German IBU and the Catalan DAPc (presented in *Section 5.9*). Even though Portugal does not have a national EPD system, for this comparison, it will be used a published study that includes the environmental impacts from the production of ceramic tiles in Portugal. This study presents the values for the same impact categories just like the other two EPDs. This way it will be possible to compare the obtained results.

The EPD documents that will be used are the following:

- Germany –Declaration number: EPD-IKF-2011111-D **[90]**
- Catalonia - Declaration number: DAPc 002.003 **[91]**
- Portugal – use of a published study based on 4 different factories (average value used) **[92].**

The methodology used in each case was:

- Germany: ISO 14025, PCR -Ceramic Tiles- version 08-2011
- Catalonia: ISO 14025, ISO 21930, PCR – 002 Productos de revestimiento ceramico- version 06-2010
- Portugal: ISO 14040, ISO 14044, ISO 14025, ISO 21930

The above documents provide information for the environmental impact of the product throughout its life cycle. The values of 10 different impact categories and indicators will be used and compared: Non-renewable resources, Renewable resources, Total water, Total waste, Global warming potential, Ozone depletion potential, Acidification potential, Eutrophication potential, Formation of photochemical ozone potential, Abiotic consumption of resources by fossil fuel. This comparison will help noticing the difference within the systems and also reach conclusions concerning the information given by the EPDs.

In general, ceramic products are manufactured from clay, non-metallic inorganic materials and metallic oxides. There is a specific procedure to be followed for the manufacturing of ceramic tiles (*Figure 11)* even though in some stages different processes (e.g. wet or dry mixing) can be chosen.

For many ceramic products, such as tile, the decision of the body composition is driven by the amount and also the type of raw materials used. In general, the raw materials determine the final color of the tile, which could be red or white, depending on the total amount of iron-containing raw materials used. Because of that, it is important to mix the correct amounts depending on the desired properties (batching). In order to achieve the wanted result batch calculations are needed, which should take into consideration the physical properties and the chemical composition of the raw materials used. After the determination of the appropriate weight of each raw material, they can be mixed together. The production of ceramic tiles typically comprises the following steps:

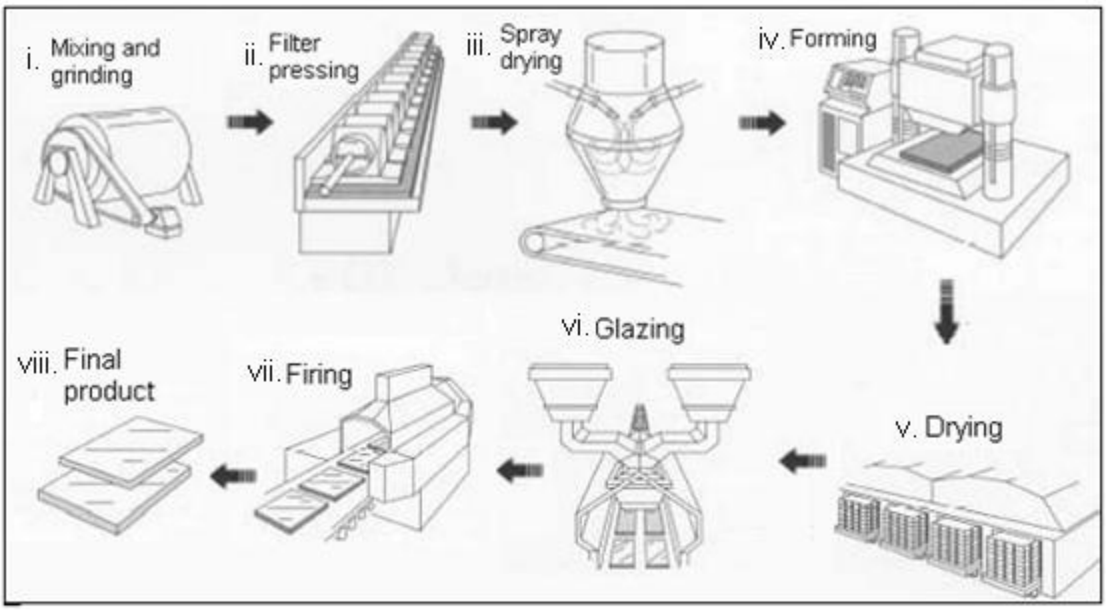

Figure 11: Manufacturing process of ceramic tiles **[93].**

i. Mixing and grinding

After weighing the ingredients, they can be added into a mixer. There are different kinds of mixers: shell, ribbon or intensive. A shell mixer has two cylinders joined into a V, which rotates to bring down and mix the material. A ribbon mixer consists of helical vanes and an intensive mixer uses rapidly revolving plows.

During this step a finer particle size can be achieved that helps improving the forming process that follows afterwards. In some cases it is needed the addition of water into the mixture in order to improve the mixing of a multiple-ingredient batch or/and to achieve finer grinding. The name of this process is wet milling and is usually performed using a ball mill. The final water containing mixture is called a slurry or slip.

ii. Filter pressing

In order to remove the water from the slurry filter pressing is used. During this process almost half of the water content is removed and then follows the dry milling for the removal of the remaining water.

iii. Spray drying

When wet milling is previously used, the water in excess is generally removed by spray drying. This process consists of pumping the slurry to a vaporizer consisting of a quickly rotating disk or nozzle. Droplets of the slurry are dried as they are heated by a rising hot air column, forming small, free flowing granules that result in a powder suitable for forming. In the case of dry milling, tiles can also be prepared by granulation. Granulation basically uses a machine where the mixture of previously dry-ground material is mixed with water in order to form the particles into granules, which again form a powder ready for forming **[94].**

iv. Forming

This process can be done in different ways. The most common methods of forming the tile bodies are:

a) <u>Dust press:</u> is used for ceramic tile only. An almost dry mixture of clays, talc and other ingredients are pressed into a mold at very high pressures (up to 2,500 tons).
b) <u>Extrusion:</u> is used for ceramic or cement tiles. In this case the ingredients are slightly wetter and are forced through a nozzle in order to form the desired tile shape.
c) <u>Slush mold or wet pour:</u> can be used for ceramic or cement tiles. A much wetter mixture of ingredients is poured into a mold to form the desired shape.

d) <u>Ram press:</u> is used for cement or ceramic tile. Is similar to the dust press method, but in this case the size of the tile shapes are generally much larger.

v. Drying

After the forming process, the ceramic tiles must be dried especially if a wet method is used. The drying process can take several days in order to remove the water at a slow rate to prevent cracks. In this procedure, continuous or tunnel driers are used heated using gas or oil, infrared lamps or microwave energy depending on the tile produced. Infrared drying is generally better for thin tile, while microwave drying is better for thicker tile. Another existing method is the impulse drying that uses pulses of hot air flowing in the transverse direction instead of continuously in the material flow direction **[94].**

vi. Glazing

To prepare the glaze, similar methods are used as for the tile body. After the drying process, the milled glazes are applied using one of the many methods available. In centrifugal glazing, the glaze is fed through a rotating disc that throws the glaze onto the tile. In the bell/waterfall method, as the tile passes on a conveyor a stream of glaze falls onto it. Sometimes, the glaze is simply sprayed on. Dry glazing is also used. This case involves the application of powders, crushed frits (glass materials) and granulated glazes onto a wet-glazed tile surface. After firing, the glaze particles melt into each other to produce a surface like granite.

vii. Firing

This is the final step of the manufacturing process. After glazing, the tile is heated intensely to strengthen and reach the wanted porosity. Generally, two types of ovens or kilns are used for firing. Wall tile or tile prepared by dry grinding (instead of wet milling) usually requires a two-step process. In this case, the tile goes through a low-temperature firing called bisque firing before glazing. This step helps removing the volatiles from the material and most (or all) of the shrinkage. Then, the body and glaze are fired together in a process called glost firing. Both firing processes take place in a tunnel or continuous kiln, consisting of a chamber through which the ware is slowly moved on a conveyor on refractory batts (shelves built of materials that are resistant to high temperatures) or in containers called saggers. Firing in a tunnel kiln may take two to three days, with very high firing temperatures (1,300 ^{o}C). After forming, the file is dried slowly (for several days) and at high humidity, to prevent cracking and shrinkage. Next, the glaze is applied, and then the tile is fired in a furnace or kiln. Although some types of tile require a two-step firing process, wet-milled tile is fired only once, at high temperatures (1,500 ^{o}C). After firing, the tile is packaged and shipped. For tile that only requires a single firing (usually prepared by wet milling) roller kilns are generally used. These kilns move the wares on a roller conveyor and do not require kiln furniture such as batts or saggers. Firing times in roller kilns can be as low as 60 minutes, with high firing temperatures (1,500 ^{o}C).

viii. Final product

After firing and testing, the tile is ready to be packaged and shipped**.**

6.2. Characteristics of each system

As it was mentioned previously (*Section 5.9*) in each different EPD system can be met different characteristics, such as systems limits, and this can cause wrong conclusions if the products are directly compared. Because of the fact that in this comparison will be used results from three different sources, this is an important aspect. This section of the thesis presents the characteristics and information given by each system so that it will be analyzed under what terms the comparison will be done. The characteristics analyzed in this section are: the system's boundaries, the product allocation and the cut-off rules.

The system's limit chosen was cradle-to-gate because two of the documents already used it (IBU, Portugal). The DAPc has more stages (cradle-to-grave) and some stages can be excluded in order the comparison to be under the same terms. Because of the fact that the PCR used in each case was not possible to be found and to be studied, in this section, will be provided information given from the EPD based on the specific PCR mentioned in the previous section. The most useful and important information given in the EPD document is presented as follows:

6.2.1 IBU characteristics

From to the official EPD document for ceramic tiles on the IBU website were found the characteristics presented here. The selected system limits comprise the manufacture of products including extraction of the raw material and provision of energy to the packaged product at the factory gate (cradle to gate). The review system boundary comprises the following stages:

- Extracting raw materials (clay, kaolin etc.)
- Reprocessing raw materials (as powdered clay and fireclay if necessary

- Manufacturing additional substances and preliminary products
- Provision of energy
- Manufacturing expenses in the plant (energy, waste, emissions)
- Transporting preliminary products
- Packaging and packaging disposal

Usage is not included in the calculation done to the multiple application possibilities and designs available and the re-use phase is not a component of this LCA either.

The cut-off criteria provide the exclusions of life cycle stages made in the LCA. In this case all operating data, i.e. all of the starting materials used thermal energy, internal fuel consumption and electricity consumption, all direct production of waste as well as all emission measurements available were taken into consideration in the analysis. Assumptions were made regarding the transport expenses associated with all input and output data taken into consideration. Accordingly, material and energy flows with a share of less than 1% were also excluded. It can be assumed that the total of all neglected processes does not exceed 5% in the effective impact categories. Machinery and plants required in the manufacturing process are neglected.

Concerning the product allocation in this case, no allocation was needed because the average volumes of ceramic tiles produced are balanced. The clay waste is burned during the production process and sold as fireclay, so it exits the system limits without any value (no credits). Also, production waste is reused internally (inert materials such as dust, pulverized stone) and it is modeled as closed-loop recycling. Waste oil and packaging materials are incinerated in a refuse incineration plant.

Finally, the following impact categories and indicators were included for this EPD:

- Primary energy consumed (renewable, non-renewable)
- Water requirements
- Waste
- Abiotic Consumption of Resources by Elements
- Abiotic Consumption of Resources by Fossil Fuels
- Global Warming Potential
- Ozone Depletion Potential
- Acidification Potential
- Eutrophication Potential
- Photochemical Ozone Creation Potential

As mentioned in the EPD document, the software used for calculations when needed and for gathering the needed values is the GaBi software.

6.2.2 DAPc characteristics

From to the official EPD document for ceramic tiles on the DAPc website were found the characteristics presented here. In this case, the EPD document presents the system's limit as well but they are different from the IBU limits. In this case information is provided throughout the whole life of the product. The phases included in the LCA are four and each one has been further divided according to the PCR used:

- Manufacture: includes extraction and transportation of the raw materials and also manufacturing (including packaging)
- Construction: includes transport and the processes of installation and construction
- Use: includes the maintenance, repair, replacement, rehabilitation and also use of operational energy
- End of life: includes the deconstruction and demolition of the product, the transport, the reuse/recycling and the final disposal.

The cut-off rules used in this EPD are similar to the ones used by IBU. According to the DAPc document, over 95% of all the inputs and outputs of mass and energy of the system were used, excluding the diffuse emissions in the factory. Because of this declaration in the EPD document, it can be assumed that the total of all neglected processes does not exceed 5% in the effective impact categories. Concerning the product allocation, in this case there is no such information. Because of that, it will be assumed that there is no product allocation in this case just like in the IBU case.

Finally, the following impact categories and indicators were included for this EPD:

- Global Warming Potential
- Ozone Depletion Potential
- Acidification Potential
- Eutrophication Potential
- Photochemical Ozone Creation Potential
- Potential for the depletion of abiotic resources
- Primary energy consumed (renewable, non-renewable)
- Use of secondary fuels (renewable, non-renewable)

- Consumption of fresh water
- Production of waste (hazardous, non-hazardous, radioactive)
- Materials released for: reuse, recycle, energy recovery

As mentioned in the EPD document, the software used for calculations when needed and for gathering the needed values (e.g. transport) is the GaBi software.

6.2.3 Portuguese study characteristics

From the Portuguese study for ceramic tiles, previously mentioned, were found the characteristics presented here. As mentioned, in the case of Portugal there is none EPD system yet. However, in this thesis it will be used a published study with information similar to the official EPDs of IBU and DAPc. The objective of the study was to present an LCA of ceramic tiles for different factories in Portugal. The Portuguese study does not follow a specified PCR so there is no possibility for further information. The study follows a cradle-to-gate LCA. In the Portuguese study the system's limits include two phases:

- Extraction: includes the extraction and transportation of the primary and raw materials
- Manufacturing: includes the ceramic tiles production and also the packaging

Regarding the cut-off rules the processes that do not contribute in more than 0.5% to the environmental impact were excluded except in the case that they are classified as dangerous (toxic). In this case, there is no product allocation either.

Finally, the following impact categories and indicators were included for this study:

- Global Warming Potential
- Ozone Depletion Potential
- Acidification Potential
- Eutrophication Potential
- Photochemical Ozone Creation Potential
- Potential for the depletion of abiotic resources
- Primary energy consumed (renewable, non-renewable)
- Consumption of fresh water
- Production of waste (hazardous, non-hazardous, radioactive)
- Materials for packaging (plastic, paper)
- Emissions to water (BOD, COD, TSS)

- Emissions to air (particles, fluorites, NOx, SOx)

As mentioned in the study, the software used for calculations for the LCA is the SimaPro software, a tool to perform professional LCA studies (It comes with a large database and a number of impact assessment methods).

6.3. Results and discussion

In order to allow a fair comparison it was needed to do some adjustments to the original results. In the case of the Portuguese study, that provides values from four different factories, it was needed to use the average of those values. Apart from that, the values used from the DAPc system exclude the stages of use and end of life, so that the results refer to the same boundaries as the other two (cradle to gate).

Even though all the cases use 1 m^2 of ceramic tiles as functional unit, the final weight of the product is different. In the German EPD, 1 m^2 equals to 15.1 kg. In the Catalan EPD, 1 m^2 equals to 24 kg. Finally in the Portuguese study, the average weight equals to 13.4 kg. The differences of the final weights can be explained by the components used for the production of the tiles. Even though the DAPc document includes the components used, namely clay, sand, feldspar, silicate and kaolin, it does not include the specific quantities. In the other two cases more information is given (Table 5).

Table 5: General components in 1 m^2 of mixture for ceramic tiles

Components in kg	**Portugal**	**Germany**
Clay	4.4	9.06
Feldspar	4.6	3.09
Sand	0.7	0.45
Dyes	0.12	-
Powder	0.5	-
Glazes	0.7	0.6
Additives (silicates, etc.)	0.88	0.6
Others (kaolin, etc.)	1.5	1.2

The values to be compared are presented in *Table 6*:

Table 6: Impact categories for ceramic tile in three different systems

Ceramic tile					
Impact category / Indicator		***Unit per m²***	***Portugal***	***Germany IBU***	***Catalonia DAPc***
1	Non-renewable resources	MJ	118.1	164.8	251
2	Renewable resources	MJ	N/A	9.1	17.2
3	Total water	L	44.5	75	87
4	Total waste	kg	1.85	25.2	8.74
5	Global warming potential	kg CO_2 equiv.	13.29	9.7	16.2
6	Ozone depletion potential	kg CFC-11 equiv.	$16.2*10^{-7}$	$4.7*10^{-7}$	$7.37*10^{-7}$
7	Acidification potential	kg SO_2 equiv.	0.04	0.02	0.05
8	Eutrophication potential	kg PO_4^{3-} equiv.	$5.67*10^{-3}$	$1.9*10^{-3}$	$4.43*10^{-3}$
9	Formation of photochemical ozone potential	kg C_2H_6 equiv.	$4.61*10^{-3}$	$1.6*10^{-3}$	$4.85*10^{-3}$

N/A: value not available

<u>*Non-renewable resources*</u>

In the non-renewable resources is included the consumption of fossil fuels such as natural gas, petroleum, etc. In this comparison category the unit is mega joules per square meter (MJ/m^2) and as it can be seen from the values in Table 6 the case with the highest consumption of non-renewable resources is DAPc (251 MJ), followed by IBU (164.8 MJ) and then by Portugal (118.1 MJ). In the documents used, the basic difference is that the information given concerning those values is not the same. In the DAPc document is mentioned the total value but there is no more detail concerning the resources specifically, so it is not possible to know whether the resource used was natural gas or petroleum for example. In the Portuguese and the IBU documents (*Table I.1-I.2*) there is more information given noticing that the resources used are natural gas and petro diesel. In the case of IBU, it can be seen (*Figure I.1*) that except for the conventional non-renewable resources there are others used as well such as uranium, but in a smaller amount.

In both the official EPD documents (IBU and DAPc) it is explained the consumption of non-renewable resources in each stage of the life-cycle. In both cases the stage included in this comparison is the manufacturing stage (has the highest consumption compared to the other stages) (*Table A.2-A.3*). In the IBU document the value is 125 MJ (almost 75% of the total value) and in the case of DAPc the value is 251 MJ (almost 87% of the total value). The reason why there is so high energy consumption in this stage can be explained by the very high temperatures needed by some steps of the production, especially the firing process (*Section 6.1*). In the Portuguese study (*Table A.1*) it can be seen that the highest energy consumption is linked to natural gas that is used in the firing process.

At the IBU document there is presented a more detailed evaluation of the use of non-regenerative primary energy for the manufacture of 1 m^2 of tiles and indicates that natural gas is used as the essential primary energy carrier. This is primarily attributable to the direct natural gas requirements in the manufacturing plants (*Figure A.1*).

Renewable resources

The renewable resources may include the wind power, water power, solar energy, etc. In this comparison category, the unit used is mega joule per square meter (MJ/m^2) and based on the values of *Table 6* it can be seen that the highest consumption value once again is from the DAPc system with 17.2 MJ followed by the IBU system with 9.1 MJ. The Portuguese study does not include this value (does not specify if the value is not available or if there are no renewable resources used).

According to the IBU document (*Table A.2*) the highest consumption of energy is noticed in the packaging stage (4.1 MJ) followed by the manufacturing stage (3.7 MJ). So, a very high percentage (87%) of the whole consumption of renewable energy is done in those two stages.

Moreover, the IBU document specifies that the renewable resources used are: wind power, solar energy and water power. A more detailed evaluation presented in the IBU document indicates that wind and solar energy are used as the essential primary energy carriers (*Figure A.1*). In the DAPc document (*Table A.3*) it can be seen that the stage with the highest consumption is the manufacturing stage (17.2 MJ).

Total water

In the comparison of the total water consumption a big difference can be noticed between the three cases. The unit used in this category was different in each case (Portugal-liters, Germany-kg, Catalonia-m^3) so it was changed for all to liters. As it can be seen in T*able 6* the Portuguese study presents a much lower value (44.5 L), half compared to the Catalan case (87 L). The German EPD presents a value of 75 Liters of water consumption.

Large quantities of water are needed in many different stages. In the case of IBU, the highest consumption of water occurs during the stage of raw materials extraction (33.6 L) specifically associated with kaolin extraction and then during the manufacturing stage (30.3 L). The rest of the stages consume a lot less water (*Table A.4*).

In the case of the DAPc system, there is a higher consumption of water and according to the EPD document there are many stages where water is needed. In this document it is mentioned as well that there are several parts of the process where water is recycled and reused. The water losses due to evaporation can be replaced by well water during the production process. The water is treated by physicochemical process and is then reintroduced in the needed processes (mixing-grinding).

Total waste

For the comparison of the total waste produced during the manufacturing of the ceramic tiles the unit used is kilogram per square meter (kg/m^2). In this comparison category some big differences can be seen in the final values. According to the values in *Table 6,* the highest waste accumulation occurs in the German system with 25.2 kg, followed by the Catalan system with 8.74 kg and finally by the Portuguese with 1.85 kg.

The Portuguese study provides the lowest value. This very low value could be explained in part by the fact that the factories used for the evaluation do not include the packaging procedure in the LCA. As it is mentioned, they receive ready the packaging for the ceramic tiles.

The highest value for waste production is in the manufacturing stage and this is the explanation for these great differences between the values. As it is noted in the EPD documents, Germany uses locally extracted material, whereas Catalonia and partly Portugal import materials for the manufacturing process. This could explain the fact that the values in the case of Germany are higher. In the German EPD (*Table A.6*) is noted that there are two stages with high waste values. Those stages are the manufacturing and the primary products excavation stages.

In the Catalan EPD (*Table A.7*) it is also noted that the stage with the highest value is the one of production. In the study for the Portuguese factories it is not specified the stage with the highest values.

Global warming potential

The unit used for the comparison in this impact category is kilogram of carbon dioxide equivalent per square meter (kg CO_2 equivalent/m^2). The comparison between the three cases (*Table 6*) shows that the German product has the lowest impact with 9.7 kg CO_2 equivalent, followed by the Portuguese with 13.29 kg CO_2 equivalent and finally by the Catalan with 16.2 kg CO_2 equivalent.

Once again the stage with the highest contribution to this impact category is the manufacturing stage. In the EPD document for IBU (*Table A.8*) it can be seen that the manufacturing stage contributes 6.9 out of the whole 9.7 kg CO_2 equivalent. The remaining quantity is divided between the other stages. However, the German product has by far the lowest global warming potential compared to the other two cases. According to the direct emission measurement the global warming potential is dominated by more than 95% by CO_2 emissions. Almost half of this volume is attributable to direct emissions in the plant as a result of the firing process, a 16% is attributable to the electricity generation chain and another 15% is accounted for by the manufacture of preliminary products including the extraction of raw materials.

On the other hand, the Catalan product has the highest impact. The Catalan EPD (*Table A.9*) states that the manufacturing stage has the highest impact with 16.2 kg CO_2 equivalent. This big difference in the final values of the three cases could be explained by the consumption of fossil fuels. However, as mentioned before, the DAPc document does not provide details for this information.

Ozone depletion potential

The unit used for this comparison category is kilogram of trichlorofluoromethane equivalent per square meter (kg CFC-11 equivalent/m^2). According to the final values of each system in *Table 6,* the highest value is for Portugal with $16.2*10^{-7}$ kg CFC-11 equivalent, followed by Catalonia with $7.37*10^{-7}$ kg CFC-11 equivalent and finally by Germany with $4.7*10^{-7}$ kg CFC-11 equivalent.

In the IBU document (*Table A.8*) where all the stages are presented for the different environmental impact categories, it can be seen that all the values are very low. However, if compared to each other, the stage with the highest value is the one of manufacturing with

2.9 *10^{-7} kg CFC-11 equivalent, followed by the primary products stage (excavation stage) with 1.3*10^{-7} kg CFC-11 equivalent.

On the other hand, the DAPc document (*Table A.9*) shows that the total value in this case is divided differently. There is quite a big difference between the values of the life cycle stages. The stage with the obviously highest value is the stage of manufacturing with 7.37 *10^{-7} kg CFC-11 equivalent.

It should be noted once again that the main process during the manufacturing stage having a significant environmental impact is the firing process that needs extremely high temperatures. In this category is influential because when clays and glazes are fired, they may release various gases, vapors and fumes.

Acidification potential

The unit used for this comparison is kilogram of sulfur dioxide equivalent per square meter (kg SO_2 equivalent/m^2). In this comparison the difference between the three cases are very small but once again the IBU value is the lowest. For this category the highest value is from the DAPc with 0.05 kg SO_2 equivalent, followed by the Portuguese value with 0.04 kg SO_2 equivalent and then by the IBU with 0.02 kg SO_2 equivalent.

In the EPD document of IBU (*Table A.8*) the values show once again that the highest value is for the manufacturing stage with 8.6*10^{-3} kg SO_2 equivalent. However, in this case there is another high value of 5.7*10^{-3} kg SO_2 equivalent that represents the stage of glazing. According to the EPD document, the acidification potential in the manufacture of one 1 m^2 of ceramic tiles is dominated by more than 64% by SO_2 emissions and 30% by nitrogen oxides (NOx). Almost one-third of SO_2 emissions arise directly in the plant as a result of production (emission value measured) while another 30% is accounted for by the upstream chains associated with the manufacture of glaze components. Concerning the NOx emissions, almost one-third is emitted directly from the plant as a result of the production (emission values measured), another 12% is attributed to the electricity provision chain of the electricity consumed directly in the plant and finally a 19% is accounted for by transporting the raw materials and preliminary products. This is the first category until now that the glazing stage has such a significant part in the final value.

In the DAPc document (*Table A.9*) the stage that makes the biggest difference is the one of manufacturing with 4.77*10^{-2} kg SO_2.

Eutrophication potential

The unit used for this comparison is kilogram of phosphate equivalent per square meter (kg PO_4^{3-} equivalent/m^2). In this comparison there is a small difference between the three documents (*Table 6*). The highest value is from the Portuguese study with $5.67*10^{-3}$ kg PO_4^{3-} equivalent followed by the DAPc document with $4.43*10^{-3}$ kg PO_4^{3-} equivalent and finally by the German EPD having the lowest value of $1.9*10^{-3}$ kg PO_4^{3-} equivalent.

In the IBU document (*Table A.8*) demonstrating the values of each stage, the one with the highest value is that of manufacturing with $9.2*10^{-4}$ kg PO_4^{3-} equivalent. The stage following is once again the excavation of the primary products stage with $3.1*10^{-4}$ kg PO_4^{3-} equivalent but there is a big difference between the values. According to direct emission measurement, NOx contribute around 80% to the eutrophication potential in the manufacturing stage of one square meter of ceramic tiles and one-third of this value arises directly in the plant as a result of the production. Another 12% is attributable to the electricity provision chain of the electricity consumed directly in the plant while a further 19% is accounted for by transporting the raw materials and preliminary products. The manufacture of components for refinement and/or glazing and the manufacture of preliminary products contribute 17% each to the eutrophication potential.

In the case of the DAPc document (*Table A.9*) it can be seen that the stage with the highest value is the one of manufacturing with $4.43*10^{-3}$ kg PO_4^{3-} equivalent. The Portuguese study does not include any more information concerning the stages in which the impact was higher.

Formation of photochemical ozone potential

This comparison category presents the potential of chemical ozone formation and the unit used is that of kilogram of ethane equivalent per square meter (kg C_2H_6 equivalent/m^2). The comparison table (*Table 6*) shows that the three cases have a small difference in their final values. However, once again that the DAPc system has the highest value $4.85*10^{-3}$ kg C_2H_6 equivalent, followed by the Portuguese with $4.61*10^{-3}$ kg C_2H_6 equivalent and finally by the German one with $1.6*10^{-3}$ kg C_2H_6 equivalent.

More specifically, in the IBU document (*Table A.8*) it can be seen that the stage with the highest value is the one of manufacturing with $8.5*10^{-4}$ kg C_2H_6 equivalent followed by the stage of glazing with $3.1*10^{-4}$ kg C_2H_6 equivalent. This is the second category after the eutrophication potential in which the glazing stage has the second position of importance for the total value. The formation of photochemical ozone potential is basically attributed to SO_2 emissions with an accounting for more than 30%, as well as non-methane volatile organic compounds (NMVOCs) attribute a 35% and finally NOx almost a 20%. VOCs evolve during the upstream chains associated with providing natural gas. NOx and SO_2 are largely attributable to the emissions evolving directly in the plant (emission values measured) as well as the upstream chains associated with providing electricity but also the upstream chains involved in the manufacture of glaze components.

In the DAPc document (*Table A.9*) the manufacturing stage has the highest value with $4.85*10^{-4}$ kg C_2H_6 equivalent. In this stage is included the transport of the raw materials and as it was mentioned before the raw materials are imported from other countries.

6.4. DAPc system comparison cradle-to-gate and cradle-to-grave

In this section, the differences in the results within one system while using different system limits is compared. In order to do that, the DAPc document that includes all the life cycle stages is used. The categories of comparison are the same as in the previous section.

Table 7: Comparison of different system limits for DAP system

Ceramic Tile				
Impact category / Indicator		***Unit per m²***	***DAPc Cradle-to-gate***	***DAPc Cradle-to-grave***
1	Non-renewable resources	MJ	252	309.87
2	Renewable resources	MJ	17.2	78.7
3	Total water	L	87	312.28
4	Total waste	kg	8.74	33.55
5	Global warming potential	kg CO_2 equiv.	16.2	21.72
6	Ozone depletion potential	kg CFC-11 equiv.	$7.37*10^{-7}$	$23.06*10^{-7}$
7	Acidification potential	kg SO_2 equiv.	0.05	0.09
8	Eutrophication potential	kg PO_4^{3-} equiv.	$4.43*10^{-3}$	$11.69*10^{-3}$
9	Formation of photochemical ozone potential	kg C_2H_6 equiv.	$4.85*10^{-3}$	$13.92*10^{-3}$

Non-renewable resources

As it can be seen in *Table 7,* there is a small difference between the value of the whole life cycle and the value of the cradle-to-gate approach. In the cradle-to-gate the value is 252 MJ while in the cradle-to-grave the value is 309.87 MJ.

As it can be seen (*Table A.11*) the stage with the biggest influence in this comparison category is the manufacturing stage which represents almost 81% of the total value. The reason why the manufacturing stage has such a great influence in this stage is the firing process that needs very high temperatures, which means high energy consumption.

Because of that fact, the difference between the value of the cradle-to-gate and the cradle-to-grave approach is not that big. The other stages included of the whole life cycle (construction, use and end-of-life) do not have high values and do not influence a lot the final value.

Renewable resources

Based on the values of *Table 7,* it can be seen a big increase when the system's limits change. In the cradle-to-gate the value is 17.2 MJ while in the cradle-to-grave the value is 78.7 MJ. In this case, the value of the cradle-to-gate approach is about 22% of the total value.

In this category, the stage of manufacturing does not have the biggest influence on the total value. As it can be seen in *Table A.11,* the stage that influences the total value in the case of cradle-to-grave is the stage of construction (use, maintenance and transport) that has a value of 37.3 MJ.

The great influence that this stage has in the environmental impact of the product can be seen by the fact that this stage represents around 78% of the total value in this impact category.

Total water

In the comparison of the total water consumption can be noticed a big difference between the two cases. In the cradle-to-gate case the value is 87 liters and in the cradle-to-grave case the value is 312.28 liters. In this case the cradle-to-gate approach represents around 28% of the total value. This means that the manufacturing stage does not influence a lot the final result.

As it can be seen from the EPD document, the stage that causes this great difference between the two approaches is the stage of use (maintenance and transport). Because of the impact category it is more logical that the difference is caused mostly by the maintenance part where there is more water needed for the cleaning of the product.

Total waste

The comparison table (*Table 7*) shows that there is a big difference between the values when all stages are included. In the cradle-to-gate case the value is 8.74 kg and in the cradle-to-grave case the value is 33.55 kg. In this category, the cradle-to-gate value represents around 26% of the total value.

From the DAPc document (*Table A.11*) it can be seen that the stage with the major role in this comparison is the end-of-life stage and more specifically the disposal of the product (24 kg). The value of this stage represents around 72% of the total value. This result makes sense because this is the last part (after recycling and reuse) in which the product cannot be used anymore and needs to be disposed in an area, so it will cause waste.

Global warming potential

The comparison between the two cases (*Table 7*) shows a small increase when the limits of the system were increased up to the end-of-life stage. In the cradle-to-gate case the value was 16.2 kg CO_2 equivalent while in the cradle-to-grave the value increased to 21.72 kg CO_2 equivalent. In this category, the value of the cradle-to-gate approach represents around 75% of the total value.

In the EPD document where all the stages are presented, it can be seen that the stage with the highest value is the manufacturing stage and that is why there is not a big difference between the two cases. Because when the rest of the stages are added to this value, they do not influence the final result. As mentioned above, the reason why there is such an influence from the manufacturing stage is the firing process of the product.

Ozone depletion potential

According to the final values of each case (*Table 7*) there is a big difference between the values when all stages are included. In the cradle-to-gate case, the value is $7.37*10^{-7}$ kg CFC-11 equivalent and in the cradle-to-grave case, the total value is $23.06*10^{-7}$ kg CFC-11 equivalent. In this category, the cradle-to-gate value represents around 32% of the total value that is a low percentage.

As it can be concluded from the EPD document (*Table A.11*) the stage with the highest influence is the one of use (maintenance and transport) with a value of $15.6*10^{-7}$ kg CFC-11 equivalent that represents around 68%. As mentioned in the DAPc document, the specific factory exports a high percentage of its products. More specifically, 54% of the production travels outside Spain for installation (33% to Europe, 21% to the rest of the world). Because of this fact, it can be assumed that the transport of the product is more harmful than the maintenance of the ceramic tiles.

Acidification potential

In this comparison the difference between the two cases are very small but once again the comparison table (*Table 7*) shows differences between the two values. In the cradle-to-gate case, the value is 0.05 kg SO_2 equivalent and in the cradle-to-grave case, the total value is 0.09 kg SO_2 equivalent. In this category, the manufacturing stage represents around 56% of the total value.

By using the EPD document (*Table A.11*) it can be seen that there is no big difference between the values of the different stages. However, the one with a slightly higher value is the manufacturing stage.

Eutrophication potential

In this comparison there is a small difference between the two cases (*Table 7*). In the case of cradle-to-gate the value is $4.43*10^{-3}$ kg PO_4^{3-} equivalent and the case of cradle-to-grave the value is $11.69*10^{-3}$ kg PO_4^{3-} equivalent. In this case the cradle-to-gate approach represents 38% of the total value.

In this comparison category, it can be seen in the EPD document (*Table A.11*) that there are two stages influencing the total value. The one with the highest value is the manufacturing stage but there is another stage influencing the total value that is the maintenance and transport of the product with a value of $3.78*10^{-3}$ kg PO_4^{3-} equivalent that represents around 32% of the total value. As explained above, the reason why the manufacturing stage influences this value is the glazing and also the firing stage.

Formation of photochemical ozone potential

The comparison table (*Table 7*) shows that the two cases have a difference of values with the cradle-to-gate having a value of $4.85*10^{-3}$ kg C_2H_6 equivalent and the cradle-to-grave having around the double with a value of $13.92*10^{-3}$ kg C_2H_6 equivalent. In this category, the cradle-to-gate value represents around 35% of the total value.

From the DAPc official document it can be seen that there are many stages with similar values. However, the one with the highest value is the use stage (maintenance and transport) with a value of $7.22*10^{-3}$ kg C_2H_6 equivalent that represents 52% of the total value. The second highest value is from the manufacturing stage.

6.5. Conclusions of the case study

In the case study of ceramic tiles two different EPDs (German and Catalan) and a Portuguese study were analyzed. This way it was easier to visualize the information given by an EPD. The environmental impacts throughout the life cycle of the ceramic tiles were presented and compared. With this comparison it was seen that the production of the same type of product may have different environmental impacts depending on the methodology used for the production, the primary energy used and the import of materials from other countries. Moreover, as it was seen in the second comparison (DAPc EPD), the final results were influenced by the system's boundaries.

More specifically, through the comparison of the different systems it was seen that the information and the details given in each document varies. In some cases this could make a difference in the final results and in the level of their understanding. The results showed that in general the German manufacturing process was more efficient in terms of environmental behavior and it was important the fact that it was the only manufacturing process using renewable resources (wind, sun, etc.).

Apart from that it was seen that the most important stage influencing the environmental impact was the stage of manufacturing. The firing process needs very high temperatures (1,150^{o}C) and this has as a result high energy consumption. The manufacturing stage influences the final value of some impact categories (global warming potential, acidification potential, eutrophication potential and formation of photochemical ozone potential). However, it does not cause a significant change in some other categories (ozone depletion potential, water consumption and waste produced). Moreover, in the case that only fossil fuels are consumed in the manufacturing stage, the renewable resources are not influenced either.

The use of the case study shows that the differences in the manufacturing process and the energy resources used could have a significant difference in the final environmental impact. This could help the better choice of methodologies and techniques used for the manufacturing of other materials as well.

Moreover, in the case of the EPD from the DAPc system, it was noticed a great influence from the stage of maintenance and transportation as well as the stage of raw materials transport. The reason for that is the need for import of raw materials from different countries (Turkey, Ukraine) and also the export of manufactured product abroad. In this case, it should be given attention to the materials used and maybe finding more efficient ways to extract raw materials from locations closer to the factory so that the transport impact is lower.

Concerning the influence of the system limits in the results obtained from the LCA, it was seen that in some cases the difference in the final value when adding all the cycle stages was very big.

In the comparison between the different system limits done for the Catalan EPD, any time the largest influence was from the manufacturing stage for some impact categories (non-renewable resources, global warming potential, acidification potential, eutrophication potential) there was not a big difference when the end of life stage was added. In the cases where the production was not the highest influence (renewable resources, total water, Total waste, ozone depletion potential, formation of photochemical ozone), the value difference between the two cases was a lot bigger and in this case the stage with the highest impact was that of use (maintenance and transport).

In general, from the above comparisons can be concluded that the most important stage concerning the environmental impact is the manufacturing stage. This is the part where attention should be given and new ways should be found for the most influential part of this stage that is the firing process of the product. Another stage needing more consideration is the extraction of raw materials stage, where renewable resources should be used more and local materials should be preferred in order to reduce the air emissions and related impacts.

7. CONCLUSIONS AND FUTURE WORK

7.1. Conclusions

Since the construction industry consumes large amounts of materials and energy it was concluded that there should be a way to change this outcome in order to decrease the environmental impact of this sector. One of the ways to achieve that could be by using alternative materials. Those materials could be more durable, with lower embodied energy and even recycled in order to help constructing a more sustainable building **[96].**

Regarding the environmental labeling, this thesis highlights the important role that the environmental seal sets and also the increasing recognition, credibility and trust that it gains by demonstrating the guarantee of environmental preservation while showing the quality of the product. It is encouraging the fact that worldwide the tendency of using environmental labels is increasing not only company-wise but also consumer-wise. In order to get the information needed concerning the environmental behavior of a product, a consumer or a company can use an EPD that is a technical document issued by the producing companies to disclose the environmental impacts generated by their products throughout their life cycle.

As it was mentioned above, EPDs are an important tool for the manufacturers in order to identify the negative impacts of a product throughout its life cycle and then try improving those aspects. The tool used for the assessment of the environmental impacts throughout a product´s life cycle is the technique of LCA. Different environmental impact categories (global warming potential, eutrophication potential, etc.) are evaluated through this technique. Even though the EPDs are statements based on LCA, they need a validation performed by an external verifier in order to be statements of the type III, according to the classification of ISO 14025.

Concerning the level of regulation, it is clear that the International and European Organizations for Standardization (ISO) have developed a series of documents relating to environmental statements. Some of them were highlighted in this thesis such as the ISO 14025 standard on the Type III environmental declarations, the ISO 21930 which describes the rules for issuing an EPD for a construction product and the CEN / TR 15941concerning the methodology for the selection and use of information in developing an EPD. In the meanwhile, in 2012, was published a new standard (EN 15 804) that defines the rules for each product category for the development of an EPD.

Throughout this thesis, it was seen that up to now there is no homogeneity in the creation of an EPD. This has as a result the existence of many different methodologies depending on the country, system and product in discussion. As it was presented, nowadays in Europe and around the world exist different EPD systems. This raises difficulties in the comparison of products and communication of environmental information. It is evident that the limitations resulting from the use of different European EPD registration systems could be avoided by developing an international system, having the same guidelines and criteria for all the users.

The presentation and explanation of the existing systems in Europe and the identification of their differences may help the understanding of the weak points existing and may help reaching the solution of this problem.

Some final conclusions that could highlight the most important parts of the thesis are the following:

- The use of EPDs can be very important and helpful in order to assess and evaluate the environmental impact of a product throughout its life. EPDs could be a basic tool for the increase and evolution of the sustainable construction.
- The EPDs could be used by architects and designers of buildings or construction sites as a source of information for assessing the sustainability of buildings and other construction works. Thus, they also play a vital role in meeting constructive solutions among the various technical solutions that the market offers, in order to identify the most sustainable and environmentally friendly.
- Because of the fact that the is no universal EPD system there should be a general try in order to study and evolve a new international system that could help improving the communication and better understanding of the documents.
- Concerning the case study, in which were presented the actual results of a construction product (ceramic tiles), it was noticed that the manufacturing process was the most influential stage in terms of environmental impact. Because of that it can be concluded that the focus should be on this stage in order to decrease the environmental impact. There should be more attention given to the ways energy is spent throughout this stage, a try to decrease the consumption of fossil fuels should be attempted and as consequence the decrease of the air emissions could be lower. Moreover, it could be tried a new way of firing this kind of products where lower temperatures could be used without compromising the final result.

7.2. Future work

This work could be enriched by future studies including an actual creation of an EPD using real data. This way could be spotted and commented the existing limitations and difficulties.

Another aspect that could be significant is the effect of economic and social analysis to the study of the life cycle sustainability, considering external effects generated throughout the production chain of conversion systems and thereby evaluating the three pillars of sustainability**.**

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ANNEX

*Table A.1: Values for the Portuguese factories **[92]***

Parameter	Unit/m^2	Factory 1	Factory 2	Factory 3	Factory 4	Total
Total waste	kg	3.43	2.0	1.16	0.8	1.85
Water	liters	15	25	13	125	44.5
Natural gas	GJ	0.12	0.09	0.1	0.09	0.1
Electricity	kWh	5.4	4.9	4.3	4.1	4.675
Diesel	MJ	1.0	0.7	2.7	0.7	1.275
Global warming potential	kg CO_2 equiv.	16.5	14.4	11.68	10.6	13.29
Ozone depletion potential	kg CFC-11 equiv.	$2.1*10^{-6}$	$1.9*10^{-6}$	$1.22*10^{-6}$	$1.27*10^{-6}$	$16.2*10^{-7}$
Acidification potential	kg SO_2 equiv.	$6.2*10^{-2}$	$6.2*10^{-2}$	$3.5*10^{-2}$	$3.4*10^{-2}$	0.04
Eutrophication potential	kg PO_4^{3-} equiv.	$6.5*10^{-3}$	$8.7*10^{-3}$	$2.5*10^{-3}$	$2.3*10^{-3}$	$5.67*10^{-3}$
Formation of photochemical ozone potential	kg C_2H_6 equiv.	$7.9*10^{-3}$	$6.1*10^{-3}$	$6.7*10^{-4}$	$3.8*10^{-3}$	$4.61*10^{-3}$

Table A.2: Use of primary energy in the German EPD system

Use of primary energy - manufacturing ceramic tiles							
Evaluation factor	Unit	Refinement / Glaze	Primary products	Transport	Production	Packaging	Total
Primary energy, non-renewable	[MJ/m^2]	13.1	25.9	3.3	125.0	-2.5	164.8
Primary energy, regenerative	[MJ/m^2]	0.4	0.9	0.0	3.7	4.1	9.1

Table A.3: Use of primary energy in the Catalan EPD system

Parameter evaluated	Unit per m^2 of panel	Manufacture
Consumption of primary renewable energy	MJ (net calorific value)	1.72E+01
Consumption of primary non-renewable energy	MJ (net calorific value)	2.51E+02

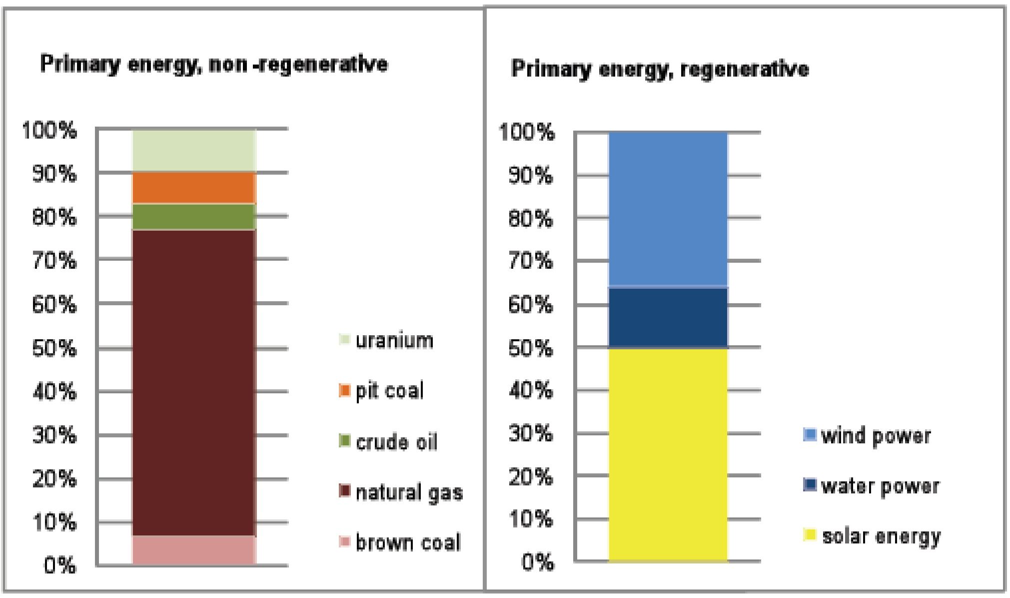

Figure A.1: Type and distribution of primary energy carriers in the manufacturing of 1m² ceramic tiles

Table A.4 Water requirements in the manufacture of 1m² of ceramic tiles German EPD system

Manufacturing ceramic tiles						
Evaluation factor	Refinement / Glaze	Primary products	Transport	Production	Packaging	Total
Water requirements Lt	9.6	33.6	0.14	30.3	1.4	75.0

Table A.5 Water requirements in the manufacture of 1m² of ceramic tiles Catalan EPD system

Parameter evaluated	Unit per m² of panel	Manufacture
Consumption of fresh water	Lt	87

Table A.6: Waste incurred in the manufacture of 1m² ceramic tiles in the German system

Manufacturing ceramic tiles						
Evaluation factor	Refineme nt / Glaze	Primary products	Transport	Productio n	Packaging	Total
Excavatio n waste	2.7	10.0	0.045	11.9	-0.2	24.6

Table A.7: Waste incurred in the manufacture of 1m² ceramic tiles in the Catalan system

Parameter evaluated	Unit per m² of panel	Manufacture
Production of waste	kg	8.74

Table A.8 Environmental impact during the manufacturing of 1m² of ceramic tile in the German system

Size	Unit per m^2	Refinement / Glaze	Primary products	Transport	Production	Packaging	Total
Global Warming Potential	kg CO_2 eq.	1.0	1.6	0.2	6.9	$20*10^{-2}$	9.7
Ozone Depletion Potential	kg CFC 11 eq	$5.2*10^{-8}$	$1.3*10^{-7}$	$2.4*10^{-9}$	$2.9*10^{-7}$	$-2.8*10^{-10}$	$4.7*10^{-7}$
Acidification Potential	kg SO_2 eq.	$5.7*10^{-3}$	$3.4*10^{-3}$	$1.8*10^{-3}$	$8.6*10^{-3}$	$3.1*10^{-4}$	0.020
Eutrophication Potential	kg PO_4^{3-} eq	$2.9*10^{-4}$	$3.1*10^{-4}$	$2.9*10^{-4}$	$9.2*10^{-4}$	$9.0*10^{-5}$	$1.9*10^{-3}$
Formation of photochemical ozone potential	kg C_2H_6 eq.	$3.1*10^{-4}$	$2.9*10^{-4}$	$1.4*10^{-4}$	$8.5*10^{-4}$	$4.9*10^{-5}$	$1.6*10^{-3}$

Table A.9 Environmental impact during the manufacturing of 1m² of ceramic tile in the Catalan system

Parameter evaluated	Unit per m² of panel	Manufacture
Potential for global warming	kg CO_2 eq.	$1.62*10^{1}$
Potential for depletion of stratospheric ozone	kg CFC 11 eq	$7.37*10^{-7}$
Potential for acidification	kg SO_2 eq.	$4.77*10^{-2}$
Potential for eutrophication	kg PO_4^{3-} eq.	$4.43*10^{-3}$
Potential for the formation of photochemical ozone	kg C_2H_6 eq.	$4.85*10^{-3}$

Table A.10: Abiotic Consumption of Resources by Fossil Fuels in the German EPD system

Manufacturing ceramic tiles							
Size	Unit per m^2	Refinement / Glaze	Primary products	Transport	Production	Packaging	Total
ADP fossil	[MJ]	10.5	18.3	3.2	93.4	-1.6	123.7

Table A.11: All stages evaluation of the DAP system

Parameter evaluated	Unit per m² of panel	Manufacture	Construction		Use							End of life			
		A1. – A3.	A4.	A5.	B1.	B2.	B3.	B4.	B5.	B6.	B7.	C1.	C2.	C3.	C4.
Consumption of primary renewable energy	MJ (net calorific value)	1.72E+01	4.95E-02	4.88E-03	-	6.12E+01	-	-	-	-	-	-	5.07E-03	0.00E+00	2.53E-01
Consumption of primary non-renewable energy	MJ (net calorific value)	2.51E+02	3.71E+01	1.85E-01	-	1.51E+01	-	-	-	-	-	-	2.73E+00	0.00E+00	3.76E+00
Consumption of fresh water	m^3	8.70E-02	2.74E-04	1.04E-03	-	2.98E-01	-	-	-	-	-	-	8.02E-05	0.00E+00	6.23E-03
Production of waste	kg	8.74E+00	9.34E-02	8.40E-02	-	7.45E-01	-	-	-	-	-	-	8.81E-03	0.00E+00	2.39E+01
Potential for global warming	kg of CO_2 eq.	1.62E+01	2.63E+00	6.72E-02	-	2.25E+00	-	-	-	-	-	-	1.94E-01	0.00E+00	4.54E-01
Potential for depletion of stratospheric ozone	kg of CFC11 eq.	7.37E-07	4.99E-09	7.58E-10	-	1.56E-06	-	-	-	-	-	-	3.71E-10	0.00E+00	3.90E-09
Potential for acidification	kg of SO_2 eq.	4.77E-02	1.81E-02	9.36E-05	-	1.92E-02	-	-	-	-	-	-	1.26E-03	0.00E+00	1.94E-03
Potential for eutrophication	kg of PO_4^{3-} eq.	4.43E-03	2.94E-03	9.10E-05	-	3.78E-03	-	-	-	-	-	-	2.00E-04	0.00E+00	2.56E-04
Potential for the formation of photochemical ozone	kg of ethane eq.	4.85E-03	1.41E-03	1.95E-05	-	7.22E-03	-	-	-	-	-	-	1.10E-04	0.00E+00	3.08E-04

A1. Supply of raw materials
A2. Transport
A3 Manufacture (according to figure 1)
A4. Transport
A5. Processes of installation and construction

B1. Use
B2. Maintenance and transport
B3. Repair
B4. Replacement
B5. Rehabilitation
B6. Use of operational energy
B7. Use of operational water

C1. Deconstruction and demolition
C2. Transport
C3. Waste management for reuse, recovery and recycling
C4. Disposal

-: The PCR do not provide for the calculation of this impact, as it is not relevant to this type of product.