Universidade de Aveiro
2015

Departamento de Ambiente e Ordenamento

EUNICE PEREIRA RAMOS

ENERGY SYSTEMS ANALYSIS OF TRANSBOUNDARY RIVER BASINS IN A NEXUS APPROACH – THE SAVA RIVER BASIN STUDY CASE

ANÁLISE INTEGRADA DE SISTEMAS ENERGÉTICOS DE BACIAS HIDROGRÁFICAS TRANSFRONTEIRIÇAS – CASO DE ESTUDO DA BACIA DO RIO SAVA

Universidade de Aveiro
2015

Departamento de Ambiente e Ordenamento

EUNICE PEREIRA RAMOS

ENERGY SYSTEMS ANALYSIS OF TRANSBOUNDARY RIVER BASINS IN A NEXUS APPROACH – THE SAVA RIVER BASIN STUDY CASE

ANÁLISE INTEGRADA DE SISTEMAS ENERGÉTICOS DE BACIAS HIDROGRÁFICAS TRANSFRONTEIRIÇAS – CASO DE ESTUDO DA BACIA DO RIO SAVA

Dissertation submitted to University of Aveiro for the fulfilment of the requirements to obtain the Master Degree in Sustainable Energy Systems, carried out under the scientific supervision of Professor Luís António da Cruz Tarelho, Assistant Professor at the Department of Environment and Planning of the University of Aveiro, and co-supervision of Professor Mark Howells, Professor at the Department of Energy Technology of Kungliga Tekniska Högskola.

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Sistemas Energéticos Sustentáveis, realizada sob a orientação científica do Doutor Luís António da Cruz Tarelho, Professor Auxiliar do Departamento de Ambiente e Ordenamento da Universidade de Aveiro, e sob co-orientação do Doutor Mark Howells, Professor do Department of Energy Technology do Kungliga Tekniska Högskola.

o júri

presidente

Professor Doutor António Gil D'Orey De Andrade Campos

Professor Auxiliar

Departamento de Engenharia Mecânica - Universidade de Aveiro

Professora Doutora Myriam Alexandra Dos Santos Batalha Dias Nunes Lopes

Professora Auxiliar

Departamento de Ambiente e Ordenamento - Universidade de Aveiro

Professor Doutor Luís António Da Cruz Tarelho

Professor Auxiliar

Departamento de Ambiente e Ordenamento - Universidade de Aveiro

acknowledgements

Firstly, I would like express my sincere gratitude to my Dissertation Supervisor Prof. Luís da Cruz Tarelho for his enduring support, guidance and encouragement in the process of writing this dissertation. Furthermore I would like to thank the KTH-dESA team and my co-Supervisor Professor Mark Howells for all the learning shared and for the honour of contributing to their excellent work. Without this opportunity and their support it would have not been possible to conduct this study. Not to mention, the Erasmus Coordinators, Prof. António Gil d'Orey De Andrade Campos and Prof. Mário Cerqueira, and Marta Oliveira of the International Office of Universidade de Aveiro, and again Prof. Luís da Cruz Tarelho, who tirelessly helped me in the struggle of benefitting from the Erasmus+ Programme at the Royal Institute of Technology, in Stockholm, Sweden.

I would also like to thanks Prof. Rosário Correia and Prof. Vítor Hugo Bonifácio, of the Department of Physics of Universidade de Aveiro, for their lifelong inspiration and invaluable teachings.

A special thanks to my friends Vignesh Sridharan, Linda Randall and Igor Santos for the constant encouragement, optimism and unfailing trust. Last but not least, I would also like to thank my parents, sister and friends, for the all-time support, patience and motivation.

palavras-chave

Sistemas energéticos, relação água-energia, alterações climáticas, bacias hidrográficas transfronteiriças, fontes de energia renováveis

resumo

As políticas de gestão de recursos são, frequentemente, desenvolvidas e planeadas para fazer face às necessidades específicas de determinados sectores, sem terem em conta os interesses de outros sectores que também utilizam os mesmos recursos. Num cenário de esgotamento de recursos, crescimento populacional, aumento da procura de energia e sensibilização para as mudanças climáticas, é de grande importância promover a avaliação de ligações intersectoriais e, ao fazê-lo, perceber as suas implicações e efeitos. Esta necessidade é ainda maior quando o uso comum de recursos não é relevante apenas a nível nacional mas também quando a distribuição de recursos se alarga a outras nações diferentes.

A presente dissertação centra-se no estudo dos sistemas energéticos de cinco países da região sudeste da Europa que partilham a bacia do rio Sava (BRS), recorrendo a uma abordagem da relação água-alimentação(agricultura)-energia. No caso do sector de produção de eletricidade a utilização da água é essencial para a integridade dos sistemas energéticos, pois a produção de energia nos países da BRS provém de duas tecnologias principais que dependem da água: centrais hídricas e térmicas. A título de exemplo, em 2012, da produção de eletricidade dos países da BRS, 37% foi gerada a partir de energia hídrica e 61% produzida por centrais térmoelétricas. Olhando para a BRS, em termos da potência instalada existente, a bacia acomoda cerca de um décimo de toda a potência hidroelétrica instalada e, ao mesmo tempo, contribui com água para os sistemas de arrefecimento de 42% da potência total instalada das centrais térmicas em funcionamento na região.

Este estudo integrado do nexus para a energia explora a dependência entre os sistemas energéticos da região com os recursos hídricos da bacia, entre os anos 2015 e 2030. Para tal, foi desenvolvido um modelo do sistema elétrico transnacional para fornecer uma base quantificavel à análise, usando o software de código aberto OSeMOSYS.

A análise é feita a três áreas principais: a primeira corresponde ao impacto das estratégias de eficiência energética e energias renováveis no mix energético de produção de eletricidade; a segunda relaciona-se com os potenciais impactos das alterações climáticas, atendendo a previsões de um cenário moderado de mudanças climáticas e, por último, decorrente do ponto anterior, o impacto cumulativo do aumento da procura de água para irrigação no sector agrícola. Este estudo inclui ainda uma comparação da dinâmica da exportação/importação de eletricidade nos diferentes cenários, com o objetivo de investigar as implicações que os fatores mencionados anteriormente poderão ter nos mercados da eletricidade dos países desta região.

keywords

Energy systems analysis, energy-water nexus, climate change, transboundary rivers, integrated assessments, renewable energy sources

abstract

Resource management policies are frequently designed and planned to target specific needs of particular sectors, without taking into account the interests of other sectors who share the same resources. In a climate of resource depletion, population growth, increase in energy demand and climate change awareness, it is of great importance to promote the assessment of intersectoral linkages and, by doing so, understand their effects and implications. This need is further augmented when common use of resources might not be solely relevant at national level, but also when the distribution of resources ranges over different nations.

This dissertation focuses on the study of the energy systems of five south eastern European countries, which share the Sava River Basin, using a water-food(agriculture)-energy nexus approach. In the case of the electricity generation sector, the use of water is essential for the integrity of the energy systems, as the electricity production in the riparian countries relies on two major technologies dependent on water resources: hydro and thermal power plants. For example, in 2012, an average of 37% of the electricity production in the SRB countries was generated by hydropower and 61% in thermal power plants. Focusing on the SRB, in terms of existing installed capacities, the basin accommodates close to a tenth of all hydropower capacity while providing water for cooling to 42% of the net capacity of thermal power currently in operation in the basin.

This energy-oriented nexus study explores the dependency on the basin's water resources of the energy systems in the region for the period between 2015 and 2030. To do so, a multi-country electricity model was developed to provide a quantification ground to the analysis, using the open-source software modelling tool OSeMOSYS. Three main areas are subject to analysis: first, the impact of energy efficiency and renewable energy strategies in the electricity generation mix; secondly, the potential impacts of climate change under a moderate climate change projection scenario; and finally, deriving from the latter point, the cumulative impact of an increase in water demand in the agriculture sector, for irrigation. Additionally, electricity trade dynamics are compared across the different scenarios under scrutiny, as an effort to investigate the implications of the aforementioned factors in the electricity markets in the region.

CONTENTS

LIST OF FIGURES

List of Tables

Acronyms and Abbreviations

AEE	Additional Energy Efficiency
AL	Albania
AT	Austria
BA	Bosnia and Herzegovina
BG	Bulgaria
CC	Combined Cycle
CCS	Carbon Capture and Sequestration
CLEWs	Climate, Land, Energy and Water strategies
CSP	Concentrated Solar Power
DMCSEE	Drought Management Centre for South-eastern Europe
EC	Energy Community
ENTSO-E	European Network of Transmission System Operators for Electricity
FASRB	Framework Agreement of the Sava River Basin
GHG	Greenhouse Gases
HPP	Hydropower Plant
HR	Croatia
HU	Hungary
IPARD	Instrument for Pre-accession Assistance for Rural Development
IRR MAX	Irrigation Maximum
ISRBC	International Sava River Basin Commission
IT	Italy
KMNI	Royal Netherlands Meteorological Institute
ME	Montenegro
MENP-HR	Ministry of Environmental and Nature Protection of the Republic of Croatia
MESP-RS	Ministry of Environment and Spatial Planning of the Republic of Slovenia

MK	Republic of Macedonia
MSDT-ME	Ministry of Sustainable Development and Tourism of the Republic of Montenegro
MSPCE-BA	Ministry for Spatial Planning, Construction and Ecology
NREAP	National Renewable Energy Action Plan
OSeMOSYS	Open Source energy MOdeling SYstem
PV	Photovoltaic
RCP4.5	Representative Concentration Pathway 4.5
REF	Reference
RES	Renewable Energy Sources
RO	Romania
RS	Serbia
SI	Slovenia
SRB	Sava River Basin
TPP	Thermal Power Plant
TSO	Transmission System Operator
UNECE	United Nations Economic Commission for Europe
WFD	Water Framework Directive

1 INTRODUCTION

1.1 FRAMEWORK

Nature is a stateless system to which geopolitical boundaries are meaningless. For humankind the understanding is different. Natural resources and geographical conditions share its role on shaping the identity of a nation and water is undoubtedly one of the most transversal and essential resource.

Boundaries aside, what happens when such valuable resource is shared between nations? It is not a proprietary issue since technically it belongs to none, but all depend on it. This is the case for transboundary river basins. Resources can be managed at the national level, but when geopolitical boundaries are confronted with different natural boundaries, the awareness on how the common resource is used in riparian nations is important. The upstream use of water can impact directly the availability downstream, leading to tensions between states. See for example the case of the Aral Sea drainage basin. Intensive use of water in the downstream countries allowed for a thriving economy from cotton production but led to the dry up of the Aral Sea in forty years (UNECE 2011; UNEP, 2005). In recent years, water is being stored by upstream nations during rainy season for electricity production during winter months, with limited releases during the months crops require irrigation and, by doing so, affecting agriculture in the downstream countries (Fritzsche *et al.*, 2011; Sorg *et al.*, 2014; World Bank, 2004). Transboundary water management is essential for peaceful coexistence and sustainability of independent nations and for this, integrated assessments at multi country levels in this particular setting can provide useful insights of interactions between crucial sectors within a state and amongst its neighbours or the riparian countries.

The heavy reliance of energy generation on water resources makes the study of this interlinkage both pertinent and necessary. A set of factors defines the energy-water nexus dynamic. On the one hand, water availability can curtail electricity production, on the other, water systems rely on energy to operate. At a first glance, hydropower is easily seen as the most susceptible electricity generation technology to be affected by changes in water availability. Hydrology is considered good or favourable whenever more generation from hydropower is achieved, whereas deemed unfavourable if precipitation levels are below average. It is with this simple example that the analysis of the water-energy nexus begins. Take a drier than average year, with both lower precipitation and higher than average annual temperature. If hydropower represents a significant share in the generation mix of a country, a reduction of 20% hydroelectricity in a drier year will certainly impose the need for higher production from fossil fuel technologies and/or the increase of electricity imports, in case the renewable energy sources (RES) cannot provide compensation. The result is simple - a higher cost of electricity, as alternatives are always more costly and consumption is unlikely to decrease. To add complexity to the example, consider that the hydropower system of the country is constituted by multipurpose reservoirs, with the water stored being used for public supply and irrigation, while environmental flows have to be met to sustain environmental services. All these factors can limit even further the operation of hydropower plants and should be taken into account as a whole. It becomes obvious the importance of water management and the multi-uses of water resources. Stretching the limits of the analysis even further, water availability can affect other power generation facilities, which also depend on water to operate, namely for cooling purposes and process water. Depending on the type of cooling technology and fuel type, also thermal power plants can be subject to reduced efficiencies and operation curtailment if water temperatures are too high or its availability does not allow for cooling to be performed. Again, in this case, if non-hydro renewable energy cannot compensate the decrease in electricity generation, electricity imports would cover the production deficit.

Although pessimistic the previous example is not unrealistic. Several and recent examples can state this important interconnection, affecting different geographic locations, from the USA, to Europe and India, to name a few (IEA, 2012; Rebetez *et al*, 2009). While the example may seem quite straightforward, the exercise was applied on a single country perspective, taking as boundaries for resources the same as the political border. What if the water resources were not limited to a country's borders but were shared between several other countries? What if climatic conditions affected the region differently? How would the energy systems of the different countries react to changes in water availability? Which country would be the most or least vulnerable? Could different water demands of one country affect another riparian country? Could water or energy strategic plans affect another country? What could be the implications of a changing climate in the shared water resources region?

1.2 Dissertation Objectives

Not tailored to be a complete nexus assessment, this dissertation addresses key interactions between the different dimensions of water resources use, electricity generation and climate change at a multi-country level. This multidisciplinary effort is therefore organized through a set of constructive objectives.

The first objective aims at characterizing each one of the dimensions, both at national and regional level. This scrutiny allows for the understanding of each countries' characteristics and specificities and how these converge in a multi-region structure. Ultimately, the importance of the shared water resources of the Sava River Basin is clarified, interactions are mapped and pressure points are identified. Part of this main objective lies in understanding the extent to which the energy supply of the Sava River Basin riparian countries depends on the water resources of the shared basin, considering the intersectorial water usage and climate change effects.

Secondly, a multi-country energy model for the region was designed to represent the combination of the power systems in the transboundary region. To do so, the energy systems analysis optimization tool OSeMOSYS was used. The modeling exercise was developed to portray the role of the basin's water resources in the operation of the electricity systems, from the supply side. The modeling approach aims at providing insights of the reliance and potential repercussion of impacts on the common use of water resources through means of quantification. Electricity trade between the riparian countries and neighbouring nations is also analysed.

With a modeling framework in place, the exploration of multiple scenarios on a nexus approach, to investigate further the role of water resources in the region represents the third main objective. Although multiple analysis can be undertaken, this study focuses on the quantification of a selected few, with the aim of illustrating the relevance of the implementation of integrated assessments and how these can play a vital role on the development of sectoral sustainable and sound policies and national plans. The purposed scenarios include the investigation of the dependencies between the Sava River Basin water resources and the electricity systems sector; the identification of the possible impacts of climate change on hydropower generation through changes in water availability in the region; the assessment of the implications on electricity generation of an increase in water demand in the agriculture sector, more specifically, for irrigation purposes; and, lastly, the exploration of the dynamics of electricity trade as buffer when national power systems do not suffice to meet the electricity demand.

The ultimate objective of this work is to provide a quantitative interpretation of the energy-water resource systems interconnection and highlight the importance that integrated management of resources can have, both at national and transboundary levels.

1.3 DISSERTATION CONTRIBUTION

This dissertation contributes to the area of integrated assessment models and transboundary river basins joint management. The analysis of the interactions and impacts beyond single-nation borders is one of the major contributions of this work. In regard to that, a better understanding of the complexity of the intersectoral implications of the use of common resources was accomplished. Sectors sustainability can no longer be regarded in a sector-exclusive manner with fixed boundaries defined between different dimensions, water, energy and the environment. A consistent and meaningful analysis requires the understanding of sectoral interlinkages so to sustainably plan for the medium and long term. This type of assessment, bridging science and policy development, strengthens the importance of energy systems analysis shifting towards a systems integration approach. Applied systematically, the integrated approach could contribute to the increase of results reliability, which could then better inform policy makers and relevant stakeholders.

1.4 DISSERTATION STRUCTURE

This dissertation is organized in six main chapters. The first is dedicated to the framework, objectives and contribution of the work. On the second chapter a literature review sets the basis for the study. In this chapter an overview of the water-energy nexus is provided with special focus on the water use in the electricity generation sector. In addition, the potential implications on power systems of climate variability and climate change are briefly explored, along with the importance of water management in transboundary river basins contexts. The rationale and description of the Sava River Basin case study is given on Chapter 3. The fourth chapter is dedicated to the description of the methodological approach and includes a brief explanation of the modeling tool chosen for the analysis. A description of the multi-country energy systems model developed for the Sava River Basin is also included in Chapter 4. The results from the energy systems model and correspondent analysis are provided in Chapter 5, where a comparison of scenarios is executed. Chapter 6 concludes with remarks over the main objectives of the dissertation, highlighting the major findings of the case study investigation. An additional section of this chapter is dedicated at discussing the limitations of the study and of future work opportunities.

2 LITERATURE REVIEW

2.1 INTRODUCTION

Water and energy are interlinked and depend on each other. Energy needs water in all the different stages of electricity generation, not just in the operational phase but also for fuel extraction, component manufacturing and power plant construction. According to the UN-Water (2014), 90% of worldwide energy is water intensive, with the existing water models proving to be unsustainable. On the other hand, water systems rely on energy to operate at every stage, from water abstraction and production, diversion, treatment, use and disposal. Energy requirements to power water systems will depend on many factors, from the water source, resource availability, distance to the demand site and type of supply technology, to name a few (Plappally *et al.*, 2012). Wastewater treatment, recovery and reuse and end use of water will also have different energy intensities attached. In the case of water supply in agriculture, the supply option will depend on water availability, seasonality of the crop and type of irrigation technology.

An interesting example of the water-energy interconnection is the Navajo coal power plant in the state of Arizona, in the United States of America. Close to 25% of its annual generation is used to power water pumps to transport water from the Colorado River basin, across the desert and over 500 km, to cities located in southern Arizona, like Phoenix and Tucson. The channel is the main supply source of water in the region and without it settlements would not strive. The power plant, with a power capacity of 2.25 GW, burns 8 million tons of coal annually, being responsible for 29% of the $CO_{2,eq}$ emissions of the state of Arizona[1]. Efforts are being made to reduce emissions and the use of alternative energy sources to aid in powering the water systems is being investigated. As water needs energy, energy needs water. In 2013 the power plant consumed, 25.0 million m^3 of water from Lake Powell for cooling and operative uses (USBR, 2014). Considering an annual water use rate of 65

[1] http://www.scientificamerican.com/article/navajo-generating-station-powers-and-paralyzes-the-western-u-s/

m³/capita, the water consumed by the thermal power plant could have covered the water demand of close to 385,000 people.

The demand for freshwater and energy is expected to increase in the future, driven by population growth, which is expected to surpass 8.3 billion by 2030 and 9.6 billion by 2050. At the same time, urban population will rise and economic development will potentiate the expansion of middle class, changing of lifestyles and the access to a more varied dietary option. Efforts are underway to improve the living conditions of nearly one billion people, who live without access to energy, water and sanitation, and proper nutrition.

The OECD (2012) projects an increase of 55% in water demand between 2000 and 2050, with a 140% increase in the electricity generation sector alone, as it is illustrated in Figure 1. In non-OECD countries, water demand for electricity production is expected to quintuple by 2050, while in OECD countries a 5% decrease is forecasted. This growth is surely connected to the expected increase in electricity demand, 70% by 2035 (UN-Water, 2014), which usually relies on production from thermal power facilities, which require water for cooling. The water demand for electricity generation will represent 25% of water requirements in 2050, while in 2000 it corresponded to 16% of the water needs. In contrast, a reduction of 14% is foreseen for the water requirement for irrigation purposes.

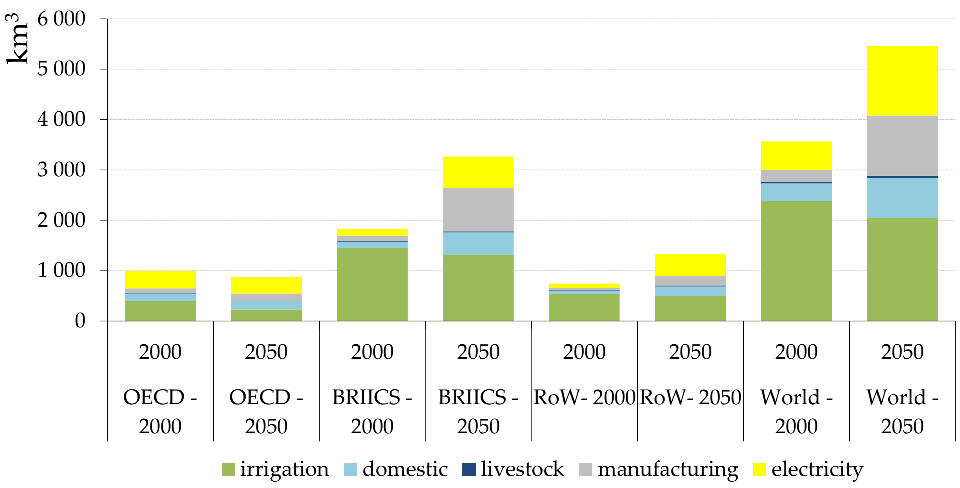


Figure 1. Global (blue) water demand by sector for 2000 and 2050 (OECD, 2012 - baseline scenario). (BRIICS – Brazil, Russia, India, Indonesia, China and South Africa; RoW – Rest of the World)

This awareness is important to understand how transversal water is as a resource. It is central to the functioning of different sectors, as it is essential for life and ecosystems preservation. As other resources, its distribution is diverse, and along with the activities it allows, can be more or less vulnerable. In a globalised world, with large-scale trade happening between distant nations, virtual transfers of water are real, implicit to the production of goods being exchanged.

Cooperation is needed between sectors through a sound and efficient management of resources, which minimize trade-offs between clashing interests and harvest co-benefits, contributing effectively for a sustainable use of resources. Planners and decision-makers should be informed of the competing interested of both water and energy sectors in order to plan more adequately, in an integrated and coordinated manner. Only then, with a perspective of integration, sustainable development can be accomplished in its three dimensions.

2.2 Nexus approach in energy systems analysis and the CLEWS methodology

The integrated analysis of different resources or sectors is the basis for the nexus approach. In essence, a nexus assessment targets interactions between two or more resource systems, like water and energy, or can expand wider to include further dimensions, such as climate, water, energy and land use and food. The application of this type of analysis has flexible spatial boundaries, and can be done at the scale of interest, from city-level to national, regional or even global.

The ultimate aim of implementing a nexus approach is to assess relevant interactions between sectors for the development of synergies that allow for the simultaneous accomplishment of sectoral objectives. This type of analysis can be achieved with the use of quantification tools that can give meaningful insights of how systems interact and inform. This is particularly useful in assessing the effectiveness of existing policies and in enabling greater policy coherence.

Examples of established nexus frameworks are summarised in Table 1. Nexus assessments are different from other integrated resource evaluations for the fact the analysis is not biased towards a specific sector. Focus is given to the sectoral interlinkages and the dynamics of their impacts. Take as example some the application of the Climate, Land, Energy and Water strategies (CLEWs) approach to the pioneer study of the island state of Mauritius (Howells *et al*, 2013). It was verified that biofuel production from sugarcane could offset the revenue losses of sugar exports, in periods of high prices of oil and non-competitive market prices for sugar. Additionally, the potential effects of climate change in the island were taken in consideration in the study. The expected decrease in precipitation levels would have impacts in water availability for sugar cane production, which would require more water to be withdrawn from surface and groundwater to maintain production levels. This would trigger the increase of energy demand to power the pumping systems, creating a chain effect that would propagate through all the energy system.

Table 1. Selected nexus frameworks (Bajželj et al., 2014; Belinskij, 2015; Biggs et al, 2015; FAO, 2014; Giampietro et al., 2013; Hoff, 2011; Howells et al., 2013; Strasser et al., 2014).

Nexus framework	Description	Leading institution(s)
The water, energy, food security nexus (Hoff, 2011)	Conceptual framework that provides guidance in the identification of trade-offs and synergies that meet demand without hindering sustainability, oriented by three principles: investing to sustain ecosystem services; creating more with less; and accelerating access while integrating the poorest.	Stockholm Environment Institute (SEI)
Water-Energy-Food Nexus (WEF) (FAO, 214)	Conceptual approach for the systematic analysis of the interactions between human activities and the environment, through the identification of trade-offs and by building synergies that allow for a better coordinated management and efficient use of resources across sectors and scales. The nexus approach analysis is organised in three working areas (evidence, scenario development, and response options) and developed with stakeholder involvement.	Food and Agriculture Organisation (FAO)
Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) (Giampietro et al., 2013)	Integrated diagnostic tool of the energy-food-land use-water nexus through means of quantification of the metabolic patterns of the nexus dimensions in relation to socio-economic and ecological variables. It can be used for simulation purposes and scenario analysis.	LIPHE4
UNECE Transboundary Rivers nexus approach (Belinskij, 2015; Strasser *et al.*, 2014)	This approach is heavily reliant cooperation and dialogue between riparian countries, as it focuses on the common use of water resources. The participatory process allows for the quantification study of relevant interactions in the Water-Food-Energy-Ecosystems nexus. In this way, potential conflicts between countries can be minimised with the identification of opportunities for improvement.	UNECE, KTH
Climate, Land, Energy and Water strategies (CLEWs) (Howells *et al.*, 2013)	Integrated modelling approach that combines the functionalities of different resource-specific analysis tools in the analysis of the nexus interactions. After the development of reference models for each sector, an integrative exercise between modelling tools is performed in line with the key interactions identified in a pre-nexus assessment, prior to the modelling phase.	IAEA, KTH, IIASA
FORESEER (Bajželj *et al.*, 2014)	Scenario generation tool to investigate the water, energy and land resources nexus, with strong visualization capabilities of resource futures through sets of Sankey diagrams. The tool is the result of the linking of physical models of resources and the technologies that use them to produce the final services.	Low Carbon and Materials Processing group, Cambridge University

2.3 WATER USE BY POWER PRODUCTION TECHNOLOGIES

According to UN-Water (2014) the energy sector was responsible for 15% of global water withdrawals in 2010, accounting to a withdrawn amount of 583 billion m^3. Approximately 11% of this volume was consumed, meaning it was not incorporated back into the system from which it was removed. Most of this share was used to feed cooling systems in thermal power plants. In Europe, it is estimated that 45% of water withdrawals are directed to the energy sector.

Water is used differently in electricity generation, depending on the production technology. In hydropower plants water is driven through turbines to produce electricity, flowing back to the watercourse, stored in the reservoirs or alternatively pumped up to higher-level reservoirs to be used to cover peak demand. This type of use is non-consumptive, as the water is returned to the water source system. Water consumption in hydropower is essentially related with the type of power plant in question and linked mostly to evaporation losses. The case of thermal power plants, including nuclear, is in turn more complex. For the purpose of this analysis is relevant to differentiate the type of water use in withdrawals and consumption. These two categories of water use are both dependent on fuel type used for thermal power generation and on the cooling system technology used. For some cooling systems, withdrawals can be significant but could entail low consumption of water, while for others, e.g. cooling towers, the opposite happens. For the same cooling system, coal and nuclear power plants usually require more water for cooling purposes, while natural gas requires a lesser amount. Both consumptive and non-consumptive uses are relevant and may impact regional water availability and quality. The effects of such impacts vary according to the vulnerability of the water resources.

2.3.1 Water use in hydropower generation

Water consumption from hydropower plants is a recent study field where involving the use of different methodologies which application is varied and not always consensual. A study review carried out by Bakken *et al*. (2013) highlights existing methods imprecision and inconsistencies, which simplistically link the hydropower water footprint to the gross evaporation losses of a reservoir. Crucial factors as the spacial-temporal boundaries of a hydropower system, not only the reservoir, the multi-purpose uses of a reservoir and the specificities of cascaded systems are pointed out in the study to be of high relevance for a more accurate estimation of water consumption of a hydropower plant or system (Bakken *et al*., 2013). The difficulty in the definition of a broad methodology is linked to the complexities of water systems. Therefore, the consumptive water use hydropower plants is logically related to many different and commonly interacting factors such as the watercourse geomorphological characteristics, the regions' climate, the location of the project, flow characteristics and seasonal variability, power plant size and type, and electricity demand.

At a first glance, water consumption by hydropower plants may seem negligible as, technically, most of the water is not consumed but used, passing through the turbines. The water losses, or consumption, may however exist and are intrinsically dependent to hydropower plant type. If run-of-river hydropower plants water consumption can be considered insignificant (IPCC, 2012; Bakken, 2013), the same does not apply to reservoir-type power plants. In this case, water losses are directly linked to evaporation losses, in result of a larger surface area created by the reservoir. River water discharged is then more susceptible to ambient air and river water temperatures, and pressure, and humidity levels changes. However, the allocation of water use in reservoir is not always trivial. If the reservoir serves different purposes, e.g. public supply, industry use, irrigation, and/or flood control, the water losses due to evapotranspiration should not be directly hold responsible electricity production, but weightily shared between the different uses.

From a water management perspective, it is important to understand the implications to water availability of hydropower use of water, either this being turbinated water or consumptive use. The multipurpose use of reservoirs should be clearly accounted for in order to understand cross-sectoral impacts of use of water and to define adequate priorities in use of water. Also, downstream impacts of cascade systems should be analysed from the perspective of downstream water users and ecosystems. Reservoirs may be filled up with water from different tributaries as well as ground water flows, if this balance is disturbed either caused by abstraction for other uses and/or diversions, water releases in the reservoir may have to be reduced due to low levels. As these are more susceptible to water temperature increase, evaporation rates are also likely increase, leading to higher water losses or consumption.

To exemplify the wide range of estimates, and their variability in terms of location, project scope and methodology, Table 2 summarises values found in the literature for water consumption or blue water footprint of hydropower. Estimates vary between methods and are often linked to specific number of hydropower plants, making it difficult to objectively and accurately compare different results. The most common method used is the gross water consumption method, where the annual evaporation losses from the reservoir surface are divided by the electricity production of the downstream hydropower plant, in the same period. Although this method is often used on a yearly basis, for specific cases it could be relevant to analyse shorter periods, depending on the seasonal changes of climatic parameters and electricity demand load profile. In Bakken *et al.* (2013) two alternative methods are described: the net evaporation method and the water balance. In the net water consumption method, the evaporation prior to the reservoir inundation is subtracted to the reservoir evaporation, and then divided by the annual power generation. This method is especially relevant in cases when a natural lake existed prior to the construction of the hydropower plant. On the third approach, the water balance, direct rainfall to the reservoir is deducted from the evaporation losses, and the result divided by the hydropower annual production. This method is indicated to be contradictory, as evaporation losses may be evened out or surpassed by rainfall, resulting in a negative value for the water footprint, inconsistent with the definition.

Recent studies investigate deeper the contribution of the electricity generation sector to water consumption by assessing the main stages of the process, namely fuel supply, construction and operation (Mekonnen *et al*., 2015a; Meldrum *et al*., 2013).

In Mekonnen *et al*. (2015b), a global analysis of the water footprint of electricity and heat generation was carried out for the period 2008 - 2012, with the global consumptive use of electricity and heat estimated to be 378 billion m^3 per year – an increase of 12% in comparison to 2000. Electricity generation corresponds to 90% of this estimate and the weighted average of the water footprint for electricity to 4,241 m^3/TJ or 15.27 m^3/MWh. For hydropower, the global consumptive water footprint of electricity and heat production was estimated to be of 185 billion m^3, 49% of the global consumptive water footprint. Hydropower water consumption in Europe reached 42 billion m^3, with southern Europe accounting for the least share 1.5% of this amount and Eastern Europe the highest, with 87.3%. In terms of global weighted average for hydropower consumption, the estimate was conditioned by lack of data at the country level, having to be based on estimates for specific countries or regions. The consumptive water footprint for hydropower was estimated to range between 1.08 and 3,060 m^3/MWh with an average of 54.47 m^3/MWh, with construction stage contributing to less than 0.002% to this value and with no fuel cycle costs added. Due to the complexity of the analysis, lack of data and uncertainties, (Meldrum et al., 2013) did not included selected technologies in their study, including hydropower, co-generation, biopower ad ocean power. The value indicated for hydropower present in this study is the same as referred in (Macknick et al., 2012), retrieved from (Gleick, 1994) and (Torcellini *et al*., 2003). This study is focused in the US only.

Table 2. Estimates for hydropower water consumptive use from selected references.

Reference	Water consumption rate (m^3 /MWh)	Region	Comments
Zhao and Liu (2015)	1.5	Three Gorges Reservoir, China	Multipurpose reservoir analysis integrating the economic value of the activities depending on the reservoir in combination with the gross water consumption method. In the case all evaporation losses are allocated to hydroelectricity the water consumption estimate raises to 2.9 m^3/MWh.
Mekonnen *et al.* (2015)	54	Global	Life cycle assessment of the consumptive water footprint of electricity and heat generation
Bakken *et al.*, 2013	33	Average value for climate zone D	Value corresponds to the average of six data points obtained with the gross water consumption method, from hydropower plants in Austria (including the Danube river), Turkey and Canada.
Bakken *et al.*, 2013	0.8 to 34.8	Mandal River Basin, Norway	Analysis of a cascade of six hydropower plants to exemplify how the definition of the spatial boundaries affects the estimation of water consumption. The presented range corresponds to the approach in which evaporation losses of a reservoir are allocated to the closest downstream power plant using the net water consumption method.
Macknick *et al.* (2012)	0 to 68	US	Gross water consumption method. Range resulting from other reference studies (Gleick, 1994; Torcellini, 2003).
Mekonnen and Hoekstra, 2012	245	35 power plants, the majority in the Southern Hemisphere	Average value using the gross water consumption method, with water consumption values ranging from 0.4 to 3,046 m^3/MWh.
IPCC, 2012	209	US	Gross water consumption method.

2.3.2 Water use in nuclear and fossil fuelled thermoelectric power generation

Power plant cooling is responsible for 43% of total freshwater withdrawals in Europe (more than 50% in some countries), nearly 50% in the US, and more than 10% in China (UN Water, 2014). However, the higher withdrawals do not correspond to the highest water consumption. As mentioned before, both withdrawals and consumption of water resources for cooling requirements in thermoelectric plants depend on the fuel use, type of cycle and type of cooling technology. Thermal power plants usually work on a combination of cooling systems and frequently once-through cooling is used in combination with an evaporative tower, reducing the cooling water temperature discharged to water body (Johst and Rothstein, 2014). Table 3 summarises the range of medians of the water use factors in thermoelectric power plants compiled by Macknick *et al.* (2012).

Important at this stage is to understand the differences between cooling technologies. These can be grouped in two main classes, wet or evaporative, if use water for cooling; and dry cooling, if air is used instead. A brief description of the main deployed technologies is provided below (EPA, 2014; Koch and Vögele, 2013; Williams and Rasul, 2008; Johst and Rothstein, 2014):

- *Once-through cooling*: water is withdrawn from a water body that can either be a lake or a river to be used for cooling in the condenser. The amount withdrawn is delivered back to the original water source, increasing temporarily and locally the water body evaporation rate. This system requires considerable amounts of water withdrawals. These cooling systems are more vulnerable to changes in water temperature.

- *Once-through cooling with cooling tower*: Water withdrawn from the water body is used several times, with the rejection heat dissipated when the cooling water evaporates to the atmosphere in a cooling tower. With respect to the once through cooling, water withdrawals are lesser with these technologies, but water consumption is considerably higher, with most of the water (60% and above) not returning to the original water source.

- *Closed-loop circuit cooling or wet recirculating*: the water heated in the condenser is cooled in a tower and directed back to the condenser. This cooling system allows for less water withdrawal requirements and consumption than the conventional open loop cooling with cooling tower. For this type of systems local climate conditions are important, humidity levels and air temperature, as these condition evaporation.

- *Dry cooling*: water is replaced as cooling agent by air, which is used to cool down steam by ventilation. In this way, water consumption can be reduced in more than 90%. The disadvantages of using this type of technology are related to its costs and to the lower cooling efficiencies, requiring more energy to operate. Dry-cooling is mainly used in small capacity plants and in natural gas combined-cycle power plants.

- *Hybrid cooling*: this technology results from a combination of air and wet cooling. Its main objective is to provide the condenser with the lowest possible temperature so it can accommodate the seasonal variations in the ambient temperature and relative humidity with the most economic turbine exhaust backpressure. This can be achieved by a flexible regulation of the cooling system units and not compromising peak load in extreme weather conditions due to water availability.

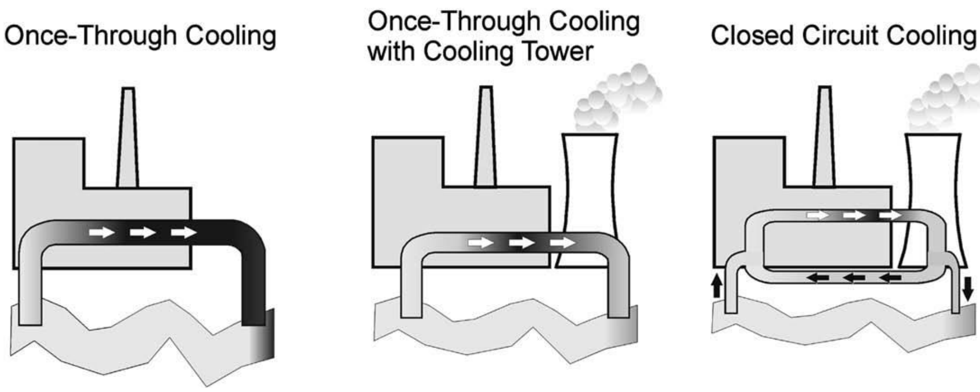


Figure 2. Illustrative examples of cooling systems of power plants (Koch and Vögele, 2009).

Once-through cooling, although representing the higher withdrawal per unit of electricity produced, of over 150 m^3 per MWh produced, is not the cooling technology linked to higher consumption rates. Cooling towers indicate to be, across the fossil fuel and nuclear range, the technology responsible for the greatest consumption of water. Although the water requirement needs for cooling towers is significantly lower than once-through systems, the consumption rate is frequently two times higher than the latter, considering the same fuel and operating cycle.

The use of pond cooling may minimise the amount of water withdrawn from the water body but, due to evaporative losses, water consumption can be significant reaching values close to evaporative towers. See for example the case of a thermal power plant running on coal. For a generic steam turbine cycle, and taking the median values for the analysis, pond cooling would require 60% less water withdrawals but water losses through evaporation will be 120% higher.

When comparing different fuel technologies, but same operating cycle, nuclear and coal power plants are the most water demanding technologies, for the different cooling technologies. Natural gas is the fuel with the lower water footprint in terms of power plant operation. Natural gas in combined cycle power plants requires the least water withdrawals, of around 1.0 m^3 per MWh, when cooling towers are used for cooling; and least water consumption, of less than 400 L of water per MWh of electricity generated, for the use of once-through cooling.

As expected, dry cooling uses a residual amount of water, both for withdrawal and consumption, being mainly used for natural gas based thermoelectric plants.

Also shown in Table 3 is the suggested impact in water use of power plants if carbon capture and sequestration (CCS) technologies are implemented, to reduce the emission of greenhouse gases (GHG) released by fossil fuel based power plants. It is seen that one environmental benefit, the reduction of emissions, does not allow for a simultaneous reduction in water use but in turn, the opposite. The combination of lower plant efficiencies with the deployment of CCS technologies and additional requirements for process water are pointed out by Meldrum *et al.* (2013) and Macknick *et al.* (2012) to justify the increase in water withdrawals and consumption. Byers *et al* (2014) also acknowledges the impacts of CCS in water availability, projecting an increase in water uptake from gas and coal power facilities in the United Kingdom from 14% and 3%, respectively, to 36% and 39%, due to capacity developments equipped with CCS technology.

Table 3. Water use in fossil and nuclear thermal power plants for different cooling technologies (adapted from Macknick et al, 2012).

Fuel type	**Cooling System**	**Technology**	**Consumption (m^3 MWh^{-1})**			**Withdrawal (m^3 MWh^{-1})**			**Consumption-Withdrawal ratio**
			Median	**Min**	**Max**	**Median**	**Min**	**Max**	
Nuclear	Tower	Generic	2.54	2.20	3.20	4.17	3.03	9.84	0.61
	Once-through	Generic	1.02	0.38	1.51	167.88	94.64	227.12	0.01
	Pond	Generic	2.31	2.12	2.73	26.69	1.89	49.21	0.09
Natural Gas	Tower	CC	0.78	0.49	1.14	0.97	0.57	1.07	0.80
		Steam	3.13	2.51	4.43	4.55	3.60	5.53	0.69
		CC with CCS	1.49	1.43	1.54	1.92	1.84	2.06	0.78
	Once-through	CC	0.38	0.08	0.38	43.08	28.39	75.71	0.01
		Steam	0.91	0.36	1.10	132.49	37.85	227.12	0.01
	Pond	CC	0.91	0.91	0.91	22.52	22.52	22.52	0.04
	Dry	CC	0.01	0.00	0.02	0.01	0.00	0.02	1.00
Coal	Tower	Generic	2.60	1.82	4.16	3.80	1.89	4.54	0.68
		Subcritical	1.81	1.49	2.51	2.22	1.75	2.70	0.82
		Supercritical	1.87	1.68	2.25	2.40	2.20	2.54	0.78
		IGCC	1.44	1.20	1.66	1.49	1.36	2.29	0.97
		Subcritical with CCS	3.49	3.41	3.57	5.03	4.63	5.49	0.69
		Supercritical with CCS	3.20	3.09	3.43	4.34	4.16	4.38	0.74
		IGCC with CCS	2.08	1.98	2.29	2.43	1.81	2.81	0.86
	Once-through	Generic	0.95	0.38	1.20	137.60	75.71	189.27	0.01
		Subcritical	0.43	0.27	0.52	102.54	102.38	102.63	0
		Supercritical	0.39	0.24	0.47	85.51	85.36	85.59	0
	Pond	Generic	2.06	1.14	2.65	46.28	1.14	90.85	0.04
		Subcritical	2.95	2.79	3.04	67.81	67.60	67.86	0.04
		Supercritical	0.16	0.02	0.24	56.96	56.77	57.00	0

2.3.3 Water use in non-hydro renewable energy technologies

Water may also play a determinant role in the operation of non-hydropower renewable technologies, namely for technologies which involve thermal generation. This is the case of geothermal and concentrated solar power (CSP) generation facilities. Figure 3 shows a comparison of water consumption per MWh of electricity generated taking into consideration the life cycle of each technology (Meldrum *et al.*, 2013).

Surprisingly, CSP is the technology that consumes more water per unit of electricity produced, if cooling towers are used, offsetting coal and nuclear power plants using the same cooling technology. More interesting even is the fact that the preferential sites for the placement of such technologies are arid regions, with high solar radiation, and where water resources may not be abundant. However, if dry cooling or a hybrid option is used, water consumption can decrease significantly, but in turn will increase the investment costs.

The use of water by geothermal power plants depends on several factors such as the plant size, the working temperature, cooling system, and geothermal water availability. The analysis of the water use and consumption by this technology can be controversial, especially when the geothermal fluid is considered a water resource and is accounted for. Bayer *et al.* (2013) discuss this representation issue highlighting that geothermal fluids cannot be used in wet recirculating systems and are usually discharged back into the source reservoir; and also that make-up water does not exclusively equates to freshwater. Waste heat produced in geothermal power plants is frequently released at the plant site when not used as an energy carrier, i.e. district heating. Nonetheless, if water is required to be used for cooling, consumption can be significant. Air and hybrid cooling are still the least water intensive options with consumption rates ranging from 0 to 2 m^3 per MWh.

With less significant water requirements for operation stand out wind and solar photovoltaic (PV) technologies. As illustrated in Figure 3, solar technologies might require significant amounts of water in the manufacturing phase, while very few during operation. Comparing against fossil fuel sources, for operation needs, only natural gas combined cycle power plant with a dry cooling system could compete with these two RE technologies in terms of the consumptive use of water.

In a global study of the consumptive water footprint of electricity and heat, in three stages of electricity production: fuel supply, construction and operation (Mekonnen *et al.*, 2015b), wind power and solar PV are also pointed out as the least water intensive technologies. Wind power however is the least water dependent technology with maximum estimated global gross water footprint of 0.04 m^3 per MWh of electricity generated during the lifetime of the plant. Photovoltaic electricity generation has its highest share in water consumption during the construction phase, varying between 0.02 and 0.80 m^3 per MWh of electricity produced during operation.

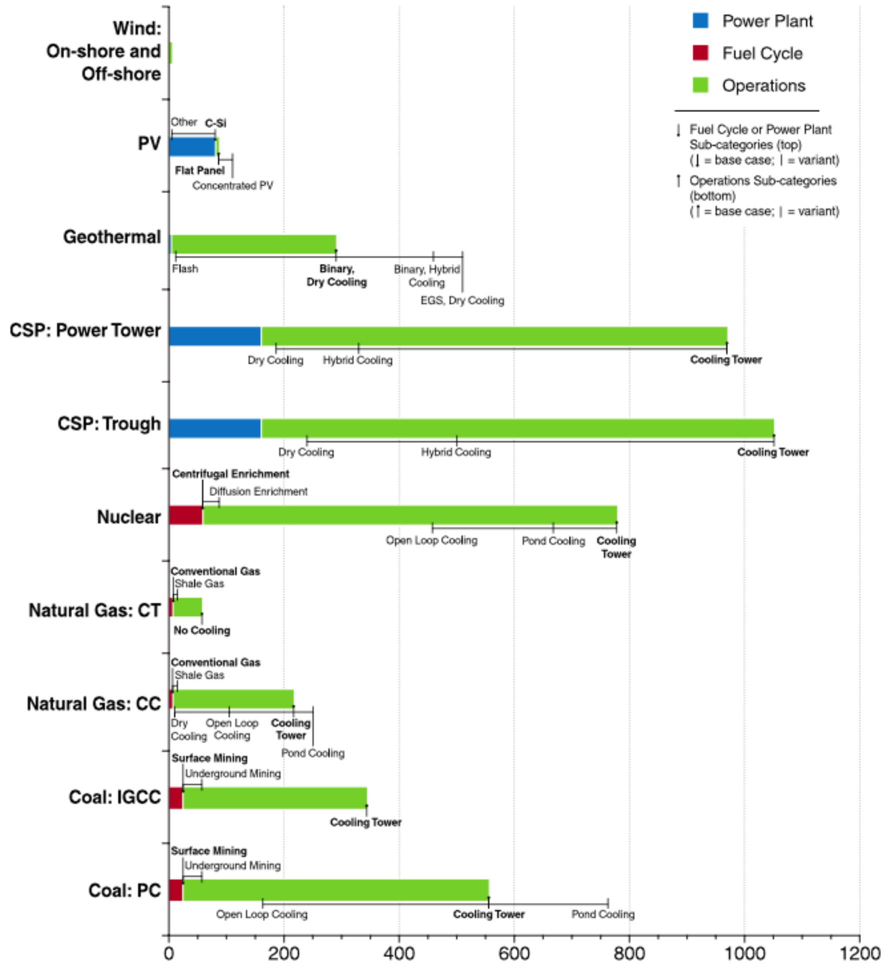


Figure 3. Life cycle water consumption of thermal power plants in US gallons (3.785 L) per MWh (Meldrum et al, 2013).

2.4 Adaptation solutions for water use in thermoelectric generation

Several options are suggested in the literature to prevent or counteract the impacts of water availability constraints on cooling systems of thermal power plants. These span from cooling technology shifting, change in fuel type, balancing electricity generation with non-hydro renewable energy technologies and the implementation of effective water resources management strategies taking into account the energy sector water requirements.

If upgrading cooling systems is necessary due to water stress that limit water abstractions, dry cooling systems or the use of the hybrid counterpart would reduce significantly water withdrawals in comparison to once-through or pond-cooling systems; and water consumption, in substitution of cooling towers. Hybrid cooling systems are particularly indicated to adapt to seasonal changes of flow, when flow rates are too low to allow for normal operation of the power plant, or when the temperature of the watercourse is too high to be withdrawn. Another factor could be due to environmental regulations, in terms of water temperatures and minimum flow requirements. However, the deployment of such systems requires energy to function and can be linked to a reduction in the power plant output of 3 to 11%, depending on the ambient temperature (Byers *et al.*, 2014).

In regard to use of multiple water sources, (Byers *et al.*, 2014) based on the study focused on the United Kingdom example, identify as a possible solution to regions where water vulnerability might be an issue in the future, the distribution of thermal capacity to locations where another source of cooling water could be used, i.e. tidal water and seawater. This is also the case for countries where inland surface water abstractions is not a possibility, and power plants are mostly located by the sea or in low coastal areas drained by tidal streams.

Alternatively, it is proven to be technologically feasible the use of municipal wastewater in thermoelectric cooling purposes (Macknick *et al.*, 2012). The choice for this option would depend on the distance from the wastewater treatment facility and the thermal power plant, and would probably require adaptation of the cooling system. In the US, the nuclear power plant Palo Verde, located in Arizona, uses this type of cooling source for its closed-cycle cooling system. The use of waste water allows for daily water savings of 208 thousand m^3 of freshwater, equivalent to 76 million m^3 of freshwater per year (NRDC, 2014).

Another option possible would be the diversification of the electricity generation mix, thus lowering its dependency from water-reliant technologies, such as hydropower and thermal power plants. As seen before, the most advantageous technologies in this case, would be wind power and solar PV, as the least water consumption alternatives. This type of technologies, if potentially deployable, would be especially interesting in covering peak demands in warmer periods. A study by Johst and Rothstein (2014) focused on assessing the contribution of wind power and PV to the reduction of water consumption by thermal power plants in Germany during the period between July 2011 and June 2013. The analysis indicated that cooling water requirements from coal power plants reduced between 4 and 11%, depending on the season. It was also found that the major reductions were verified during the spring and autumns months matching with periods of medium and high electricity demand. Figure 4 elucidates the reductions in water consumption on the Neckar River, which supplies the three power plants in the Baden-Wüttemberg region, one nuclear and two running on coal, estimated for one week in September 2013.

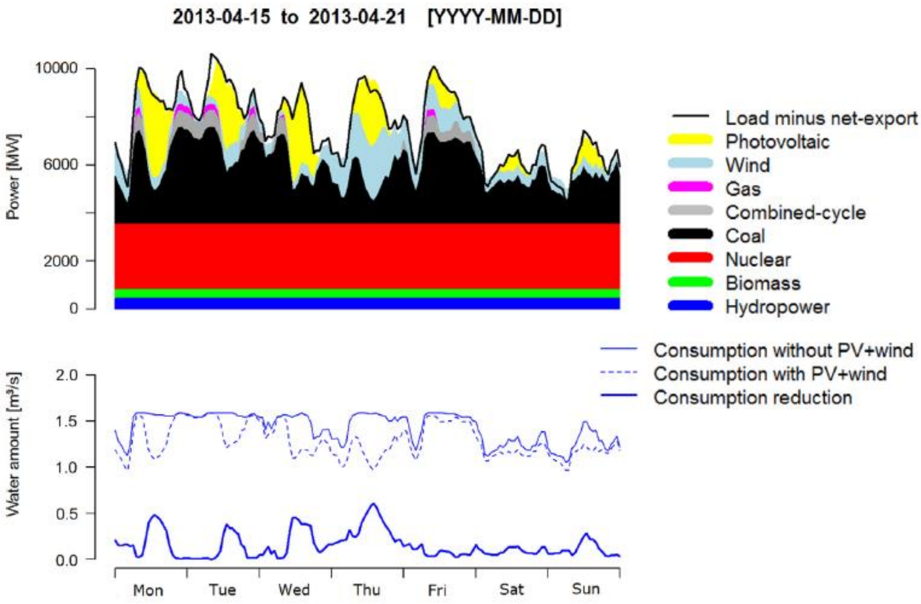


Figure 4. Reduction in cooling water requirements of coal thermal power plants in the Badden-Wüttemberg region (Germany) due to the contribution of PV and wind power (Johst and Rothstein, 2014).

Reasonable planning approaches are required for the implementation of most technical solutions listed before. Regulation plays a definite role in water conservation in the energy sector. Also, the communication between electric power utilities and local, regional and national authorities could contribute to avoid the construction of power plants in basins with increased water stress (Tidwell *et al.*, 2012). The design of integrated water and energy policies could allow for the identification of crucial vulnerabilities of water systems, which if not pondered in advance could not just affect electricity generation but also curtail the functioning of other sectors, affect water public supply and/or impact the environment. Additionally, the necessity of balancing trade-offs can be anticipated and appropriately accounted for. An example is the deployment of CCS technologies to restrict GHG emissions by thermal power plants, which may have an additional water requirement that might not be feasible in the future. In that case, reduction in water availability would require higher fuel consumption, potentially offsetting the aimed emission reduction. Other factors subject to the energy-water interlinkage, such as the cost of production electricity and security of supply, have also to be adequately pondered when planning energy and water strategies (Byers *et al.*, 2014).

2.5 The interdependence between water and energy

As noted in the previous section, the most frequently deployed electricity production technologies depend on water to operate. The degree of dependence is variable as are the impacts on water availability caused by the use of water, with an important distinction to be made when analysing the water-energy interlinkages, between withdrawals and consumption. This section explores the one-way implications of one system over the other, i.e. how water affects electricity generation and, inversely, how energy systems impact water resources; seeking to facilitate the comprehension of the complex interactions under investigation.

2.5.1 How water constraints influence electricity generation

Water sources can impact considerably the operation of power plants, curtailing or interrupting electricity generation. Three types of physical constraints related to water availability and quality are often cited in the literature (Byers *et al*, 2014; Ebinger and Vergara, 2011; IEA, 2012; Koch and Vögele, 2013) as impacting directly electricity production: a) water shortage and low water flows; b) high temperature of water intake; and, c) temperature of water discharged above the regulated limits. The constraints linked to water temperature affect mostly the operation of thermal power plants. The latter mentioned limitation can be particularly important when the same water body supplies water to several power plants.

A reduction in the water flow when a thermal power plant is working at a constant generation rate causes the increase of the condenser temperatures, which in turn result in the increase of the temperature difference between the condenser inlet and the condenser outlet. This could particularly represent an issue during warmer periods, frequently linked to higher electricity demand for cooling. The increase of the condenser temperature leads to a higher turbine exhaust pressure, and in consequence, to the reduction of turbine efficiency. Higher flow levels are better from an operational perspective (EPA, 2014).

The other two factors related to the temperature of the water body have similar consequences, reducing the efficiency and the load, limited by the maximum condenser pressure. The cooling system becomes less efficient due to the lower temperature difference.

Baseload plants, usually coal and nuclear, which have a constant demand for heat rejection, due to operating continuously, are likely to be more vulnerable to lower flow conditions. Regulations may apply differently in these cases, as they are more susceptible to the impacts of water availability and temperature, and energy security might need to be prioritized. Another outcome could be the rise of energy prices in periods of water shortages, affecting large regions (Koch and Vögele, 2013), due to the need of increasing electricity imports.

All of these conditions, mainly induced by climate variability and enhanced by competing uses of water resources, are known to affect power systems imposing restrictions to their operation. Examples of such events are listed in Table 4.

Table 4. Examples of impacts of water constraints in power generation worldwide (Ebinger and Vergara, 2011; IEA, 2012; Rebetez et al, 2009; Rübbelke and Vögele, 2011; FAE, 2015).

Location / year	Description
France, 2003	An extended heat wave forced EdF to curtail nuclear power output equivalent to the loss of 4,000 MW of capacity, costing an estimated €300 million euros to import electricity.
Midwest United States, 2006	High water temperature of the Mississippi River, in result of a heat wave, forced nuclear plants to reduce their output.
Southeast United States, 2007	Water conservation measures during a period of drought, imposed by Tennessee Valley Authority curtailed hydro generation and reduced output from nuclear and fossil fuel-based plants.
Vietnam, Philippines (2010)	A several months long drought, caused by El Niño, led to reduction in hydro generation causing electricity shortages.
China, 2011	Limitations in hydro generation along the Yangtze River, induced by drought, contributing to the higher coal demand (and prices) and forced some provinces to implement restrictions to electricity access.
India, 2012	Electricity blackouts derived from reduced hydro generation and increase in energy requirements to power irrigation systems, affecting 600 million people.
France, Spain and Germany, 2006	The 2006 heatwave caused the curtailment of power output from nuclear plants with some given special exemption to discharge water with temperature above the regulated limit.
France, 2009	Cooling water shortages due to a summer heat wave in 2009 led to the operation curtailment of a third of the French nuclear power stations. Electricity was imported from the United Kingdom.
Poland, 2015	A heatwave in the summer of 2015 in combination with unfavourable hydrological conditions of main rivers in Poland resulted in a power deficit in the Polish power system. In consequence, the national TSO had to impose limits to power supply for industrial consumers until the end of August.

Electricity trading along with appropriate water management governance can have an important role in buffering the drawbacks of constraints to water resources. As it was seen in Table 4, the events were triggered from extreme climate conditions like droughts and heatwaves. These types of events propagate in different scopes, and do not affect solely water systems. Thus, power systems are affected by different fronts and problems related with electricity supply do not happen in isolation. It is important to note that in in drier weather conditions, electricity demand increases due to higher cooling requirements. Transmission and distribution systems are also affected, as losses increase with the increase of ambient air temperature.

The vulnerability of power systems to climate variability, which directly impacts water systems, needs to be properly accounted for in medium and long term planning of energy systems. If climate change projections verify, some regions will likely be affected at different levels, including their power systems infrastructure either in terms of supply as demand side.

2.5.2 How electricity generation impacts water availability and quality

Many factors determine the extent of the impact of the operation of electricity production technologies on water availability, quality and, consequently, on the environment. If on the one hand these factors are transversal, on the other they are specific according to the technology type.

From the water resources perspective, such factors include geophysical configuration, the region's climate and water use profile, which is an external conditioning. This variability is then subjected to strains induced by the water requirements for electricity generation dependent on the technology type, its characteristics and location.

As seen before, water consumption varies significantly between technology types and within the same technology. However, the span of the impacts span is not directly proportional to the use, with their implications or consequences needing further examination to understand the cumulative results of water use in electricity production. These will then allow a better understanding of the potential implications and clashes with other water use sectors.

Hydropower plants, as the least consumptive users of water in regard to their water-dependence, are responsible for well-known impacts over watercourses and the environment. These trade-offs with energy production vary in severity and are closely linked to reservoir or dam-type plants. This type of technology, while interfering with the natural configuration of the river, creates artificial barriers to the flow and fish migration, through the creation of artificial lakes; imposing flow regulation, therefore altering the natural seasonal flow, and promote sediment accumulation (IPCC, 2012). These alterations will have negative implications for the ecosystems prompted by stratification in reservoirs in result of changes in depth, temperature increase due to low discharge, changes in riverside vegetation, which decrease contributes to less shaded area and increase watercourses' vulnerability to ambient air temperatures.

Water is used in thermal power plants for different reasons, both for process, anti-fouling, general wash, and, most importantly from the water consumption point of view, cooling. It is estimated that around 75% of the abstracted water for cooling is loss through evaporation in the cooling towers and the temperature of the effluent water to be 5 to 15°C above the ambient temperature (Perry and Vanderklein, 1996). When cooling towers are used, evaporative water is not returned do the watercourse once abstracted, affecting water availability downstream. More water has then to be withdrawn for cooling, as the remainder condensing water is over concentrated in salts, potentially dissolved air pollutants, heavy metals and biocides. The quality of the water discharged to the river is therefore different from the water initially abstracted.

Run-through or river pond cooling systems also have impacts on water quality, as increased water temperatures cause the decrease of oxygen solubility, proliferation of some species and endangerment of others. The natural seasonality of the water sources is also affected and conditioned by the variability of power production.

Both sets of impacts from the two power production technologies discussed can result in impacts to climate at the local/regional level due to the interference in the natural water cycle which can be expressed in the form of micro-climate conditions, decreased water flow downstream, decrease of water availability for other sectors and disruption of ecosystems services.

2.6 CHAPTER SUMMARY

The present chapter was dedicated to the analysis of the interactions between energy and water resource systems. Special focused was given to the "water for energy" direction, in order to inform about the how the power generation sector is dependent on water and how it can be impacted by water availability constraints. A brief review of the nexus approaches was provided to stress the importance and relevance of integrated assessments.

3 THE SAVA RIVER BASIN STUDY CASE

3.1 CONTEXT

Rivers act as natural boundaries in a landscape and can simultaneously be used as foundation to political borders between states. The Sava River basin (SRB) is located in the Southern Eastern Europe, spreading across the territories of six Balkan countries: Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and Albania. Its basin represents close to 12% of the Danube River Basin, draining to the Black Sea (*ISRBC 2013a*, 2013). The classification of the Sava River as an international watercourse is relatively recent, dating from early 1990s after the dissolution of former Republic of Yugoslavia. In fact, when the Kingdom of Yugoslavia was created after the First World War, the provinces of the Kingdom were named after the main river of each region (see Figure 5). The northwest region was known as Drava and from when the Sava River begins, extending over what corresponds now to central Slovenia and western Croatia, limited by Hungarian border and the Adriatic Sea, was the province called Sava.

Figure 5. Provinces of the Kingdom of Yugoslavia in the period 1929 -1939 (ReISS, 2014).

Throughout the 20th century the political boundaries of the now SRB countries assumed different configurations. From 2006 on, when Serbia and Montenegro became independent states, the share of Sava River water resources acquired the present geographical representation that can be seen in Figure 6. The capital city of each country is also shown on the map.

Figure 6. Sava River Basin and riparian countries political boundaries (UNECE, 2011).

It is clear the distribution of basin area is not equal among the riparian countries. Around 65% of the basin area, of a total of 97,500 km^2, is distributed between Croatia and Bosnia and Herzegovina. A section of the political border between these two countries is in fact a stretch of the Sava River, connecting Jasenovac, in Croatia, to Vrsani in Bosnia and Herzegovina, after which the border with Serbia starts. However, different shares of the basin do not directly correlate with the basin importance in terms of national territory. With the exception of Serbia, the share of the national territory of the remainder countries goes from approximately 50% and above, reads Table 7. Bosnia and Herzegovina stands out with the highest share of the basin, with close to 76% and, expectedly, with the longest river network. Note that for this case study five out of the six SRB countries were analysed, with Albania being excluded from the analysis due its low relevance in terms of basin area share, with less than 0.2%.

Understandably, the Sava River will have different significance from each country's perspective, depending on the type of activities that take place in each area and the distribution of human settlements. The SRB accommodates approximately half of the 18 million people living in the five countries (*ISRBC*, 2013a). The river waters cross two capital cities: Ljubljana, in Slovenia, and Zagreb, in Croatia. Sarajevo, capital city of Bosnia and Herzegovina, is also located in the basin, as is Beograd, in Serbia. For this case, the Serbian capital lays at the confluence point of the Sava with the Danube River.

Table 5. Area and share of national territory of the Sava River Basin in each country. Adapted from ISRBC (2013a).

Country	Share of national territory in the SRB (%)	Area of the country in the SRB (km^2)	Share of SRB area (%)	Length of national SRB river network (km)
Slovenia (SI)	52.8	11,734.8	12.0	675.2
Croatia (HR)	45.2	25,373.5	26.0	1,816.2
Bosnia and Herzegovina (BA)	75.8	38,349.1	39.3	2,273.1
Serbia (RS)	17.4	15,147.0	15.5	904.78
Montenegro (ME)	49.6	6,929.8	7.1	356.2
Albania (AL)	0.6	27,398	0.2	n.a.

The basin is strategically important for all the riparian countries, which depend on the region's resources for many economic activities, from agriculture, industry, power production to navigation and tourism.

3.2 TOPOGRAPHY, CLIMATE AND HYDROLOGICAL CONTEXT OF THE REGION

The Sava River results from the union of two headwaters in the Julian Alps of Slovenia - the Sava Dolinka, emerging from the Nadiža Creek; and the Sava Bohinjka, which starts from the springs of the valley of the Triglav lakes. These two headwaters converge in Radovljika, in north-western Slovenia, forming the Sava River. The river then flows through Slovenia, Croatia, along the border between Croatia and Bosnia and Herzegovina, and finally through Serbia until it reaches Belgrade, discharging to the Danube.

TOPOGRAPHY

The Sava River extends over a length of approximately 950 km. Its main tributaries are the rivers Una (shared between Slovenia and Croatia; the Vrbas, Bosna, in Bosnia and Herzegovina; the Drina, natural border between Bosnia and Herzegovina and Serbia; and the Lim and Tara, tributaries to the Drina that flow in the territories of Montenegro, Serbia and Bosnia and Herzegovina. Along its way to the river mouth, the Sava flows through a diverse landscape from the Julian Alps and the Dinarides upstream, and through the Pannonian plain, with floodplains that typify the right bank of the basin, as it can be seen in *Figure 7*. Elevation in the basin varies significantly from 71 m.a.s.l. at the river mouth to the highest altitude of 2,864 m.a.s.l. in the Triglav lakes, in Slovenia (*ISRBC*, 2009). The right tributaries to the Sava stream mostly through rugged mountains until they reach Sava or other main tributary. Close to 55% of the basin area is covered by forests and semi natural areas, followed by agricultural land (42%), while settlements and other artificial areas occupy a share slightly above 2% (Komatina and Grošelj, 2015).

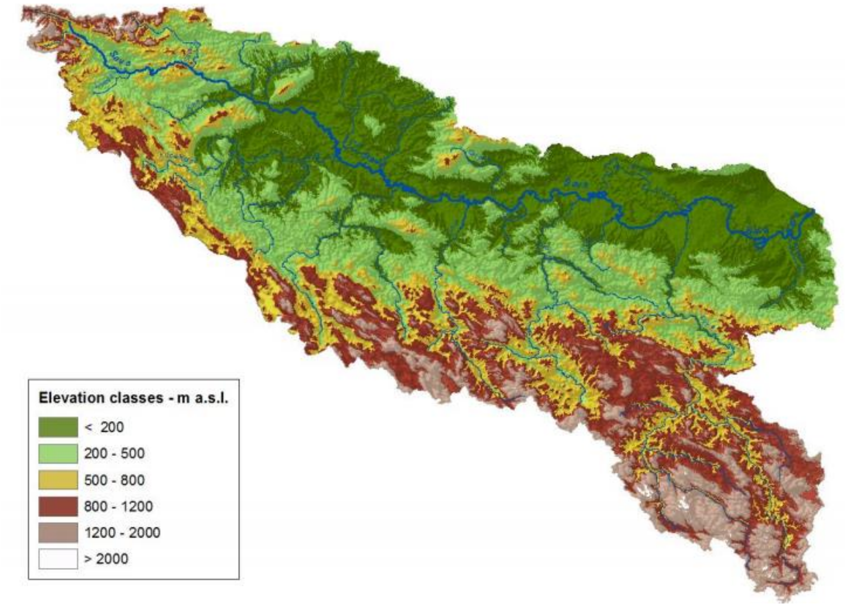


Figure 7. Topography of the Sava River Basin (ISRBC, 2013a).

CLIMATE

An overview of the types of climatic conditions that characterize the SRB region is illustrated on Figure x (Peel *et al.*, 2007), based on the Köppen-Geiger classification, and supported by each climate type description on Table x. The climate in the basin varies from Alpine upstream and moderate continental in the middle part of the basin and in the region of the catchments of the right tributaries. As for the left tributaries' catchments, in the Pannonian region of the basin, evidence predominantly characteristics of mid-European moderate continental climate (*ISRBC*, 2010). Three main drivers affect the climate in the region: temperature, precipitation and evapotranspiration. These climate parameters vary greatly in the region. In overall average terms, the annual air temperature is estimated to be about 9.5°C, varying from a mean temperature in January of -1.5 °C to close to 20°C in

July. Annual precipitation corresponds to 1,100 mm and the average annual evapotranspiration of the basin area is estimated to be 530 mm.

Below a description of each riparian country is provided as an effort to understand differences that characterize the SRB region in this transboundary context. Whilst direct impacts on the basin area affect water resources in the region and their related activities, external conditions must be acknowledged as these can either act as agents of pressure or allowing for buffer compensation.

Slovenia's location between the Alps, the Dinaric Mountains, the Adriatic Sea and the Pannonian plain justifies its diverse climate in relation to its territory area. Slovenia's central and eastern regions are characterized by a continental climate, while the northwest, closer to the Alps, with Alpine climate; as for coastal areas, sub-Mediterranean conditions are verified. Precipitation is unequally distributed, with lowest rainfall registered usually in the north-eastern part of the country and by the coast. On the other hand, highest precipitation levels are recorded in the Julian Alps and the Dinaric range, which serve as physical boundaries for the Mediterranean climate influence (DMCSEE, 2011).

In Croatia the climate is mainly of two types: continental climate with warm summers on the eastern part and on the left bank of the Sava River, and a temperate climate, with hot summers, on the side of the Adriatic Coast, resembling characteristics of a Mediterranean climate. Climate of the subtype *Df*, corresponding to a humid snowy forest climate, prevails in the regions above 1,200 m and in the Dinaric Alps (*MENP-HR*, 2014). The mean annual precipitation can vary from 300 mm to 3,500 mm. Lower precipitation is frequently registered in the southern Adriatic islands and in the eastern regions. In the islands and coastal areas of central and northern Dalmatia, precipitation can range between 800 to 900 mm. In the Pannonian basin, rainfall decreases from the west to the east and, in general terms, the amount of precipitation increases from the coast to the inland. Higher rainfall levels are recorded on the slopes and peaks of the coastal Dinaric Alps (DMCSEE, 2011). January is usually the month when lowest temperatures are recorded, while the hottest month is generally July.

With a similar type of climate is Bosnia and Herzegovina. Continental climate influences a significant area of the territory, complemented with a share of temperate climate, with warm summers, which affects mostly the north and central regions – the Pannonian lowlands located along the Sava River and in the foothill areas. On the other hand, the coast and Herzegovian lowlands present a Mediterranean and modified Mediterranean climate. Alpine climate characterises the mountain regions of the Dinarides (*MSPCE-BA*, 2013). Precipitation in the continental part of the Danube River catchment area occurs mainly in the warmer part of the year, with maximum levels recorded usually in June. In this region that coincides with the SRB, annual precipitation corresponds to an average of 800 mm.

Higher levels of precipitation of around 2,000 mm/year are registered in central and south-eastern areas. In the mountain regions, precipitation patterns are influenced by the Mediterranean Sea, with monthly maximum values of rainfall being recorded in late autumn and in the first winter months. Analysis of historical records between 1981 and 2010 indicate a decrease of annual precipitation in the lowlands whereas an increase was verified in the mountains. In comparison to the 1962-1990 period, in the last three decades a more uneven distribution of precipitation was noticed, linked to more frequent droughts and flood (*MSPCE-BA*, 2013).

The climate in Serbia is majorly of the temperate continental type in the north, with cold winters and hot humid summers with well-distributed precipitation patterns. The southern part of the territory the climate is influenced by the Adriatic Sea, with hot and dry summers and autumns, and moderately cold winters with heavy inland snowfall (DMCSEE, 2011). Above 1,000 m altitude, continental climate prevails. Similarly to Croatia, the coldest month of the year is January whilst July is the warmest. Accumulated annual precipitation is frequently higher in mountainous regions, ranging from 800 to 1,000mm per year. In the Sava and great Morava regions, as well as in the South Morava valley, annual precipitation ranges between 600 and 700 mm (*MESP-RS*, 2010).

In Montenegro the climate is subject to the closeness to the Adriatic Sea and the mountains' massifs, shifting from Mediterranean to Alpine, depending on the altitude. Several transitional climates prevail between more prominent climate-defined areas. As expected, precipitation patterns vary throughout the territory with the highest values registered in the mountain ranges closer the coastal areas (in average 4,500 mm/year), reducing towards the coast and more intense in the north and north-eastern regions (DMCSEE, 2011), where average annual rainfall may not exceed 800 mm (*MSDT-ME*, n.d.)

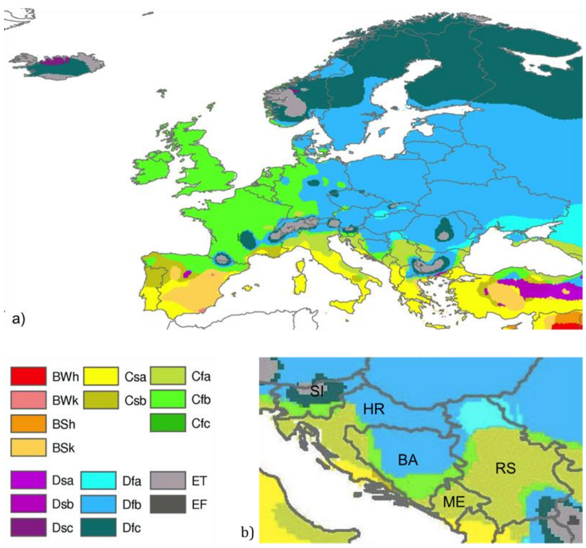


Figure 8. Climate type map according to the Köppen-Geiger classification. a) Europe; b) SRB region. (Adapted from Peel et al. (2007).

Table 6. Description of the Köppen-Geiger climate types in the SRB region. Adpated from Peel et. al. (2007).

Köppen-Geiger classification	Description	Countries
ET	Polar, Tundra	SI, RS
Dfc	Cold, without dry season, cold summer	SI
Dfb	Cold, without dry season, warm summer	SI, HR, BA, RS
Dfa	Cold, without dry season, hot summer	RS
Cfb	Temperate, without dry season, warm summer	SI, HR, BA, ME, RS
Cfa	Temperate, without dry season, hot summer	SI, HR, BA, ME, RS
Csb	Temperate, dry summer, warm summer	HR
Csa	Temperate, dry summer, hot summer	HR, BA, ME

HYDROLOGY

The Sava River, although not being the longest tributary to the Danube is the biggest by discharge. At the confluence point in Belgrade, the Sava River reaches the Danube with an average flow of 1,700 m^3/s (*ISRBC*, 2013a). An overview of the mean, maximum and minimum discharge is shown on *Figure 9*, corresponding to the gauging stations identified with numbers 1 to 9 on Figure 6. Taking the analysis of the mean discharge along the Sava River it is noticed that it generally increases to the river mouth. Mitrovica is the last river gauging station, in Serbia, before the river joins the Danube in Belgrade.

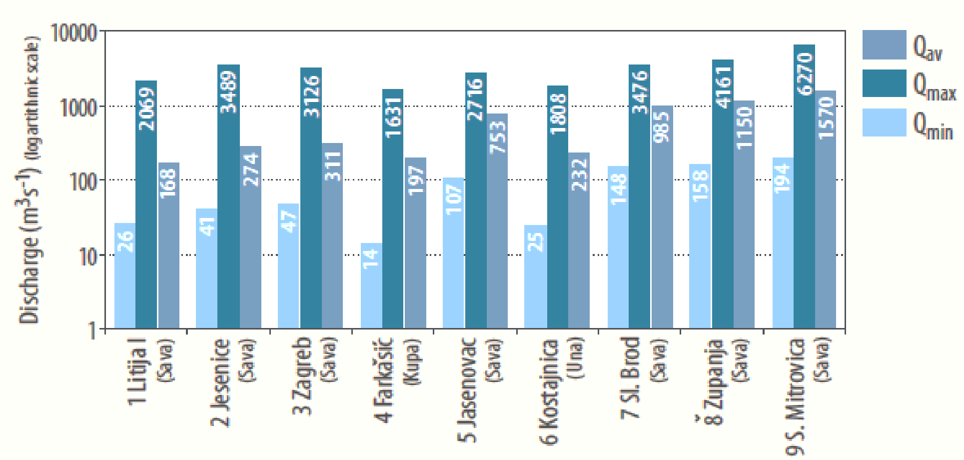


Figure 9. Discharge values in different locations along the Sava River (UNECE, 2011).

The hydrology of the basin is dominated by the interaction between different climate variables: precipitation, run-off and evapotranspiration. In turn, these are largely dependent on other factors, climatic and physical, such as temperature, geology of the basin and topography.

Precipitation varies between 600 mm and 2,300 mm, with the largest amounts of rain falling in the upper parts of the catchments of the rivers Kupa, Piva, Tara, Una, Vrbas and Drina. Lowest precipitation is registered in north-eastern part of the basin located in Croatia and Bosnia and Herzegovina. Following a similar pattern as precipitation is runoff, ranging from 150 mm/year up to 1,200 mm/year. The tributaries with higher water yields from run-off are located mainly upstream, in the more rainy area. Right tributaries, with exception of Bosut and Kolubara, in Serbia, have higher water yields than left bank tributaries, with exception to the River Savinja in Slovenia.

Floods periodically affect the middle and lower part of the basin, in result of cumulative effects of precipitation, run-off and the topography of the region. These events are more frequent in spring, longer in duration with origin from snow melt; and in autumn, of short in duration but more extreme prompted by heavy rainfall (*ISRBC*, 2013c).

Evapotranspiration is also heterogeneous. Long-term values vary from 320 and 620 mm/year. Evapotranspiration is higher in the Central Posavina, northeast of Bosnia and Herzegovina, and in the catchments of Lonja, Ilova and Kupa River. The lowest rates are verified in the upper part of the catchments of the rivers Bosna, Vrbas and Drina; and in Slovenia, in the upper catchments of the rivers Kupa and Una (*ISRBC*, 2013c).

The most relevant tributaries to this study, with catchment areas larger than 1,000 km^2, are listed on Table 7 and can be identified in Table 8. The riparian countries for each watercourse are also identified, with many of the selected tributaries sharing transboundary status.

Groundwater in the basin is greatly dependent on the geomorphology of the region. Aquifers in the basin can be grouped in two types: intergranular, in the Pannonian Basin; and limestone aquifers, along the Interior Dinarides (*ISRBC*, 2009).

Aquifers in the Pannonian Basin, over which most of the public supply relies, can be in turn subdivided in two groups: block of deposits of Pliocene age; and fluvial deposits of the Sava River and of its tributaries. In the Interior Dinarides, the predominance of limestone allows for the discharge of large amounts of water in karst wellsprings on contact with impermeable stones. This type of aquifers with high quality water is found in all countries in the basin. With low level of exploitation, greatly due to the inaccessibility of the resource, these groundwater sources are essentially used for domestic supply and industry purposes (*ISRBC*, 2009).

Table 7. Details of selected rivers in the Sava River Basin (ISRBC, 2013a).

River Name	River Basin area (km²)	River length (km)	Countries sharing the basin	Tributary order
Sava	97,713.2	944.7	SI, HR, BA, ME, RS	-
Savinja	1,860.0	40.0	SI	1st
Krka	2,247.0	94.7	SI	1st
Una	9,828.9	157.2	HR, BA	1st
Sana (Una)	4,252.7	141.1	BA	2nd
Vrbas	6,273.8	235.0	BA	1st
Bosna	10,809.8	272.0	BA	1st
Drina	20,319.9	335.7	ME, BA, RS	1st
Piva (Drina)	1,784.0	43.5	ME, BA	2nd
Tara (Drina)	2,006.0	134.2	ME, BA	2nd
Cehotina (Drina)	1,237.0	118.7	ME, BA	2nd
Lim (Drina)	5,967.7	278.5	AL, ME, RS, BA	2nd
Uvac (Lim)	1,596.3	117.7	RS, BA	3rd
Kolubara	3,368.4	86.7	RS	1st

3.3 THE ISRBC AND THE TRANSBOUNDARY MANAGEMENT OF WATER RESOURCES

The International Sava River Basin Commission (ISRBC) is the intergovernmental body responsible for the management of the water resources of the Sava River, promoting the dialogue and intervention from the several national institutes/authorities who manage the SRB waters at the national and local level, and administering the implementation of the Framework Agreement of the Sava River Basin (FASRB, 2002).

The ISRBC was formally established in June 2005, in result of a process that started in 2001, when the Sava River Basin Initiative was launched. At this stage, Montenegro was not involved in the agreement, as the country only officially separated from the former Republic of Serbia and Montenegro in 2006.

The newly formed riparian nations agreed on the establishment of cooperation efforts amongst the countries shaped into a Letter of Intent in November 2001. One year later, in December 2002, the FASRB was signed. It was its implementation that led the way for the creation of an entity, which would take lead in the coordination of the transboundary management issues. The ISRBC was established in 2005 with the Secretariat appointed in 2006.

The FASRB envisages the realisation of three main goals[2]: the establishment of an international regime of navigation on the Sava River and its navigable tributaries; the establishment of sustainable management of the basins' water resources; and undertaking measures to prevent or limit hazards, as well as reducing or eliminate the effects of floods, droughts, ice, and accidents related to the release of hazardous substances into the water system. The accomplishment by the ISRB of these objectives is possible through a group of activities which span from the coordination and development of plans for the SRB, which includes the SRB Management Plan and the Flood Risk Management Plan; the coordination of the establishment of integrated systems for monitoring the basin's resources, forecasting and emission of early warning systems; the elaboration of development plans or other strategic documents, including the coordination of studies and projects in the SRB; the harmonisation of national and, when applicable, European Union regulation; engage the cooperation and participation of the public through public consultation of draft reports or through local community, Non-Governmental Organizations and stakeholders' meetings.

The main challenges identified by the ISRBC to be targeted in the Sava River Management Plan (ISRBC, 2013a) and identified as the high priority pressures in the management of water resources include (ISRBC, 2013d) the pollution from organic compounds, nutrients and hazardous substances, hydro-morphological alterations in the basin, groundwater quality, floods, and hydropower operation. A series of other issues identified as investigation targets in the future relate to the pressures and impacts to groundwater quantity, the quantity and quality aspects of sediments, invasive species and the management of water demand.

3.4 Socioeconomics of Sava River Basin and of riparian countries

The difference in the socio-economic circumstances of the SRB region can be greatly explained with the difficult period the countries went through in the recent past, after the disaggregation of the Republic of Yugoslavia in 1991, followed by a sequential set of wars along the nations. Slovenia and Croatia were the first states to declare independence and regain recover from the conflict. This was not the case for the remainder countries, where war consequences were more severe. Serbia's economy faced a slowdown during that period in result of the conflicts and sanctions imposed to the country, hampering the ability to restore the level of development. Bosnia and Herzegovina post-war recovery is developing at a slow pace and was recently exacerbated by the crisis in 2009.

[2] http://www.savacommission.org/

The riparian countries socioeconomic context varies significantly between upstream and downstream nations. Slovenia was the first country of the SRB region to join the European Union, in 2004, followed by Croatia in 2013. These two countries perform better in the economic indicators shown on Table 8, with the Gross Domestic Product (GDP) per capita illustrating the economic detachment of the latter from the downstream countries circumstances

Table 8. Selected socio-economic indicators of the riparian countries for 2012.

	SI	HR	BA	RS	ME
Population	2,055,496	4,284,889	3,836,000	7,186,862	620,029
Unemployment rate (%)	12.0	13.5	27.5 (2014)	24.6	19.7
Net income (EUR)	991	729	457	-	487
GDP (million EUR)	36,006	43,923	12,774	29,601	3,152
GDP per capita (EUR/capita)	17,506	10,294	3,430	4,112	5,078

Sources: SI Stat'o'Book 2013; Croatia in Figures 2013; BA Agency for Statistics Institute for Statistics; RS Statistical Yearbook 2013, 2014; Montenegro Statistical Office, 2013, 2013 Statistical Yearbook.

In terms of GDP structure, from the production perspective, all countries depend largely in the services sector, which valued added represents over 60% of each country's GDP. The agriculture sector indicates to be more relevant for southernmost countries, as it can be seen in Figure 10. Montenegro complements the revenues from industrial activities with the tourism sector, which represents one of the most important economic drivers of the country.

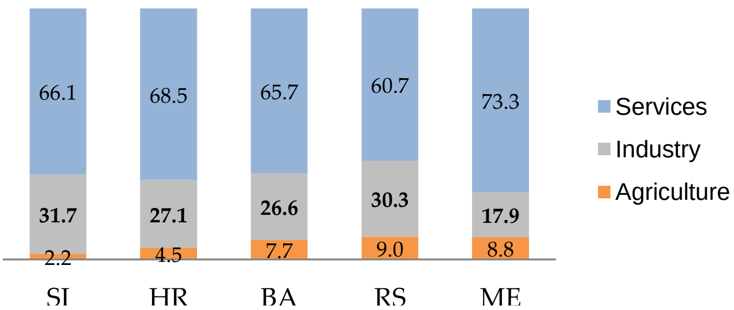


Figure 10. GDP structure per sector in 2012 (source: World Bank Database)

3.5 AGRICULTURE AND WATER USE

The SRB water resources constitute nearly 80% of the total freshwater resources in the five countries (ISRBC, 2009). Domestic supply in the region relies mostly on groundwater extraction, representing close to 90% of the supply (ISRBC, 2013a). Agriculture and industry sectors also depend on this type of resource, but not so extensively.

The main uses of SRB water are public supply and operation of thermal power plants. Demand from the agriculture sector is does not go beyond 17% of the water consumption, with the use for irrigation representing only 5% of the overall water demand in the basin, as it can be seen in Table 9. Bosnia and Herzegovina and Serbia are the countries were more water is used for this purpose, while Slovenia and Montenegro consume less than five million m³ annually for irrigation.

Table 9. Sectoral water demand by country in the SRB – scenario for 2015 based on data from 2005 (ISRBC, 2013a).

Country	Public Water supply (M m³)	Industry (M m³)	Thermal and nuclear plants (M m³)	Irrigation (M m³)	Other Agricultural (M m³)	Total water demand (M m³)
SI	86	42	570	0.4	135	833
HR	220	90	105	75	220	710
BA	415	135	59	56	83	747
RS	264	84	1,733	73	91	2,244
ME	9	2	5	4	2	22
Total SRB	994	354	2,472	208	530	4,557
Share	22%	8%	54%	5%	12%	100%

The water use profile varies between countries. Slovenia and Serbia make use of SRB water for cooling requirements of thermal power plants, as are the cases of the Krsko Nuclear power plant in Slovenia, and the Tesla A and B, Kostolac and Kolubara coal power plants in Serbia. Bosnia and Herzegovina, due to its large share in the basin's area, is the country with higher withdrawals for public water supply. Figure 11 illustrates the different uses of SRB water resources per country and by sector of activity, based on the data presented in the table above.

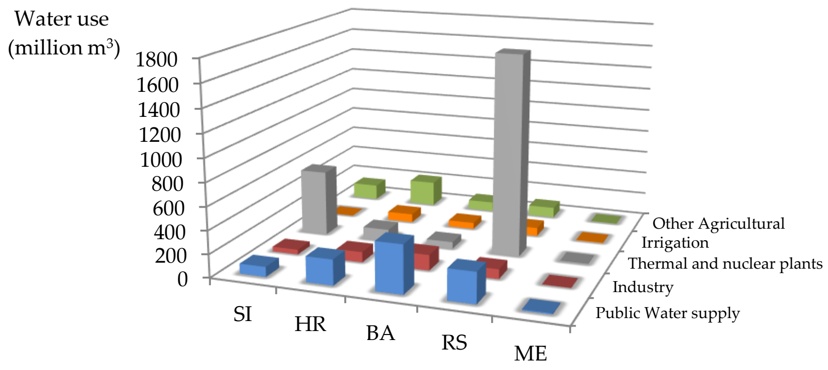


Figure 11. SRB water resources use by country and sector - projections for 2015 (ISRBC, 2013a).

Irrigation is not a commonly deployed practice among the riparian countries, with the majority of the agriculture production relying in seasonal precipitation. Rain-fed agriculture, although presenting a lower impact on the availability of water resources, is more vulnerable to climatic variations and changing of precipitation patterns than if irrigation is used. In addition, in order to secure crop yields when climatic conditions are not favourable, more fertilizers will need to be used. These circumstances would represent higher costs and increased pollution levels from agricultural practices. Agriculture is already pointed out by the ISRBC (2013a) as a current source of pollution in the SRB, closely related to the livestock production, and the use of fertilizers and pesticides. In Croatia, the existence of land mines left during the war period between 1991 and 1995 limit the expansion of agriculture in 11,000 ha (EC-RDP, n.d.b).

Transversal to all the SRB countries is the status of the agriculture sector, characterized by low productivity, the use of obsolete technologies, high fragmentation of agricultural land, contamination of water bodies from agricultural practices, and low coverage of irrigation schemes. Irrigation is used in less than 2% of the arable land in the region, which is frequently affected by droughts. With the frequency of such extreme events likely to increase in the future, irrigation is pointed as a solution that could prevent and/or minimize the damage caused to the agriculture sector (MA-HR, 2012).

Table 10 summarizes the share of land used for agriculture in each one of the SRB countries for the year of 2011. The fraction of arable land in relation to the agriculture area is also provided. Note that these values are estimated by FAO and might vary from official statistics, being used at this point to provide a simplified overview of the potential of expansion of irrigation.

Table 10. Share of agricultural area and arable land in the SRB countries in 2011 (source: FAOSTAT).

	SI	HR	BA	RS	ME
Land area (1000 ha)[3]	2,014	5,596	5,120	8,746	1,345
Agricultural area (% land area)[3]	22.8	23.7	42.2	57.9	38.1
Arable land (% agricultural area)[3]	36.8	67.6	46.7	65.1	33.6
Total area equipped for irrigation (% agricultural area)[3]	1.7	1.8	0.1	1.8	0.5
Arable land under irrigation (% arable land)	4.6	1.8	0.2	2.8	1.5

Efforts are being made by the countries to increase the share of irrigated arable land area. Bosnia and Herzegovina plans to increase in the medium-term the share of irrigated land from 0.6% to 1.6%, as part of the Irrigation Development Project in place until 2017 (HEIS,

[3] Source: *FAOSTAT database – Agri-Environmental Indicators*. URL: http://faostat3.fao.org/browse/E/EL/E

2012). This will be achieved with the rehabilitation of the irrigation infrastructure; introduction of new irrigation technologies and promoting institutional development in water resources management (World Bank, 2015). Similarly, but with no specific goals set, Serbia envisages the distribution subsidies for the installation of irrigation systems in the production of fruits and vegetables (MAEP-RS, 2014), as part of the Instrument for Pre-accession Assistance for Rural Development (IPARD) Programme for the 2014 to 2020 period.

In Montenegro, policies and strategies targeting the agriculture sector aim at developing the infrastructure in rural areas, such as electricity and water access. Montenegro is an extremely mountainous country, and for this reason with limited area for agriculture, activity which takes place mostly in rural areas. Arable land is mainly used for gardens, orchards and vineyards and nearly half of the agriculture production is dependent on livestock production. Agriculture is the main occupation of rural population and is seen as a socio-economic buffer in low-income households, alleviating poverty levels.

3.6 ENERGY SYSTEMS PROFILING OF THE SAVA RIVER BASIN COUNTRIES

Consumption of electricity in the SRB countries represents over a quarter of the total energy consumption, as it can be seen in Table 11. In terms of electricity consumption, Slovenia and Montenegro are the higher consumers, surpassing the 5,000 kWh per capita per year.

Table 11. Energy indicators of the SRB riparian countries in 2012 (source: World Bank database, 2015).

	Electricity (TJ)	**Total energy consumption (TJ)**	**% share of electricity to total energy consumption**	**Electricity consumption per capita (kWh/cap)**
SI	45,176	203,940	22%	6,160
HR	55,260	244,717	23%	3,819
BA	39,949	126,269	32%	3,276
RS	97,801	343,680	28%	4,387
ME	11,592	30,562	38%	5,481
Overall	249,778	949,168	26%	-

The power systems of the countries rely mainly in two technology types: coal thermal power plants and hydropower. Natural gas is not used widely due to the endogenous resources of coal that can be found in all countries, to a least extent in Croatia. The historic generation of the riparian countries is presented in Annex 1 (A-1), for the period 2002-2013, with exception of Slovenia, where data is provided up to 2012. In Annex 1, the total consumption per country is also represented. The comparison allows for the identification of countries which rely the most on electricity imports. This is the case of Croatia, Montenegro and to same extent Bosnia and Herzegovina.

One nuclear power plant exists in the region, the Krsko Nuclear Power Plant. It is located in Slovenia, very close to the border with Croatia. This power plant was built when the two states were part of the Republic of Yugoslavia. These days an agreement exists between the two countries and the electricity generated by the power plant is equally shared. Therefore, there is a minimum trade between the two countries, flowing from Slovenia to Croatia, correspondent to the share of Krsko Nuclear power plant generation.

Renewable energy sources just recently started to contribute to the electricity supply, and the penetration of this type of resources is not very expressive. All countries have adopted National Renewable Energy Action Plans (NREAPs) and are therefore committed to attain a target share of energy produced from renewable sources in the electricity, heating and cooling and transport sector. Renewable sources contribution to electricity generation is expected to increase by 2020.

Electricity generation in the SRB region is very much dependent on the basin's water resources, as it reads in Table 12. Close to 10% of the total installed capacity of 20 GW in the region corresponds to hydropower plants in the Sava River or in its tributaries. The thermal power capacity in the SRB is even more expressive, exceeding 40% of the total installed capacity. This means that over 50% of the generation capacity in the region is located in the basin.

Analysing the relevancy per country, Montenegro is the country with a higher dependence on the basin water resources. In this case, scale is important, and as the smallest country in the region, with the lowest installed capacity, and therefore the most vulnerable to changes in water availability in the SRB. Slovenia, Serbia and Bosnia and Herzegovina have more than 40% of their thermal power plants cooled with water from the SRB.

The existing distribution of hydropower plants in the basin is not as consistent as the verified for thermal power. This depends on the exploration of hydro-potential in other river basins in each one of the countries. Slovenia plans to expand its hydropower potential in the SRB, and nearly 1 GW of hydropower capacity is planned in the middle and lower Sava River. In the case of Croatia, the area of the SRB does not allow for wider hydropower expansion, as the course of the river goes past higher populated areas. Plans exist to expand hydro-potential around the Zagreb area, through the construction of a chain of small run-of-river power plants along a diversion canal from the Sava River. In Bosnia and Herzegovina, the Sava River flows in the border with Croatia. That segment of the river is used for navigation. For this reason no hydropower plants exist along its way. Therefore, the planned hydropower expansion in Bosnia and Herzegovina is being considered for some of the main tributaries to Sava, like the rivers Vrbas, Una, Bosna and Drina.

Table 12. Power generation capacity in the SRB (sources: Platts, 2012; NREAPs; Electricity utilities' reports; Statistical offices; National Energy Agencies' reports).

	Total National Capacity	**SRB Hydro**			**SRB Thermal**		
	MW	MW	% in Total National Capacity	% in National Hydro Capacity	MW	% in Total National Capacity	% in National Thermal Capacity
SI	3 333	209	6 %	18 %	2 106	63 %	99 %
HR	4 119	103	3 %	5 %	1079	26 %	56 %
BA	4 230	554	13 %	26 %	1756	42 %	85 %
RS	7 150	1 028	14%	41 %	3 129	44 %	68 %
ME	908	360	40 %	53 %	225	25 %	100 %
Total	**19 740**	**2 254**	**11 %**	**26 %**	**8 294**	**42 %**	**76 %**

3.7 Climate variability impacts in water availability and electricity generation

Climate conditions are of major importance for electricity production. If on the one hand, favourable hydrological conditions allow the contribution from hydropower plants to meet the electricity demand, potentiate electricity exports or decrease import dependency, it may result in profit losses for fossil fuel based generation facilities. On the other hand, if planned production from hydropower cannot be met, thermal power plants and electricity trading are expected to compensate for the generation deficit.

As it was discussed previously, the climate profile of the countries relies severely in water resources. The generation matrix is somehow similar with the five countries depending mainly on endogenous coal and hydropower. The sensitivity to climate conditions can therefore result in different outcomes from an energy systems lens. This relationship is well expressed even when short-term historical generation is analysed. Figure 12 shows the SRB countries hydropower and thermal power electricity production from 2003 to 2013, with the exception of Slovenia, from which values until 2012 are known, from data retrieved from the Annual Statistical Yearbooks and Energy Balances statistics of each country.

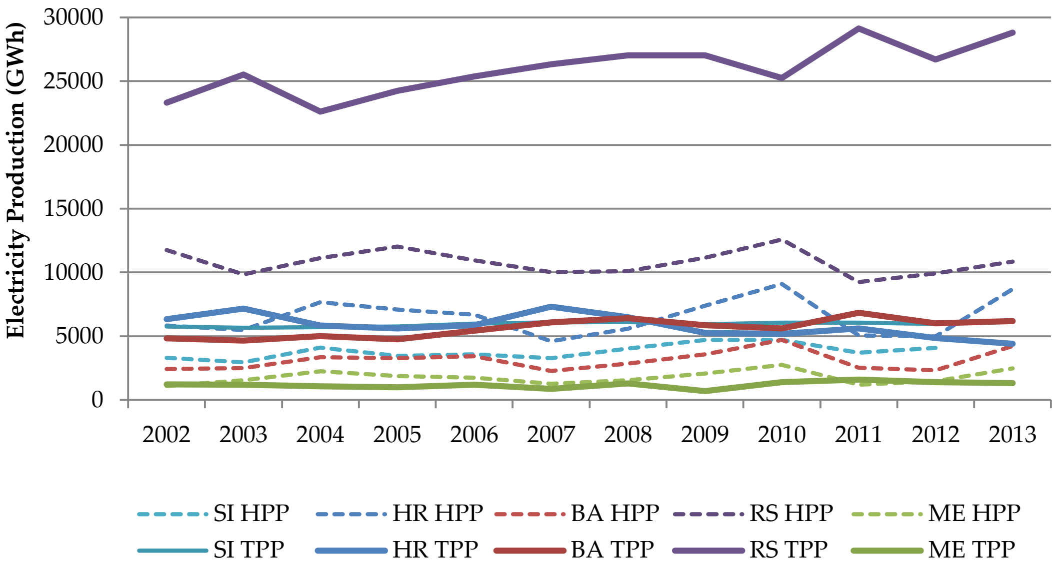


Figure 12. Historical gross electricity generation of the SRB countries, from hydropower and thermal power plants, in the period 2002 to 2013.

According to the electricity utilities annual reports from 2004-2014, unfavourable hydrological conditions were registered in the years 2003, 2007, 2011 and 2012. These years were considered dry years in terms of hydropower production and, climate wise, correspond to years when heat waves and agricultural droughts affected the region (Rebetez *et al.*, 2007; Spinoni *et. al.*, 2014; WMO, 2014). A study of the variation in hydropower production for this period was carried out and the results are shown on Table 14, for different hydropower systems, grouped according to regional proximity or river catchment. The aim of this analysis was to establish a relationship between dry events and hydropower production in the region. To do so, a compilation of dry climate conditions during the same period was prepared based on different sources and is presented in Table 13.

It is mentioned in some of the electricity utilities' reports the deviation from planned electricity production. Although lower hydropower generation was achieved in these years, not all hydropower systems were affected on the same extent. Table 14 below summarizes the change in hydropower production for the period 2003 to 2014 for different hydropower systems or regions, with the temporal cover varying with data availability. Nonetheless, the link between drier conditions and hydropower generation is obvious. In Slovenia the hydropower plants' system in the Soca River Basin, on the west part of the country, prove to be the most affected warmer weather conditions. As for Croatia, the Adriatic coastal regions, with temperate climate and hot summers, were the most affected during in the years 2011 and 2012, for the period between 2009 and 2013. Bosnia and Herzegovina, with the higher area share of the SRB of the five countries, has most of its hydropower plants in the SRB. The analysis shown that all were significantly affected in the drier years of 2011 and 2012, and hydroelectricity suffer reductions of 36% in the southern systems in 2012, in the Adriatic Coast, followed by 32% in the Vrbas River, in 2011. In Serbia, the Morava River Basin, which extends over most part of the country, was greatly affected in 2008, 2011 and 2013. Power plants in the Drina River, first tributary to the Sava, and Lim River tributary to the Drina, also experienced reductions in the aforementioned drier ears, ranging from 10 to 20%. For the Piva hydropower plant, in the Lim River, in Montenegro, similar reductions were identified, while Perucica hydropower plant, per comparison, was less affected.

In regard to the thermal power plants, the analysis of the annual generation per technology presented in Annex A-1, informs about how the generation mix responded in the drier years. It is seen for Croatia, Serbia and Montenegro, that the installed capacity of thermal power could not cover the hydropower generation deficit for the years of 2007, 2011 and 2012. These countries had to rely on electricity imports to cover the electricity demand. Imports were consistently higher in the years 2011 and 2012 during the period covered in Annex A-2, from 2008 to 2014, except for the case of Montenegro, when the highest import took place in 2014. For the specific case of 2011 and 2012, Croatia relied on higher imports from Bosnia and Herzegovina and Slovenia; in turn, Bosnia and Herzegovina imported more electricity from Croatia and Serbia; while Montenegro registered higher imports from Bosnia and Serbia. Note that the values for trade presented here correspond to annual electricity flows. For more conclusive findings, an analysis of the monthly electricity trade would be required.

It is important to highlight that the analysis is based on a restricted period of 11 years, further constrained by data availability with data gaps for certain periods or years. Even though, trends in hydropower generation seem to synchronise, stressing the cumulative vulnerability of electricity systems and the importance that regional planning could have in preparing for similar circumstances. Furthermore, the forecasted temperature increase and annual rainfall reduction will likely directly impact the operation of existing hydropower plants. A summary of climate change forecasts for each one of riparian countries, and for the climate variables of temperature and precipitation, is given in Table 15. Impacts in run-off are also provided. New hydro projects should be carefully planned so as to avoid unnecessary investments, oversized facilities, and reduce or evade impacts to ecosystems services, especially for the fact that this technology type has a long operation lifetime. The water cycle is a complex equilibrium that depend on many factors, from climate variables like temperature, precipitation, cloudiness, and wind speed; to land use, soil type and geomorphology of the region. The impacts in water resources availability results from a complex analysis of all the implicit interactions. Figure 13 illustrates the impacts of drought propagation in water availability, elucidating the vulnerability of this resource in different categories of drought, and how this extreme event affects the hydrological conditions, leading to a hydrological drought conditions, which directly affect water supply and hydropower generation and, consequently, the energy systems depending on that power source.

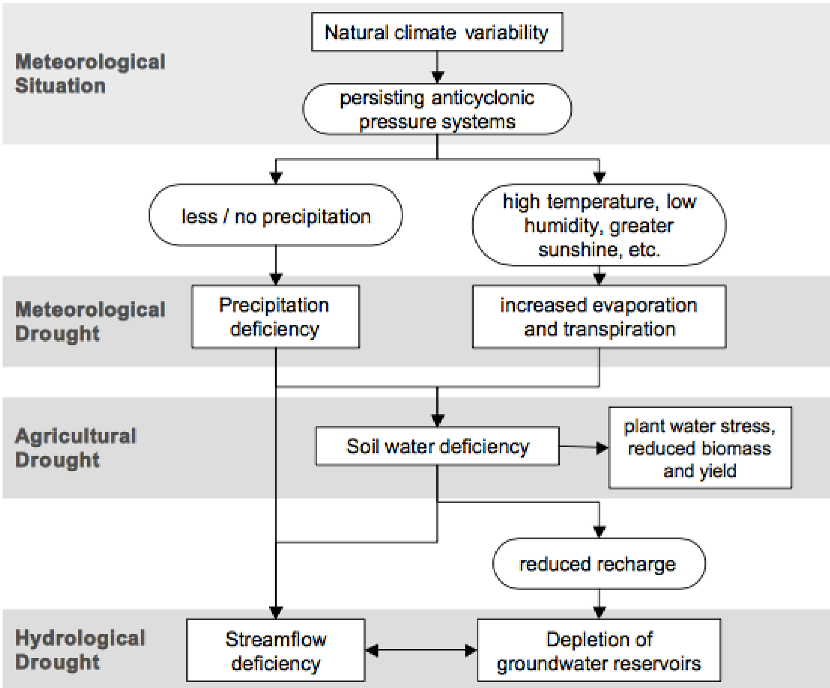


Figure 13. Propagation of drought through the hydrological cycle (Stahl, 2001).

Table 13. Compilation of drought events and extreme weather conditions in the SRB region from various sources.

Source	DMCSEE (2011)				Spinoni et. al. (2014)	WMO (2014)
Year	**SI**	**HR**	**RS**	**ME**		
2003	July	Period not specified.	Summer to Winter	Summer	Drought period in the Balkans	Much of Europe affected by extreme heat waves during summer
2004		Summer				In June and July, heat waves with near-record temperatures affected Portugal, Spain and Romania.
2005		Summer		Summer		Southern Europe affected by a heat wave in July.
2006		July		July and November		
2007	Highest mean annual temperature of the last 10 years.[4]	Period not specified	May and July	Summer	Longest drought event between 1950 and 2012 (26 months).	Two extreme heat waves affected south-eastern Europe in June and July with daily maximum temperatures exceeding 40°C
2008		Summer and Autumn	Summer	Summer		
2009		Winter to Autumn		August		
2010		Summer				Central and South Europe were affected by above normal precipitation.
2011						
2012	Highest mean annual temperature of the last 10 years.				Most severe drought in the period 1950-2012	
2013						

[4] Slovenia Bureau of Statistics (2013). *Stat'o'Book 2013*.

Table 14. Hydropower production relative change in relation to annual or average production per hydropower system and country.

Country	HPP System	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
SI	Drava	-15.5	+8.3	-7.7	-9.5	-17.0	+10.3	+38.8	+20.3	+2.8	+13.0	+9.3	
	Upper Sava	-28.2	18.5	-9.5	-7.1	-19.6	5.9	16.3	24.6	-15.4	-6.7	27.4	
	Soca (exc. Avce)	-36.8	8.0	-30.6	-15.2	-26.9	21.2	14.3	31.4	-13.4	-4.4	28.5	
HR	NE - Drava							12.8	0.8	-18.0	-3.5	8.0	
	SRB							-	12.7	-34.8	-8.7	30.8	
	NW							4.2	27.0	-42.5	-23.1	34.4	
	SW							5.0	38.9	-28.5	-36.9	21.5	
BA	Vrbas				8.9	-12.9	0.8	8.1	25.5	-31.5	-21.1	-0.2	19.2
	Drina							3.2	25.6	-29.8	-16.0	19.0	-2.1
	South HPP							6.0	32.7	-22.1	-36.2	18.6	1.1
RS	Danube*		0.2	6.8	-6.7	-5.0	-1.1	3.8	13.7	-12.0	-7.6	0.1	7.8
	Lim*		8.4	21.9	31.0	-20.0	-19.4	-13.9	21.2	-12.1	-18.3	-5.9	7.2
	Drina*		8.7	13.8	8.0	-12.0	-15.1	4.3	11.0	-20.4	-9.3	8.2	2.8
	Morava*		-6.8	39.0	30.7	-5.6	-30.8	-0.3	58.1	-33.1	-11.3	-45.0	5.1
ME	Lim (SRB)*	-	-	-	19.9	-14.1	-16.5	n.a.	9.2	-15.6	-18.5	45.8	
	Perucica*	-	-	-	-5.7	-13.5	-4.6	n.a.	8.9	-29.2	-13.0	43.1	
Overall		-14.2	9.4	6.4	1.5	-17.5	-7.4	11.1	29.8	-16.5	-12.5	15.8	

Changes in hydropower production:	> -10%	-10% to -20%	-20% to -30%	< -30%
	< 10%	10% to 20%	20% to 30%	> 30%

Notes:

- HPP – Hydropower plant
- The comparison for Slovenia and Montenegro was done against the annual planned production. As for the remainder countries, the average annual production value was used for the estimates.
- The annual variation for the HPP system in the Soca River in Slovenia does not include the operation of the PSHPP Avce, which started operation in 2009.
- For the period 2008 to 2010, the deviation shown for the HPP system in the Vrbas River (BA) corresponds only to the operation of the HPPs Jajce I and II.

Table 15. Climate change impacts projections in the SRB countries' region (ISRBC, 2013b; Ceglar et al., 2015; Heywood, 2013).

Country	Temperature	Precipitation	Run-off and water levels
Slovenia	The trend of results of temperature measurements shows a noticeable increase, since records began in 1851. By 2025, an increase of +1.0 ± 0.5 °C is predicted. By 20175, climate projections indicate an increase of (+2.5 ±1.0) °C.	Decrease in annual rainfall based on measurements. Evapotranspiration increase and change in rainfall quantity will impact surface and ground water bodies. In the medium (2025) and long term (2075), an increase in annual quantity of rainfall could vary between 0 – 10 %.	Decrease of the annual average outflow, even with an increase in precipitation. Low flows will be particularly affected, and their reduction will impact the self-cleaning capabilities of water and higher water temperatures. Increased pressure in watercourses due to water supply intensification, potentiated by temperature increases and longer droughts. Conditions of water supply likely to deteriorate. Increased vulnerability to floods due to combination of anthropogenic factors (outflow properties of watercourses, settlement of border flood regions) and climate change.
Croatia	Expected temperature increase over the territory from 2.4°C to 3.2°C in the lowland areas of the country. Summers more prone to temperature increase, between 3.2 and 3.6 °C. Reduction of daily atmospheric temperature range. Increase in potential evapotranspiration.	Annual precipitation decrease. Risks involved meeting plants water demand, run-off and soil moisture decline (exacerbated by amplified evapotranspiration).	Impacts of run-of decrease: water management and soil moisture decline, affecting vegetation. Decreasing trend in median and minimum annual water levels for the past two decades. Climate change forecast indicate reductions of 10 to 20% in runoff in catchments located in western Croatia and in the Dinaric karst region, in comparison to current situation. In the eastern part these changes are expected to be below 10%. Water demand increase expected during the summer and vegetation season (April to September).
Bosnia and Herzegovina	Temperature is likely to increase within the range 0.7- 1.6°C, per 1°C of global increase. Summer period and inland areas will register the higher increases. In winter and spring temperatures could rise up to 2°C, while in autumn the rise could be between 2 and 3 °C. Rise of the average maximal daily temperature more distinct than the minimal daily temperature.	Precipitation increase during winter (December to February), with rainfall expected to be heavier. Reduction of precipitation during summer. Effect more pronounced June and August during the period 2031 to 2060, when rainfall could be halved. In this case, half of the territory will be affected.	n.a.

Country	Temperature	Precipitation	Run-off and water levels
Serbia	General projection indicates an increase of 0.04°C per year of the average yearly temperature, except for the south-eastern regions. Temperatures have been rising in the period 1951-2004. Future trends indicate, in the A1B scenario, a possible temperature rise between 0.8 and 1.1 °C for the 2001-2030 period. When taking the results from a more severe scenario (A2), the temperature increase could rise up to 3.8 °C between 2071 and 2100.	Observed rise of yearly precipitation in the 1950 – 2004 period, except for the south and south-eastern regions of the country. Increased the number of days with intensive rainfall. Up to 2020 various climate models show the decrease of the average precipitation level in average by 15%, 16.9% in the vegetation period and 13.9% in the non-vegetation period). Up to 2100 the estimated rainfall decrease is 25.1% (in vegetation period 13.4% and in non-vegetation 39.6%).	Results of the various climate models indicate that, in comparison to current average levels, water discharge is expected to: - decrease by 12.5% until 2020 (vegetation season -11.1%) - suffer a 19% reduction until 2100 (for the vegetation period 5.4% but 32% for the non-vegetation period) Average yearly sum for evapotranspiration until 2020 will decrease for 16.5% and 27.2% until 2100.
Montenegro	Increase in temperature trend registered from the second half of the 20th century in most parts of the country. - A temperature increase of 2°C in winter; - Temperature increase between 2–3°C in summer (with projected increase of 0.2°C per decade).	A precipitation reduction of 5–15%, especially in the warmer part of the year. Reduction of soil moisture of 15–25%.	Increase of water demand and water abstraction: National statistics record a significant increase in the water abstraction for water supply from 95 million m^3, in 2002, to 102 million m^3, in 2006.

3.8 CLEWs INTERLINKAGES IN THE SAVA RIVER BASIN

The analysis of the context described in earlier sections allowed for the identification of the main interactions between the resources systems that can be studied using the CLEWs nexus approach, illustrated in Figure 14.

For this study in particular, attention was given to the energy and water linkages, although aspects from the climate dimension and land use were also taken into consideration. Thus, this study provide insights on the following interlinkages:

- *Climate-water-energy*: impact of climate change in streamflows and hydropower power production will be analysed;
- *Energy-water-land use*: competing use of water for hydropower and irrigation will also be subjected to analysis;
- *Energy-water*: the variation in the use of water for cooling in thermal power plants;
- *Social and economic drivers' implicit impacts on regional power systems*: analysis of the impact of the implementation of energy efficiency measures in the electricity sector.

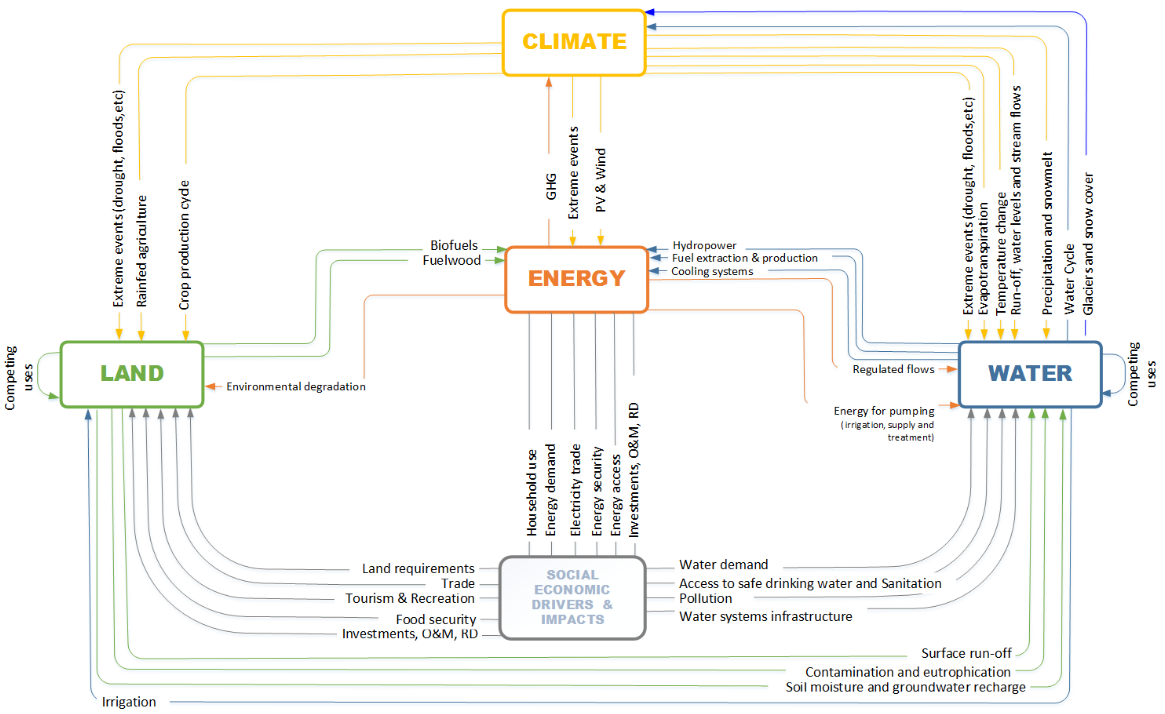


Figure 14. Mapping of the interactions between the different dimensions considered in the CLEWs methodology (KTH-dESA, 2015).

3.9 CHAPTER SUMMARY

An overview of the focal sectors of the SRB riparian countries was explored in Chapter 3, along with the characterization of the basin. Important interlinkages were already identified among different dimensions of the water energy-nexus. These span from: a) the dependence of the power systems from the SRB water resources; b) the increasing competing use of water for irrigation linked to the potential expansion of agriculture in the future; c) the vulnerability of hydropower production to climate variability, identified both at a national and as at regional level; and d) the crucial role of the regional electricity trade in balancing the deficit of power generation caused by unfavourable hydrological conditions. All of these pressure points will be subject of analysis in the modelling exercise, which will be further developed in the following chapters.

4 THE MULTI-COUNTRY ENERGY SYSTEMS MODEL

4.1 ENERGY SYSTEM ANALYSIS SOFTWARE OSEMOSYS

OSeMOSYS is a systems optimization model for long-term energy planning (Howells *et al*, 2011). The tool has been tested and compared to long established energy systems models such as MARKAL/TIMES, PRIMES or POLES and has been proven to provide similar results. Its structure in modules grants flexibility for model development and to incorporate other modeling components. Thus allowing for multiple relationships to be made between technologies. Figure 15 illustrates the building block structure and levels of abstraction.

The basic code for OSeMOSYS and an example of its implementation is available in Howells *et al.* (2011) and in the osemosys.org website. It was the simplified version of the code that was used in this analysis.

The OSeMOSYS tool is based on a cost optimisation-principle, choosing the least cost group of technologies to operate on techno-economic criteria, such as availability, capacity factor, and costs such as the capital, operating, fuel costs, or other considered in the system.

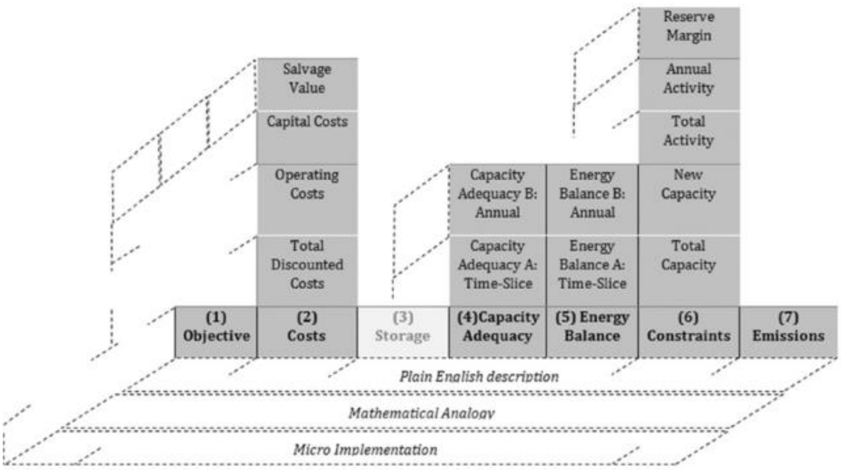


Fig. 1. Current OSeMOSYS 'blocks' and levels of abstraction.

Figure 15. OSeMOSYS building blocks and levels of abstraction (Howells et al., 2011).

4.2 Overview of the Methodology

This study relies on the development of a multi-region model of the power systems of the countries in the SRB, using the bottom-up energy systems analysis tool Open Source energy Modeling System - OSeMOSYS (Howells *et al.*, 2011). The modeling tool allows for the full representation of the energy system, from resources to the final energy consumption. The generic Reference Energy System providing guidance to this modelling effort is illustrated in Figure 16. In this, and for each one the countries under study, the power systems were scrutinised from the energy sources used and electricity production technologies, represented according to the lifetime and decommissioning of each technology. Generic investment costs were used for the planned technologies in the multi-country model, as well as for the fixed costs, representing fixed expenses linked to operation and maintenance of power plants and other technologies. Discount rate was set constant at 5%. Transmission and distribution technologies were also included to represent the electricity transfer up to meet the electricity demand. The model results are frequently expressed in a yearly basis, although production by technology is also retrieved by time slice, according to the disaggregation defined in the year split.

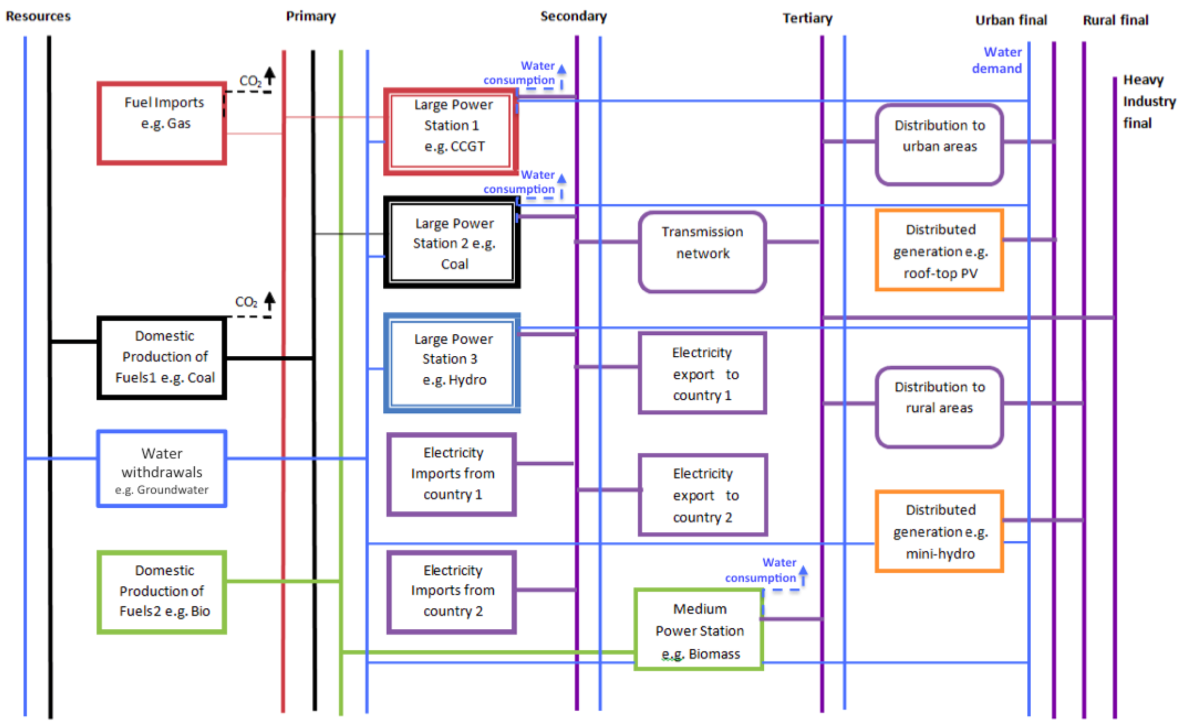


Figure 16. Simplified Reference Energy System used to build the multi-country power systems model of the Sava River Basin region.

For the sake of simplification, no distributed options were considered in the analysis and only one demand per country was used, with no further disaggregation. For water consumption by power plants, water use rates per thermal technology were used to represent such consumption.

The multi-country approach focused on the recreation of the five energy systems in an independent manner, and then interlinked via the representation of trade technologies and also of shared generation facilities, as is the case of Krsko nuclear power plant.

In each model country model, power production technologies were grouped according to their location in respect to the SRB – each technology type was subdivided in being or not located in the basin's area in each territory. The only exceptions were the technologies representing hydropower plants in the basin and the non-hydro RES technologies (biomass, geothermal, solar PV and off-shore wind power). Hydropower plants in the basin were represented individually for Slovenia, Croatia, Serbia and Montenegro. Due to the high number of hydropower projects in Bosnia and Herzegovina, these technologies were merged in groups according to the Sava River tributary where these are planned to being built.

The model will be used to simulate different energy production scenarios with special focus on the water availability in the SRB for hydropower production, e.g. climate change impacts, expansion of agriculture through the increase of water consumption for irrigation purposes and emissions accounting.

4.3 Introduction to the study case

The model aims at replicating the combined functioning of the power systems of the five riparian countries. The geographic scope groups directly the five countries, with all production technologies identified in the data sourcing process, represented in the model. An attempt to represent the neighbouring countries, with the purpose of simulating electricity trade in the region, was made through the creation of representative trade technologies.

The model structure follows a similar design as the one represented in Figure 16, conveniently adapted to the specificities of the case study.

The year 2012 was used as the reference year for this study, in the form of the load curve and to specify the demand profiles. The modelling period extended until 2030.

4.4 GENERAL ASSUMPTIONS

In this section, the assumptions for the main elements of the multi-country energy model are presented.

Year split and specified demand profile

To represent the variability of the electricity demand in each representative day of each month, an analysis of the daily load was done for the average weekly load in each month. This analysis was replicated for each one of the riparian countries and was based on data retrieved from the European Network of Transmission System Operators for Electricity (ENTSO-E) country database[5] for 2012. Figure 17 illustrates the initial analysis of the year slip for the case of Slovenia.

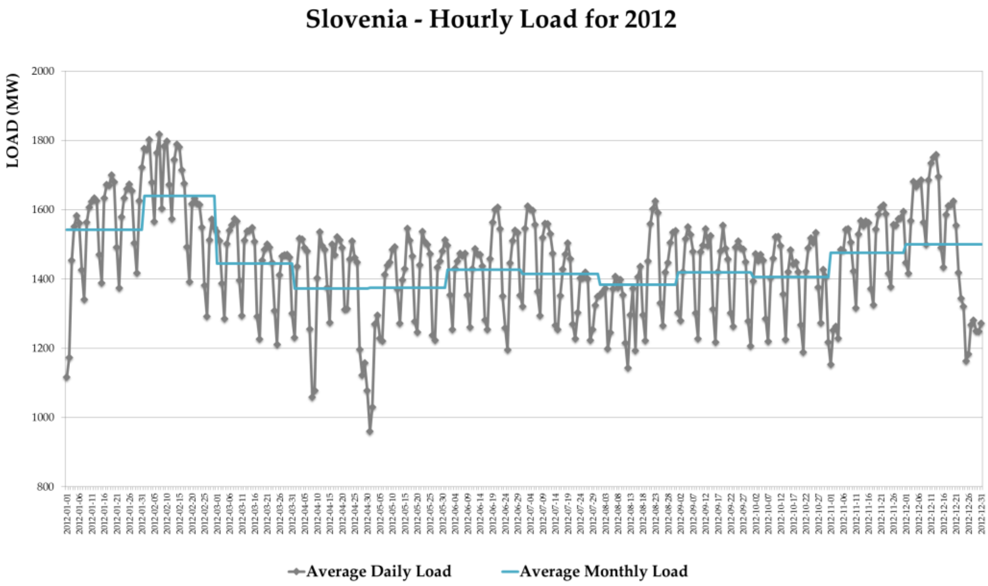


Figure 17. Load curve for Slovenia in 2012 (ENTSO-E country database).

As the daily load curves shape did not vary significantly between the days of the week, only one day type was considered, but divided in three parts to represent the lower consumption at night, medium during the day, and peak load for the periods when the demand was higher. An example of the analysis is given for Slovenia in Figure 18. Thus each year in the model is split in 36 time slices: 12 seasons, one day type and three day parts.

Each time slice represents the fraction of the year corresponding to the number of hours in a specific month under a load category (day, night and peak). Each time slice had in turn a specified demand associated to it, representing the fraction of the yearly load at one of the load categories defined.

---

[5] https://www.entsoe.eu/data/data-portal/country-packages/Pages/default.aspx

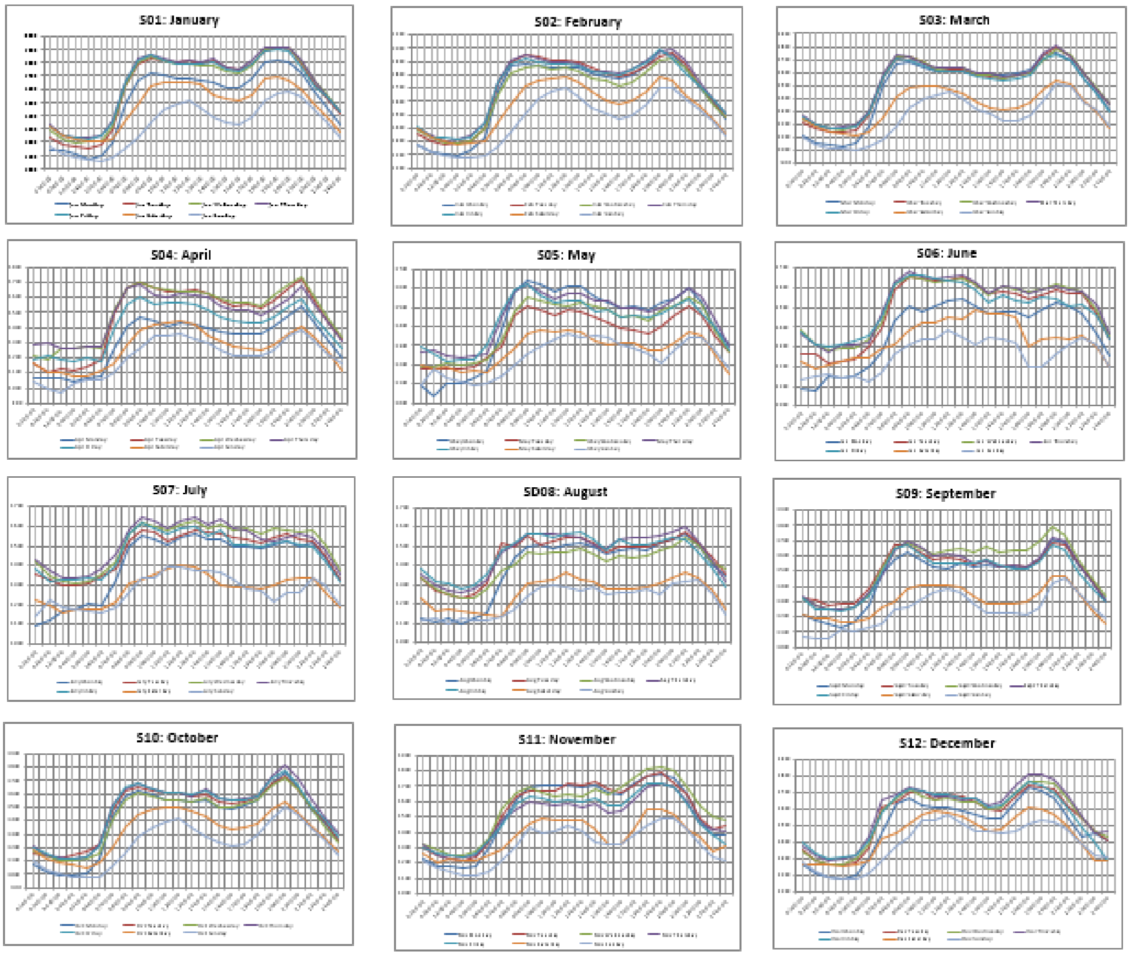


Figure 18. Example of the daily load analysis per month, using the results for Slovenia.

Electricity demand of the riparian countries

The electricity demands considered in the multi-region model were based on the NREAP projections, for the two scenarios considered in the national policy – the reference scenario (REF) and the additional energy efficiency (AEE) scenario, represented in Figure 19.

As the projections only cover the period up to 2020, the demand for the following years was estimated using the average annual growth rate of the last five years of each projection, i.e. 2016 – 2020. In the case of Slovenia, the projections for the reference scenario were not included in the NREAP. For this reason, the projections from the Development Strategy of the Slovenian TSO up to 2020 were used (ELES, 2011).

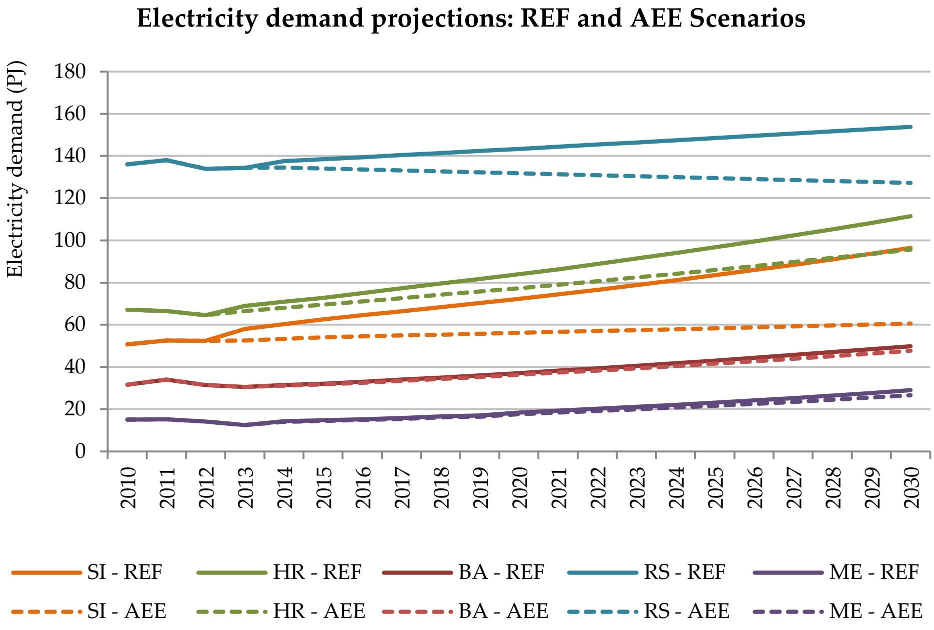


Figure 19. Electricity demand projections for the SRB countries for two scenarios: Reference and Additional Energy Efficiency (ELES; 2011; FMERI, 2014; ME, 2014; ME-HR, 2013; MEDEP-RS, 2013; SI, 2010).

The Republic of Serbia is the country with highest electricity consumption, surpassing all the demand for electricity for all other countries in both demand projections, REF and AEE. The saving potential varies between countries and it is Slovenia the country where a higher reduction in electricity consumption is expected, followed by Serbia and Slovenia. As shown in Figure 20, Bosnia and Herzegovina and Montenegro, are the two countries were the efficiency measures affecting the electricity sector have a lower impact in the sector's energy intensity.

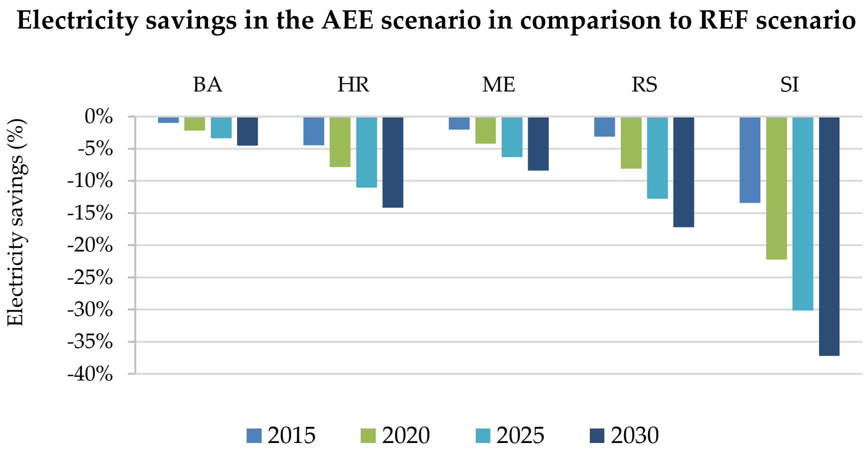


Figure 20. Electricity savings potential for the AEE demand projections in comparison to the REF scenario.

Electricity losses

Electricity losses were considered at two levels: transmission of electricity to the distribution substations; and distribution, from these to the demand sites. The share of electricity losses were estimated based on the electricity losses referred in the national statistics for the years from 2012 to 2014, when available. A target share of 2% was assumed for 2035 in order to estimate a decrease in combined losses for the modelling period. An overview of how the losses evolved over the modelling period is provided in Figure 21.

The breakdown between transmission and distribution losses was based in the ratio between these two types of losses for Croatia in 2012. To increase the accuracy of this representation, specific data for each country is needed.

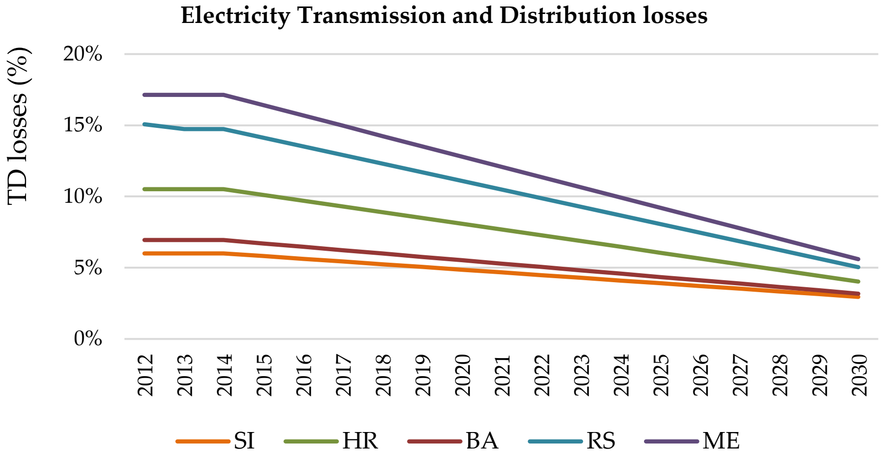


Figure 21. Share of the transmission and distribution losses in the power systems of the riparian countries.

Montenegro and Serbia are the countries with the highest losses in electricity transfer from the generation facilities to the demand sites, with starting losses over 15% as it can be seen in Figure 21. Another assumption made related to this parameter was not to represent the different voltage level consumers, but to consider all consumers after the distribution fragment.

Endogenous energy sources

Endogenous production of fuels was introduced in the model in the form of fuel reserves, for each one of the fuel types, which had significant production at the national level, as was the case of coal. As the specific cost of coal was not known for each country, an assumption the locally produced coal at 80% the international price was used. For all other imported fuels, such as oil, diesel and natural gas, the cost was considered equal to the international market value.

Power generation technologies

A database was built based, initially developing from *Platts* (2012). All existing and planned technologies were then confirmed and updated. For existing power plants, starting year of commissioning and phase-out were accounted for. As for new projects, two different approaches were followed depending on the reliability and coherency of the information. Projects identified as committed or under construction were introduced in the model as fixed investments. As for the other projects to which a date of construction was uncertain or unreliable, these were allowed flexibly in the model from 2020 onwards. In that case, these projects would only be installed if they were the least cost option.

When the information of specific costs was not available, generic costs were used, according to each technology type.

Hydropower plants

The representation of hydropower plants was simplified through the assumption that all these technologies were of the run-of-river type. Simulation of storage hydropower plants was not relevant for the aim of this analysis.

However power plants located in the SRB were represented with the level of accuracy possible using historical daily flow data of existing power pants and projected flow based for the RCP4.5 climate scenario and, under this, daily flow values for a scenario that projected agriculture expansion. The daily flow data was retrieved from a study from the Joint Research Centre (JRC). The capacity factors of existing power plants were estimated comparing the potential energy production of each power plant based on river flow and head of the power plant, and the total energy that the power plant could produce considering its nominal capacity. The location of the power plants in operation, planned committed and planned uncommitted can be seen in Figure 22.

The capacity factors of hydropower plants outside the SRB were calculated based on the historic production, which variation is represented in the previous chapter, in Table 14. In the climate scenarios, hydropower plants located in more vulnerable areas to dry events were affected by capacity factors gradually turning to the average capacity factor of the years when production fell below average. The hydropower systems considered to be most vulnerable to dry climate conditions were the hydropower plants in the Soca River Basin, in Slovenia; the hydropower systems located in the northwest (NW) and southwest (SW) of Croatia; in Bosnia and Herzegovina, the hydropower plants located in the south (South HPP) of the country, closer to the Adriatic Sea; the hydropower plants located in the Morava River Basin in Serbia; and the hydropower plant Perucica, in Montenegro.

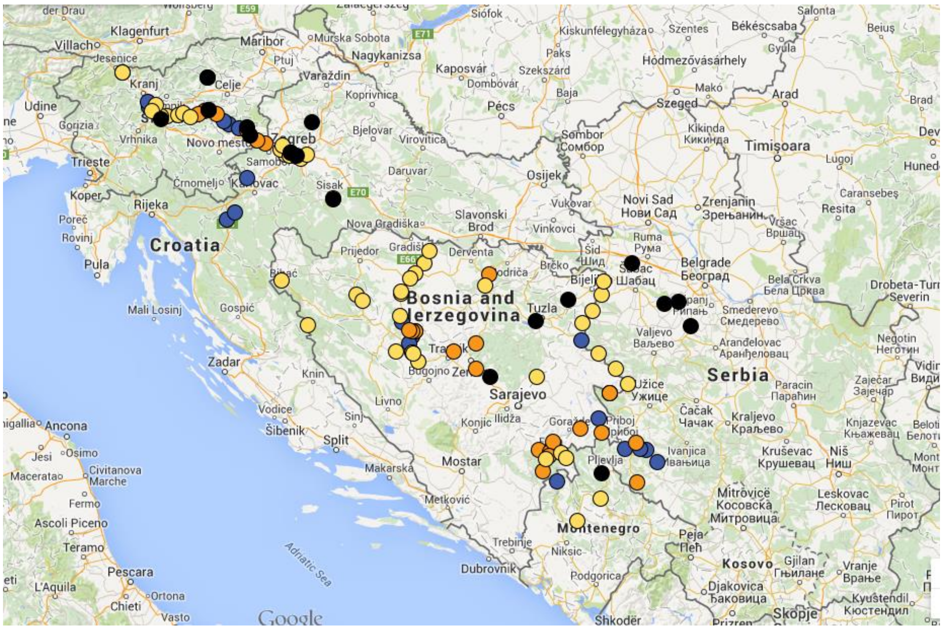


Figure 22. Existing (blue), planned committed (orange) and planned uncommitted (yellow) hydropower plants with over 10 MW and existing thermal power generation facilities (black) located in the SRB.

Thermal power plants

Thermal power plants were grouped in fuel types: biomass, coal, diesel, heavy fuel oil and natural gas. One nuclear power plant was included in the analysis and its capacity factor is related to the historical generation of the last eight years.

In terms of water consumption, it was assumed all these technologies operate with once-through cooling systems. The mean value for consumptive use of water for each fuel type (indicated on Table 3) was introduced in the model to quantify the consumption from each technology type.

Linked to the fuel feeding each thermal power technology were also linked the correspondent factors for GHG emissions.

Other power plants

Information on existing non-hydro RES was often limited or contradictory. In order to minimize this constraint, the additional capacity targets of RES up to 2020, constant in the NREAPs, were used to calibrate the contribution of this type of technologies. On a different level, the consideration of such targets allowed for concordant representation of these sources.

Electricity trade

Electricity trade is a fundamental block of the multi-country model. Figure 23 illustrates the physical flows of electricity considered in the model. Although the crucial section of the analysis is centred in the SRB countries, it was considered to be of relevance to simulate the trade with other neighbouring countries as this could influence the generation mix in the SRB region for the different scenarios studied. Also considered in the model were the planned trade links, represented in the diagram with red lines, between Italy and Montenegro and Slovenia and Hungary.

The Net Transfer Capacities (NTC) introduced in the model as to represent trade limits between countries are presented in Table 16, and correspond to yearly capacity values established for 2015. These values are defined in a yearly basis and do not necessarily correspond to the transmission capacity of the transmission interconnectors. That was verified in some cases, which required adjustments to this parameter in the model, so to allow for the average historical trade to be met between countries.

This adjustment assisted in the calibration of the model and the simulation of trade agreements that might exist between countries. Trade agreements between the countries are noticeable when analysing the historical trade. Consider for example, the case of Slovenia and Italy. From indicates that the electricity flow from Italy to Slovenia is 680 MW, while in the opposite direction is 730 MW, from Slovenia to Italy. Therefore, it is expected the countries to trade electricity extensively between them. However, it is verified that trade in the interconnector IT-SI happens mostly on one direction, from Slovenia to Italy, as it can be verified in Annex 2. In fact, electricity consumption in north-eastern Italy is heavily balanced by the electricity provided by Slovenia.

Table 16. Net Transfer Capacities, in MW, for 2015, used as reference in the SRB model (ELES, 2015; ENTSO-E, 2015; ENTSO-E, n.d.; EMS, n.d., USEA, 2014). The 2-letter country code notation was used to represent the countries in the electricity trade analysis. This have the following correspondence: AT – Austria; IT – Italy; Hungary (HU); RO – Romania; BG – Bulgaria; MK – Republic of Macedonia; AL – Albania)

From To	SI	HR	BA	RS	ME	AT	IT	HU	RO	BG	MK	AL
SI		1500				950	680 IT 730 SI					
HR	800		400	100				700 HU 600 HR				
BA		400		100	200							
RS		150	100		100			300	200 RO 150 RS	200 BG 100 RS	100	0
ME			200	100								200

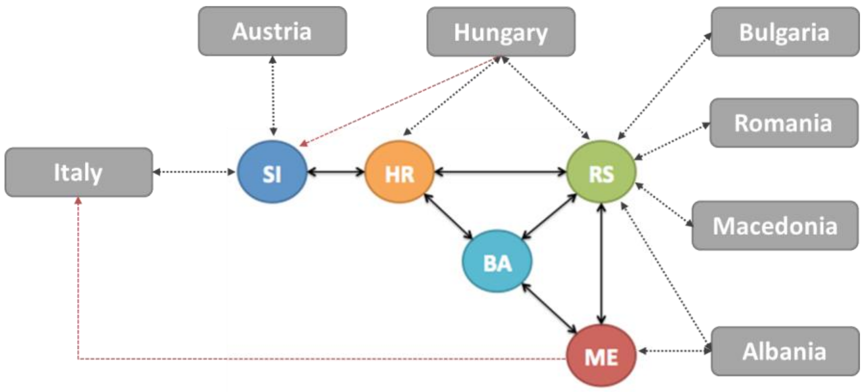


Figure 23. Diagram representing the electricity physical flows between the Sava River Basin countries and the neighbouring nations. Trade links in red represent the planned transmission interconnectors.

The analysis performed entails limitations that are related to the assumptions discussed in previous sections. These are conveniently addressed in the last chapter of the dissertation.

4.5 SCENARIO DEVELOPMENT

Six scenarios were developed to provide some insight about the possible changes in the generation mix of the countries in the SRB under different conditions related to the water-energy nexus - with a special focus on the SRB area.

4.5.1 Reference Scenario definition

The Reference scenario (REF) corresponds to the Business as Usual scenario, calibrated to represent the year 2012, and sets the model structure for the following scenarios. It takes into account the NREAPs and other power systems expansions plans, including new transmission lines' projects, decommissioning of power plants and share of RES, other than hydro. In this scenario, power plants shared between countries are also accounted for.

In the Reference scenario, historical flow data for the period from 2003 to 2013 was used to estimate the capacity factors of the 22 existing and 3 planned hydropower plants in the SRB, with power capacity above 10 MW. These values were then transposed to the remaining hydropower plants in the SRB (in construction or planned) in accordance to criteria of proximity and upstream-downstream location along the Sava River and its tributaries. The planned projects included total of 44 hydropower plants, represented in Figure 22.

4.5.2 Alternative Scenarios development

Three other scenarios were investigated, as to include energy efficiency measures and constraints to water availability in the energy systems analysis. The relationship between scenarios is expressed in Figure 24. The description of the scenarios is discussed in the following subsections.

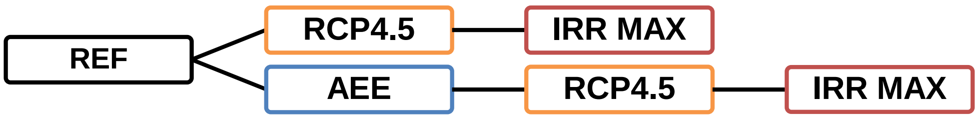


Figure 24. Diagram of the scenarios analysed with the multi-country energy systems model.

One of the scenarios is dedicated at representing changes imposed by climate change, considering river flow values estimated for the RCP4.5 scenario. This climate change scenario is identified in this analysis as "RCP4.5". The RCP4.5 scenario corresponds to the Representative Concentration Pathway 4.5[6], which represents a climate future in which the peak of GHG emissions occurs by 2040, remaining constant until 2100. Following the same methodology as described for the reference scenario, the capacity factors of the hydropower plants located in the SRB basin were estimated using the projected streamflow at specific hydropower plants' locations, but for the analysis period, from 2015 to 2030. Annual capacity factors were estimated for each existing power plant or hydropower plants systems, using the moving average of the capacity factors of the previous five years. The streamflow data used was based in the projections done by JRC (Bidoglio, 2014), using climate data for the RCP4.5 climate future from the KMNI, the Royal Netherlands Meteorological Institute.

The other scenario, and inherited from the climate change scenario "RCP4.5", contemplated the added effect on water availability for hydropower production by the competing use of water in agriculture, for irrigation if this practiced is expanded. This scenario was identified as "Irrigation Maximum" and is referred in this analysis as "IRR MAX". Again, for this scenario, streamflow data projected by JRC (Bidoglio, 2014), was used based on the same climate data retrieved from KMNI. In this case, the river flow data considered the competing use of water for irrigation if this technique was expanded in downstream countries, mostly Bosnia and Herzegovina. The capacity factors for existing and planned hydropower plants were estimated in an analogous manner, described for the RCP4.5 scenario.

[6] http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

The Additional Energy Efficiency (AEE) scenario, mentioned earlier in section 4.4, inherited from the REF scenario, considers the electricity demands indicated in the NREAPs of each country, if energy efficiency measures are implemented in the electricity sector. Inherited from this scenario were the RCP4.5 and IRR MAX scenario, in order to analyse the mitigation potential of added efficiency measures in GHG emissions.

5 RESULTS AND ANALYSIS

5.1 MODEL VALIDATION AND CALIBRATION

The model was calibrated with the simulation of the energy generation for the reference year of 2012. In addition, the analysis of the historical electricity trade within the SRB countries and other neighbouring nations allowed for a better tune of the model results in the first years of the modelling period. The results for electricity generation and electricity trade in each country, can be consulted in Annexes A-4 and A-5.

5.2 REFERENCE SCENARIO ANALYSIS

5.2.1 Power production in the region

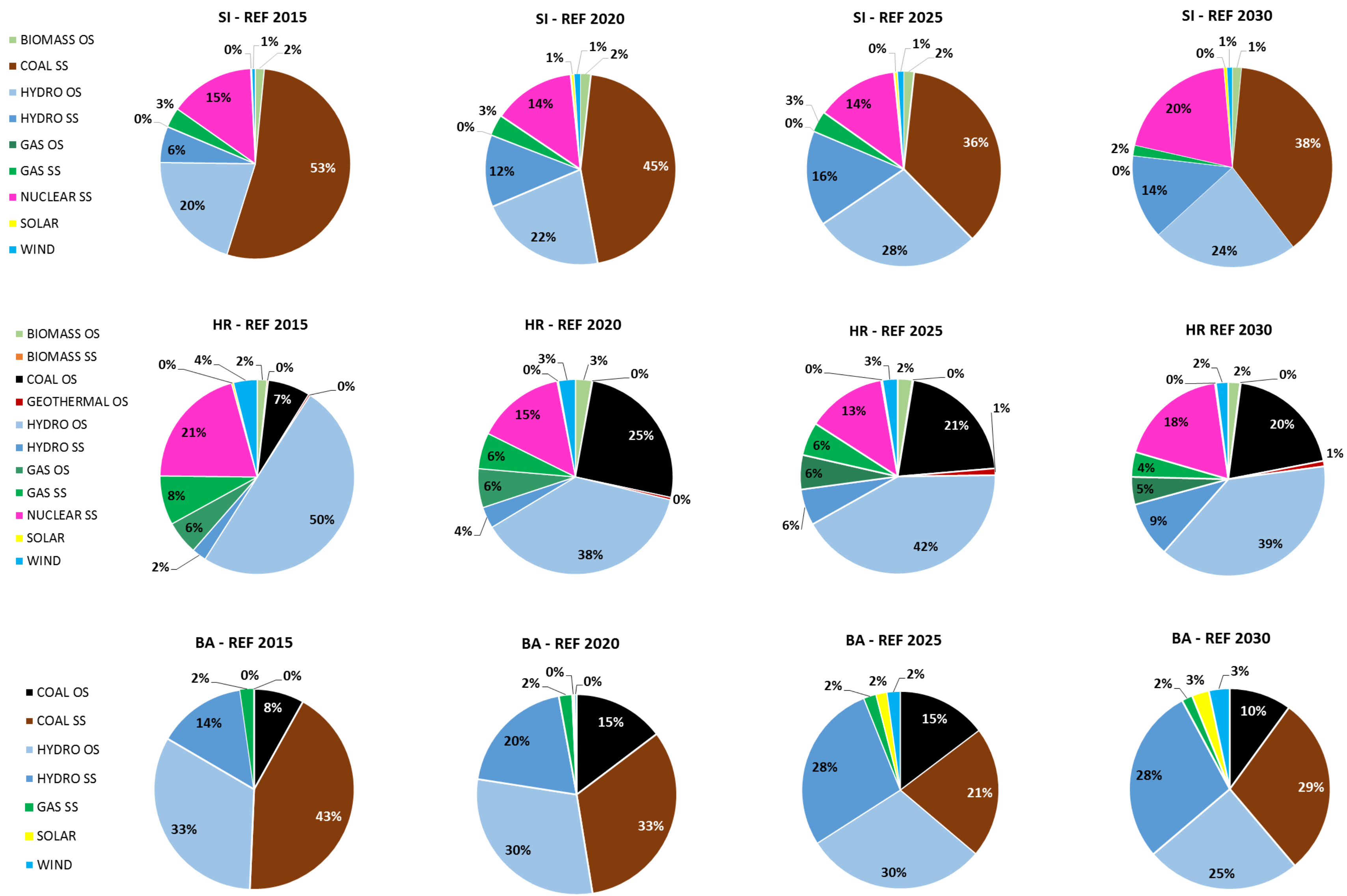
An overview of the expected electricity generation mix change in the SRB region, throughout the period of analysis, can be seen in Figure 25 for the years 2015, 2020, 2025 and 2030.

Common to all countries is the increase in electricity generation with hydropower representing a significant share in the production mix, both for the facilities located in the SRB and the hydropower plants. Coal generation in the basin, although registering a decrease in the contribution, as demands are increasing, also this power plants are producing more than in 2015.

In the reference scenario, fossil fuel thermal power plants continue to sustain the electricity demand at the national level and, together with the hydropower plants, meeting the export demand of countries in the SRB or in outside of the basin areas.

Figure 26 illustrates the electricity trade dynamics for the Reference Scenario. It can be seen that Bosnia and Herzegovina is the next exported, supplying electricity that generates mostly from coal and hydropower to the neighbouring countries, Serbia, Montenegro and Croatia. This in turn have positive net imports, meaning they rely on electricity generated outside their borders.

A clear evidence of the dependency of SRB countries from electricity produced in Bosnia and Herzegovina is seen in years 2020 and 2027 for the case of Serbia’s import behaviour that matches the exports from Bosnia and Herzegovina. This happens because Serbia is the country with the highest electricity demand, and for that reason, has the ability to shape the generation profile of neighbouring countries.



BIOMASS OS
COAL SS
HYDRO OS
HYDRO SS
GAS OS
GAS SS
NUCLEAR SS
SOLAR
WIND
SI - REF 2015
0%
1%
2%
3%
0%
15%
6%
53%
20%
SI - REF 2020
1%
1%
2%
3%
0%
14%
12%
45%
22%
SI - REF 2025
0%
1%
2%
3%
0%
14%
16%
36%
28%
SI - REF 2030
0%
1%
1%
20%
2%
0%
38%
14%
24%
BIOMASS OS
BIOMASS SS
COAL OS
GEOTHERMAL OS
HYDRO OS
HYDRO SS
GAS OS
GAS SS
NUCLEAR SS
SOLAR
WIND
HR - REF 2015
0%
4%
2%
0%
0%
7%
21%
8%
6%
50%
2%
HR - REF 2020
0%
3%
3%
0%
15%
25%
6%
6%
0%
4%
38%
HR - REF 2025
0%
3%
2%
0%
1%
13%
21%
6%
6%
6%
42%
HR REF 2030
2%
2%
0%
0%
18%
20%
1%
4%
5%
9%
39%
COAL OS
COAL SS
HYDRO OS
HYDRO SS
GAS SS
SOLAR
WIND
BA - REF 2015
2%
0%
0%
8%
14%
43%
33%
BA - REF 2020
0%
2%
0%
15%
20%
33%
30%
BA - REF 2025
2%
2%
2%
15%
28%
21%
30%
BA - REF 2030
2%
3%
3%
10%
28%
29%
25%

a)

b)

c)

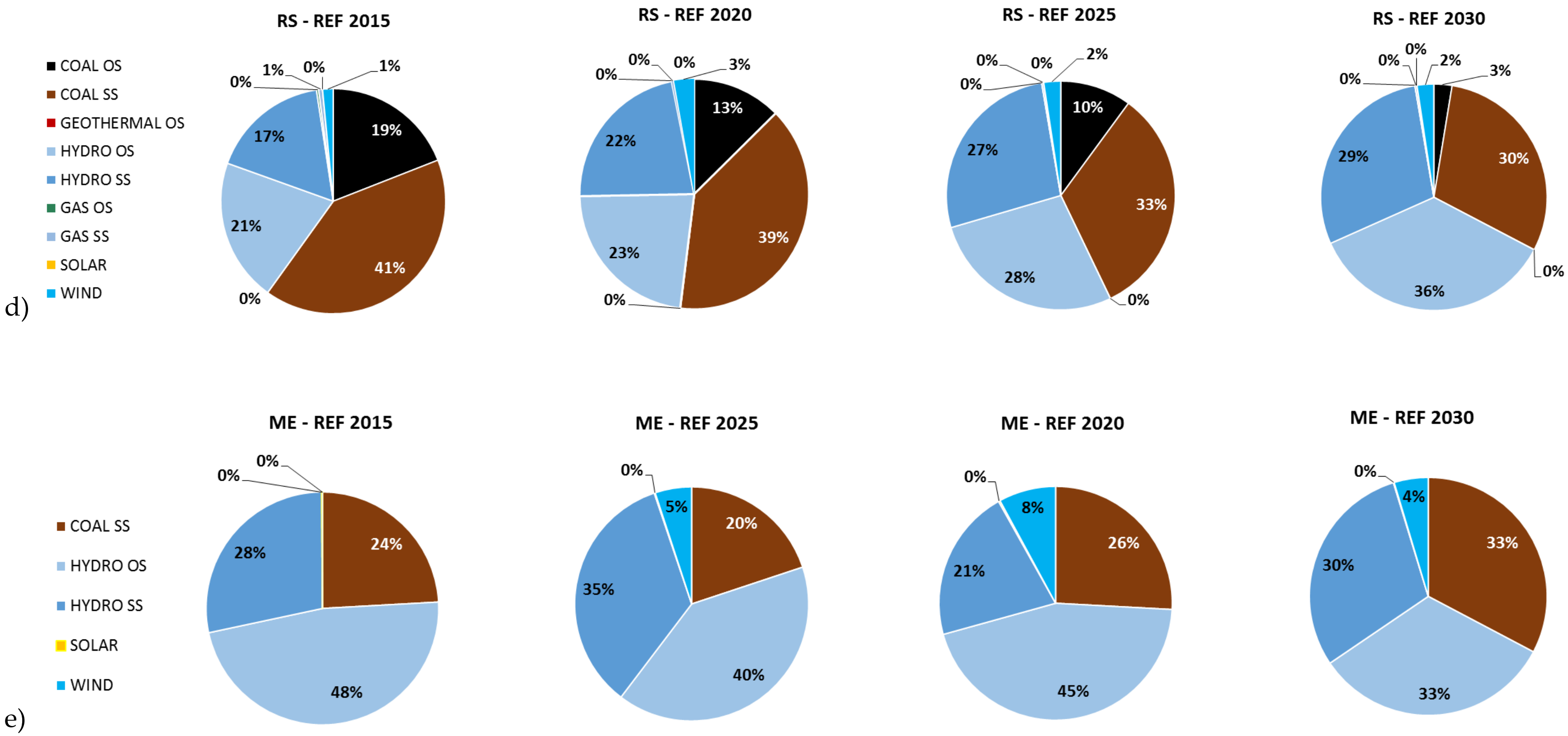


Figure 25. Reference scenario projections of the electricity generation mix of the SRB countries by fuel for the years 2015, 2020, 2025 and 2030 (OS - technology outside the SRB; SS - technology in the SRB).

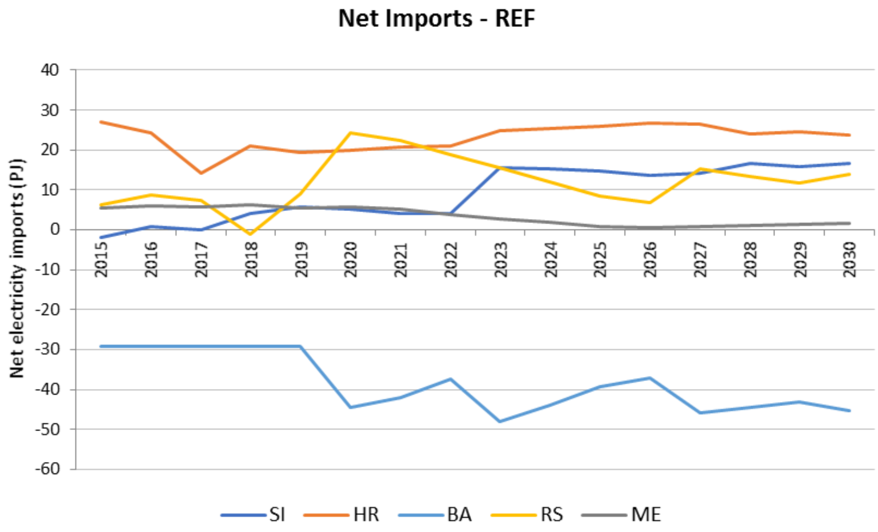


Figure 26. Net imports of the SRB countries in the Reference Scenario.

As for the GHG emissions in the reference scenario, analysing the whole contribution from the power systems of the SRB countries, it is seen in Figure 27 that, although an increase of the electricity generated by hydropower plants, the electricity demand and the electricity trade require the production from thermal power plants. As it was seen in Figure 26, it is Bosnia and Herzegovina that is the main exporter of electricity in the region. As this country has enough coal resources to supply the thermal power plants, the decrease in emissions allowed by the increased generation from hydropower plants is partially offset by the necessary use of fossil fuels.

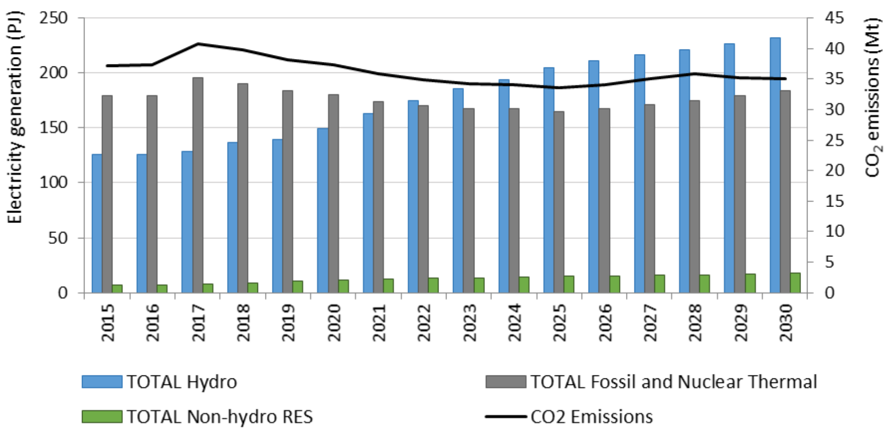


Figure 27. Overall electricity generation for the SRB countries and CO_2,eq emissions, for the Reference Scenario.

5.3 SCENARIOS COMPARISON

This section is dedicated at the comparison between the scenarios described in section 4.5.2. Special emphasis will be given to the analysis of the results for the reference scenario.

5.3.1 Hydropower production

Comparing the climate change scenario (RCP4.5) and the maximum irrigation scenario (IRR MAX) for the case of the REF scenario, no perceptible change is noticed, derived from the Reference scenario. The difference between the two scenarios in terms of hydro generation is very small, not surpassing 0.1%.

Apart from the comparison between the two climate change scenarios, Figure 28 also presents the difference in generation for the hydropower plants located in (identified as HYDRO SS) and outside of the SRB (identified as HYDRO OS).

In both cases is verified that the hydropower production is higher in the reference scenario. According to the results, hydropower generation in the SRB is more vulnerable to the impacts of climate change, expressed through the reduction of river flows.

Analysing the Reference scenario, evidence is given that hydropower expansion in the basin is favourable, only if climate change impacts do not curtail generation from this energy source.

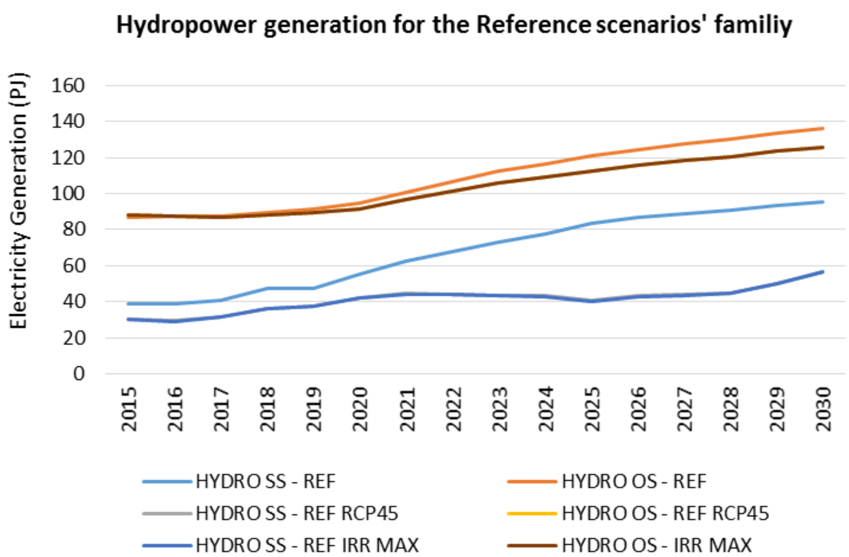


Figure 28. Variation of hydropower generation for the scenarios inherited from the Reference scenario.

5.3.2 Hydropower and thermal power generation comparison

The impact of the climate change in hydropower generation triggers the use of fossil fuel sources for power generation. When trade is required to be supplied to other nations, the stress in thermal power facilities increase, as it can be seen in Figure 29.

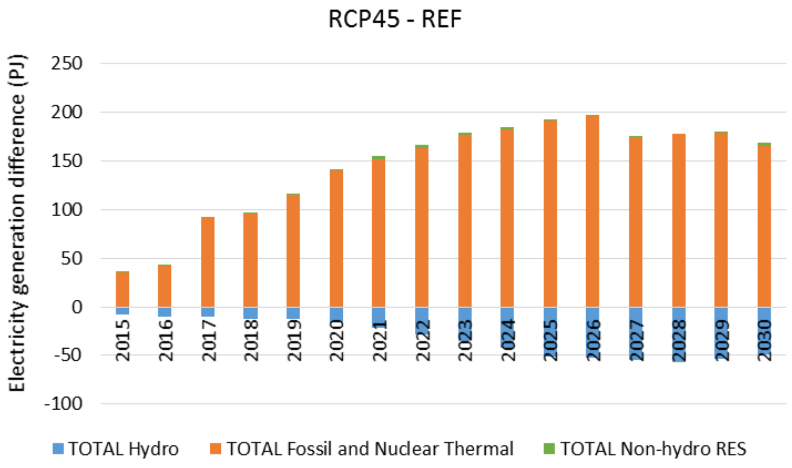


Figure 29. Comparison between the RCP4.5 and the Reference scenario in terms of the generation of electricity from different technologies.

As it was mentioned previously, hydropower generation in the Maximum Irrigation scenario decreases in respect to the climate change scenario. Figure 30 indicates this impact of the competing use of water for irrigation in the agriculture sector. This impact might not seem very expressive, however it is important to note that overall results are being analysed, which may attenuate more drastic impacts in certain countries, which are offset by increased hydropower production in others.

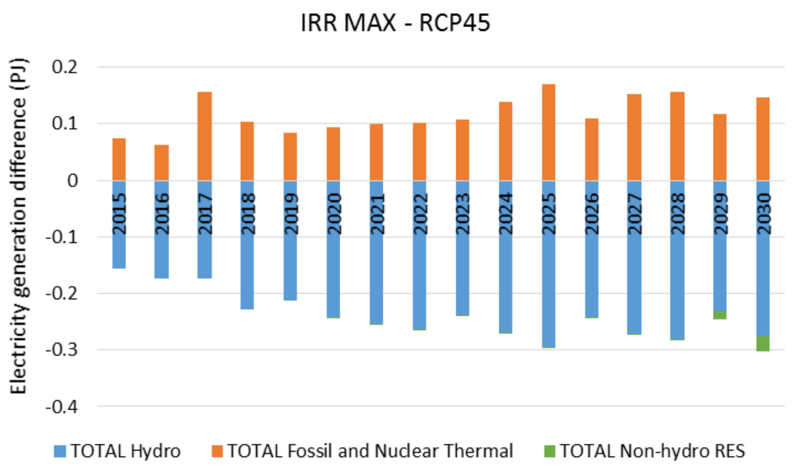


Figure 30. Difference in electricity production between the RCP4.5 and IRR MAX scenarios for the overall generation of electricity from hydropower and thermal power plants in the region.

5.3.3 Net imports – comparison between the REF scenario and REF RCP4.5

Electricity imports dynamics change drastically in a climate change scenario. It was seen previously for the REF scenario, that Bosnia and Herzegovina was the main exporter of electricity. However, due to lower availability of water for hydropower production, Serbia takes the role of electricity exports together with Bosnia and Herzegovina. It is also verified that other countries that the demand requirements from the other SRB decrease in terms of imports. The explanation lies on the fact that electricity trade with the surrounding countries to the SRB need their trade requirements to be met and by doing so, changing the pattern of the trade in the region.

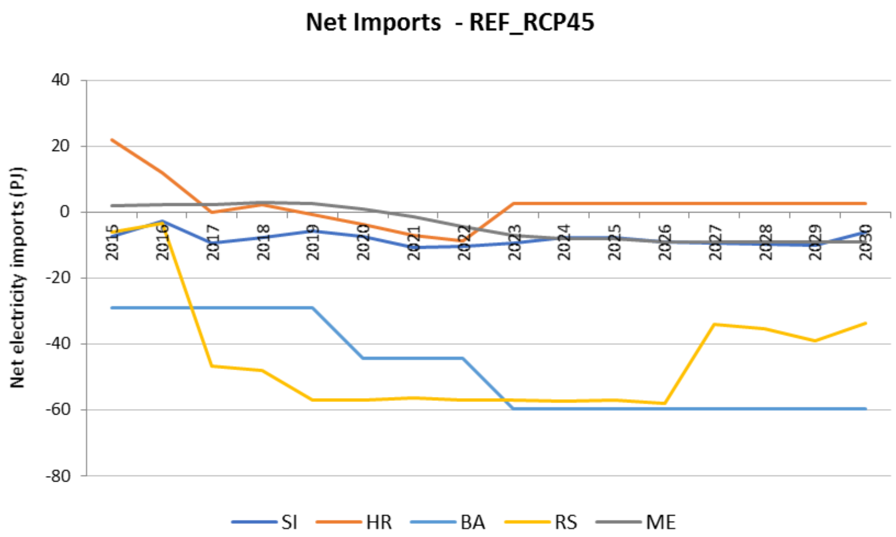


Figure 31. Net imports for the RCP4.5 scenario, inherited from the REF scenario.

5.3.4 Water use

Water consumption by thermal power plants, by SRB country, is represented in Figure 32. Water consumption will vary depending on the type of thermal power technologies in each country. In the SRB thermal power is highly dependent on coal, and therefore, apart from the water use by the nuclear power plant Krsko, all the remainder use will be related to the operation of that type of power plants.

The water consumption in Slovenia, due to the Krsko power plant, is one highest in the region. It increases further by the end of the model period because a new nuclear power plant is chosen to be installed by the model, due to the electricity demand requirements.

However, in the climate change scenario, the water consumption reduces. This happens because of the contribution of the hydropower expansion expected in the country, which has as a benefit, the reduced need of power from the nuclear power plant. Another reason, for the specific case of Slovenia is the fact the second nuclear facility is not installed, has the available installed capacity in the region is sufficient to supply the country demands and the trade requirements. In turn, the production from coal power plants in Slovenia increases to complement the regional electricity demands.

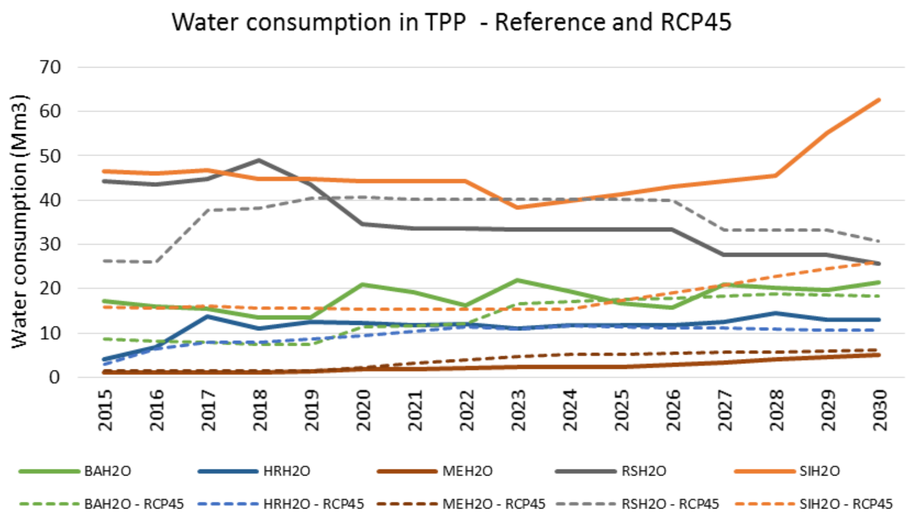


Figure 32. Water consumption in thermal power plants for the Reference and Climate change (RCP4.5) scenarios.

Comparing the RCP4.5 scenarios, for the two demand different demand scenarios, REF and AEE, it is realised that the water consumption is lower in most countries, with exception to Slovenia, where no changes are perceptible, as it can be seen in Figure 33.

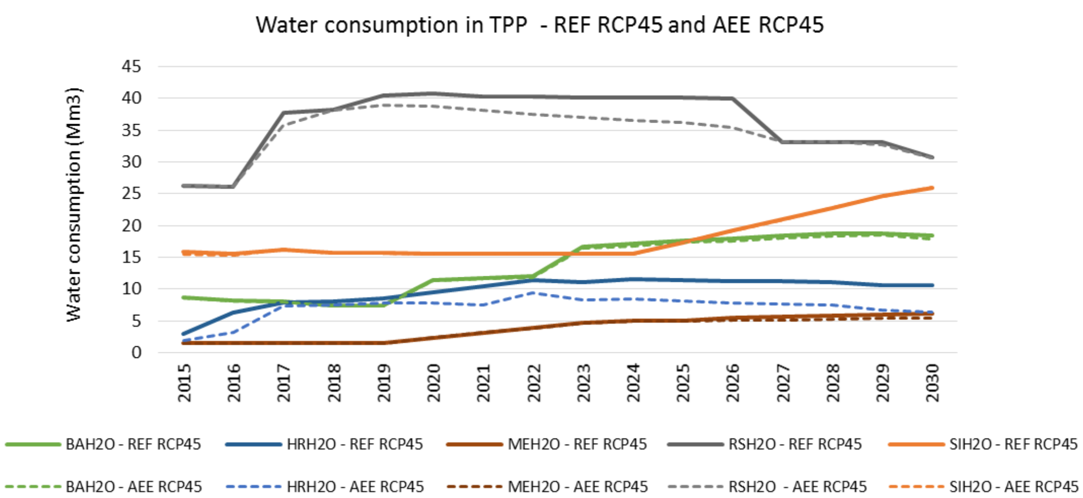


Figure 33. Water use by thermal power plants in the SRB region, for the two climate change scenarios, inherited from the REF and AEE scenarios.

5.3.5 Emissions analysis comparison between scenarios

The implementation of energy efficiency measures, in comparison with the Reference scenario, allows for a bigger reduction in GHG emissions, due to the lower contribution required from the thermal power facilities to supply electricity (Figure 34). The reduction in this case, in comparison to the emissions in 2015, is of 21%.

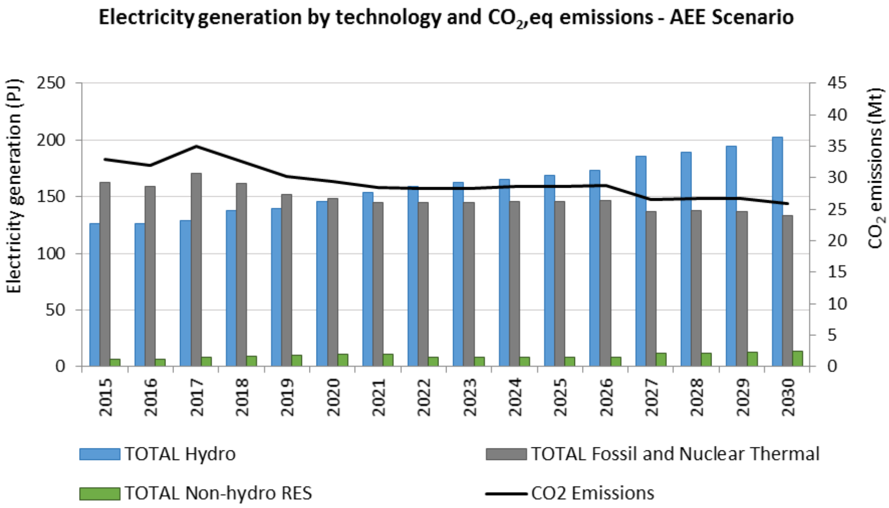


Figure 34.Electricity generation and GHG emissions comparison for the AEE Scenario.

Comparing the GHG emissions for all the scenarios under study, it verifies that the climate changes scenarios will have a significant impact in terms of GHG emissions, due to the impact on hydropower production, as it can be seen in Figure 34. However, comparing the climate change scenarios and maximum irrigation for the two demand projections, REF and AEE, the emissions increase will be lower if energy efficiency measures are put in place. As is can be realised in Figure 36, in overall terms, the increase in irrigation demand, during the modelling period, does not cause a noticeable impact in the GHG emissions. The results for both scenario families are different, but always lower than one megaton of $CO_{2,eq}$, as it can be seen in Figure 36.

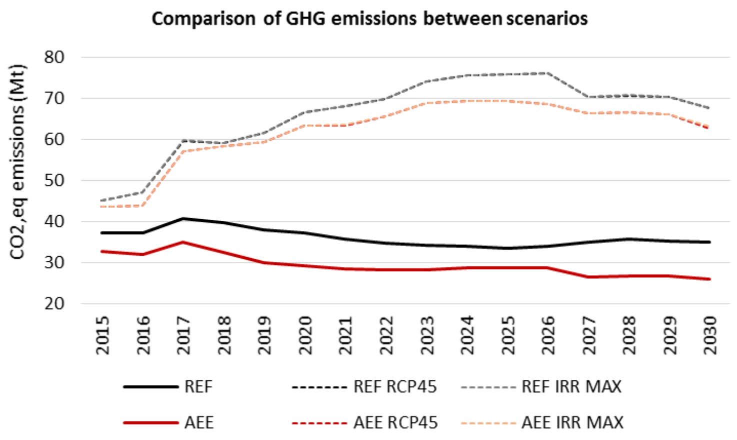


Figure 35. Comparison between the GHG emissions of all scenarios under analysis.

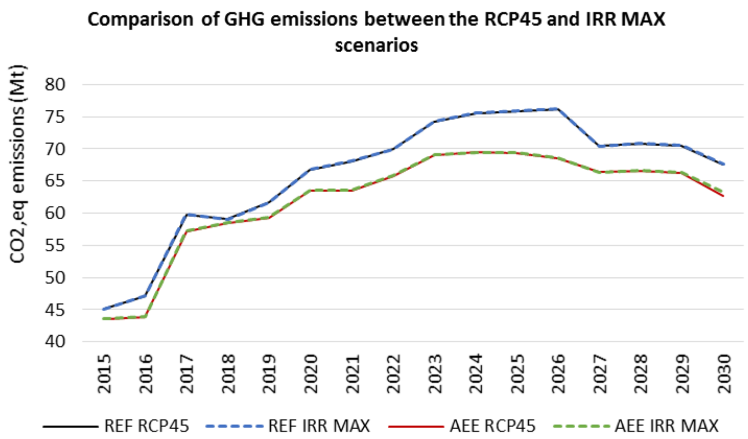


Figure 36. Comparison of the climate change scenarios (RCP4.5 and IRR MAX) for the two demand scenarios under study (REF and AEE).

5.4 Chapter Summary

Important conclusions were driven from the analysis of the results. The impact of energy efficiency measures is highly evident in the response given by the energy systems of the region. Trade varies significantly between the two demand scenarios, REF and AEE.

In respect to climate change, even under a moderate climate future, the impacts on the generation mix of the countries and the region are clear. If hydropower production is compromised by reduced water availability, due to drier conditions, more electricity will need to be produced from fossil fuels. In addition, the trade agreements with neighbouring countries will further increase the fossil fuel dependency, as no other energy source was identified in the model as a rightful competitor to this type of resources.

6 CONCLUSIONS

The study seeks to provide understanding on the extent to which the power systems of five riparian countries rely on the water resources of the Sava River Basin, and how the impact of this dependence in the long-term could evolve, under different scenarios. To do so, a multi-country energy systems model was developed using the long-term optimization tool OSeMOSYS.

It was verified that the expansion of hydropower could benefit the power systems of the region, relying on a cleaner and cheaper energy technology. However, the environmental impacts of such deployment should be considered.

It was confirmed climate change can impact severely the generation mix, urging the countries to rely on fossil fuels for energy production, which has in turn the environmental impact of increased $CO_{2,eq}$ emissions.

The expansion of agriculture, in a scenario that takes into account the impacts of climate change, could have a negative outcome in hydro production and, again, resulting in increased emissions of greenhouse gases. This impact should be analysed per country, as the overall results for the basin might absorb regional changes.

The study ultimately shows that riparian countries connection, due to the share of transboundary waters, is deeper than it might be acknowledge. When water availability impacts electricity generation, all the electricity supply of the region will likely be affected.

6.1 LIMITATIONS AND FUTURE WORK

One of the main limitations of the study is related with data sources. It was verified that information of power systems and power plants was not always convergent between different sources, i.e. electricity utilities, TSO and governmental sources. The accuracy and reliability of the information compiled, including location of power plants, capacity and installation year and electricity transmission and distribution losses, was difficult to validate and required considerable amount of time for a portfolio to be agreed upon. As the study is heavily dependent on the physical location of projects, and the power generation mix and electricity trade reactive to energy sources availability, a sensitive analysis would be required to more conveniently assess impacts in the results.

Electricity demand projections were based on one type of resource and, in the case of earlier publications; the projections might have been subjected to change. In addition, the projections used referred to a period up to 2020, and assumptions in terms of growth had to be derived and assumed as following the same growth of the last five years.

Another important factor that should be taken into account when reading the results are the climate change projections of flow at specific locations of existing hydro power plants. For hydropower projects, a proxy assumption was used to estimate the capacity factors of the new projects, which could be questioned as river flow and run-off is dependent on many different factors as the geomorphology of the site, the soil type, land use, river flow, type of hydropower plant, and other water uses. No distinction was made between hydropower plant types, with all facilities assumed as run-of-river power plants.

The representation of the regional electricity market was done as an illustrative exercise of the flexibility of the electricity generation mix of each country and of the region. The cost of electricity generation in each country, due to the assumptions made, may be exactly comparable to the real costs involved. Fluctuation of the electricity prices was not considered and with such a wide number of countries in the model, it is complex to represent. Moreover, the prices used for the external trade technologies correspond to the cost of the electricity supplied to industries in each importing, and the structure of this cost may vary between countries.

The study lacks in a methodology for estimating the climate variability and, ultimately, climate change impacts in thermal power generation, through changes in water availability and/or river water temperature. Linked to this problematic is the data sources issue, mentioned earlier in this section, in regard to the cooling systems of the power plants, water use, and other parameters related to operation. Although the impacts of competing uses of water resources and the effects of climate change were analysed for hydropower production, it was assumed thermal generation was not affected in extreme conditions. As it was seen in the literature review, power output of thermal power plants is susceptible to be affected by extreme climate conditions, which are expected to be more frequent in the future. Therefore, such type of analysis is needed to add robustness to the assessment of the resilience of the energy system as a whole.

Future work should focus on points referred previously, more precisely in the better representation of the regional electricity trade and in complementing the climate change scenario analysis to test the contribution of thermal power plants.

Other areas of improvement would be exploring the penetration of non-hydro RES considering the feed-in tariffs incentives, in place in some of the countries. The expansion of the scope of the analysis to include other relevant uses of water, such as public supply, and test the response of the energy systems for different supply priorities if applicable, could also be an interesting improvement opportunity.

REFERENCES

AE-SI (2014). Annual Report 2013. URL http://www.agen-rs.si/documents/10926/38704/Poro%C4%8Dilo%20o%20stanju%20na%20podro%C4%8Dju%20energetike%20v%20Sloveniji%20v%20letu%202013 (accessed 21/10/2014).

BA - Vlada Republike Srpske (2010). Energy Development Plan of Republike Srpske until 2030.

BA FIPA (n.d.a). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Caplje,Sanski%20Most.pdf (accessed 16/01/2015).

BA FIPA (n.d.b). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Babino%20Selo,%20Donji%20Vakuf.pdf (accessed 16/01/2015).

BA FIPA (n.d.c). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Vinac,%20Jajce.pdf (accessed 16/01/2015).

BA FIPA, (n.d.d). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Han%20Skela,%20Jajce.pdf (accessed 16/01/2015).

BA FIPA (n.d.e). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Vrletina%20kosa,%20Jajce.pdf (16/01/2015).

BA FIPA (n.d.f). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Ivik,%20Jajce.pdf (accessed 16/01/2015).

BA FIPA (n.d.g). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Ugar%20Usce,%20Jajce.pdf (accessed 16/01/2015).

BA FIPA (n.d.h). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Ustikolina,%20Gorazde.pdf (accessed 16/01/2015).

BA FIPA (n.d.i). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Drina%20I,%20Drina%20II,%20Drina%20III.pdf (accessed 16/01/2015).

BA FIPA (n.d.j). FIPA Investment Project Profile. URL http://www.fipa.gov.ba/investinbih/index_htm_files/Kovanici,%20Zenica.pdf (accessed 16/01/2015).

BA (2013). Energy Community - Statement on Security of Energy of Bosnia and Herzegovina.

Bajželj B, Richards K, Allwood J, Smith P, Dennis JS, Curmi E, & Gilligan CA (2014). Importance of food-demand management for climate mitigation. *Nature Climate Change* (4) 924-929.

Bayer, P., Rybach, R., Blum, P., Brauchler, R. (2013). Review on life cycle environmental effects of geothermal power generation. *Renewable and Sustainable Energy Reviews*, 26: 446-463.

Belinskij, A. (2015). Water-Energy-Food Necus within the Framework of International Water Law. *Water*, 7(10), 5396-5415.

BEN, 2014. [WWW document] Country Report on Energy Business - Serbia. URL: http://www.erranet.org/index.php?name=OE-eLibrary&file=download&keret=N&showheader=N&id=10229 (accessed 18/01/2014).

Bidoglio, G. (2014). Scientific Support to the EU Strategy for the Danube Region and the Danube Water Nexus project.

Byers, E., Hall, J., Amezaga, J. (2014) Electricity generation and cooling water use: UK pathways to 2050. *Global Environmental Change*, 25: 16-30.

Ceglar, A., Rakovec, J. (2015). Climate Projections for the Sava River Basin. In: Milačič, R. et at (eds). *The Sava River*. Handbook of Environmental Chemistry, 31, Springer-Verlag Berlin Heidelberg, pp. 53 – 72.

Comsar Energy Hidro (n.d.). [WWW page] URL http://comsar.com/projects-technologies/hpp-mrsovo (accessed 16/01/2015).

COWI AS (2013). Update the Basis of the Water Resources Management of the Vrbas River Basin - Module 2. Hydropower Development Study. URL http://www.wb-vrbasstudy.com/tl_files/Documents/Final%20Module%202%20with%20Appendices-May%202013.pdf (accessed 18/01/2015).

DMCSEE (2011). Archive of Local/Regional/National Drought Periods and Impacts based on Historical Records; Mitigation Practices and Drought Management from all Countries/Regions added to the Archive. Athens: Agricultural University of Athens. February 2011.

Ebinger, J., Vergara, W. (2011). *Climate Impacts on Energy Systems – Key Issues for Energy Sector Adaptation*. Washington: The World Bank. DOI: 10.1596/978-0-8213-8697-2.

EH (n.d.). Energoprojeckt Hidrinzenjering presentation brochure. URL http://www.ephydro.com/info/downloads/brochures/ephydro-presentation.pdf (accessed 28/01/2005).

ELES (2011). *Development Strategy of The Electrical Power System of the Republic of Slovenia – Supplement 23 May 2011*. Ljubljana.

EPA (2014). *Technical Development Document for the Final Section 316(b) Existing Facilities Rule*. United States Environmental Protection Agency. URL: http://www2.epa.gov/sites/production/files/2015-04/documents/cooling-water_phase-4_tdd_2014.pdf (accessed on 08/08/2015).

EPBiH (2013). Vranduk Hidroenergetski Projekt - Informativni letak o projektu. URL: http://www.elektroprivreda.ba/upload/documents/HE_Vranduk_Informativni_letak_o_projektu-NTS.pdf (accessed 15/01/2015).

EPBiH (2014). Lista - Registar Podnijetih Zahtjeva Korisnika za Prikljucak na Presnonu Mrezu Naponskog 110 kV, 220 kV i 400 kV [WWW Document]. URL http://elprenosbih.ba/Prikljucak/Lista%20-%20Registar%20podnijetih%20zahtjeva%20Korisnika%20za%20prikljucak%20na%20prenosnu%20mrezu%2013.11.2014.pdf (accessed 16/01/2015).

EPBiH (n.d.a). [WWW page] URL http://www.elektroprivreda.ba/eng/page/hydro-power-plant-janjici (accessed 15/01/2015).

EPBiH (n.d.b). [WWW page] URL http://www.elektroprivreda.ba/eng/page/hydro-power-plant-krusevo-zeleni-vir (accessed 15/01/2015).

EPS (2011). Strategic and Development Projects of the Electric Power Industry of Serbia. URL http://www.eps.rs/Eng/Pics/STRAT_RAZV_web_eng.pdf (accessed 21/01/2015).

EPS (2014). Electric Power Industry of Serbia - Annual Report 2013. URL http://www.eps.rs/Eng/Godisnji%20Izvestaji/Annual%20Report_EPS_2013_16062014_CD.pdf (accessed 21/01/2015).

European Commission – Rural Development Programme (n.d.). Factsheet on 2014-2020 Rural Development Programme for Croatia. URL: http://ec.europa.eu/agriculture/rural-development-2014-2020/country-files/hr/factsheet_en.pdf (accessed 21/10/2015).

European Commission – Rural Development Programme (n.d.). Factsheet on 2014-2020 Rural Development Programme for Sllovenia. URL: http://ec.europa.eu/agriculture/rural-development-2014-2020/country-files/si/factsheet_en.pdf (accessed 21/10/2015).

FAE (2015). "Power deficit in the Polish power system in August 2015" – comments of the Forum for Energy Analysis (Forum Analiz Energetycznych, FAE). URL: http://www.fae.org.pl/files/file_add/file_add-21.pdf.

FAO (2014). The Water–Energy–Food Nexus: A New Approach in Support of Food Security and Sustainable Agriculture. Food and Agriculture Organisation of the United Nations, Rome. URL: http://www.fao.org/nr/water/docs/fao_nexus_concept_web.pdf

Federalno Ministarstvo Energije, Rudarstva i Industrije, Federacija Bosne i Hercegovine (FMERI-BiH), (2014). Akcioni Plan. Federacije BiH za koristenje obnovljivih izvora energije (APOEF). Maj, 2014.

Fritzsche, K., Issayeva, G., Maas, A., Rüttinger, L. (2011). Climate Change and the Water-Energy-Agriculture Nexus in Central Asia. Scenario Workshop Background Paper, October 2011.

Giampietro, M., Aspinall, R., Bukkens, Cadillo Benalcazar, J., Diaz-Maurin, F., Flammini, A., Gomiero, T., Kovacic, Z., Madrid, C., Ramos-Martín, J., Serrano-Tovar, T. (2013). An Innovative Accounting Framework for the Food-Energy-Water Nexus - Application of the MuSIASEM approach to three case studies. URL: http://www.fao.org/docrep/019/i3468e/i3468e.pdf

HE na Drini (n.d). [WWW page] URL http://www.henadrini.com/hidropotencijal-sliva-drine/?lang=en (accessed 16/01/2015).

HEIS (2012). *Environmental and Social Management Framework – Irrigation Development Project in Bosnia and Herzegovina*. January 2012. URL: http://fmpvs.gov.ba/upload_files/1440489064-303_491_956_e.pdf

HES Vrbas (n.d.a). [WWW page] URL http://www.hesvrbas.com/eng/?p=bl_niska (accessed 21/10/2014).

HES Vrbas (n.d.b). [WWW page] URL http://www.hesvrbas.com/eng/?p=krupa (accessed 21/10/2014).

HESS (2006). Priloga o HE Krsko. Posavski obzornik, leto X, številka 5. URL http://www.he-ss.si/dokumenti/priloga/he_krsko_priloga.pdf (15/01/2015).

HESS (2011). Annex about HE Brezice. Posavski obzornik - leto XV, številka 3. URL http://www.he-ss.si/dokumenti/priloga/he_brezice_priloga.pdf (accessed 22/10/2014).

HESS (2013). Annex about HE Mokrice. Posavski obzornik - leto XVII, številka 26, četrtek, 19. URL http://www.he-ss.si/dokumenti/priloga/he_mokrice_priloga.pdf (accessed 22/10/2014).

HESS (2014). HESS Annual Report 2013. URL http://www.he-ss.si/pdf/letna-porocila/letno-porocilo-hess-2013.pdf (accessed 23/01/2015)

Heywood, D. (2013). Water and Climate Adaptation Plan (WATCAP) for the Sava River Basin.

Hoff, H. (2011). Understanding the Nexus. Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus. Stockholm Environment Institute, Stockholm. URL: http://www.sei-international.org/mediamanager/documents/Publications/SEI-Paper-Hoff-UnderstandingTheNexus-2011.pdf

Howells, M., Hermann, S., Welsch, M., Bazilian, M., Segerström, R., Alfstad, T., Gielen, D., Rogner, H., Fischer, G., van Velthuizen, H., Wiberg, D., Young, C., Roehrl, R.A., Mueller, A., Steduto, P., Ramma, I. (2013). Integrated analysis of climate change, land-use, energy and water strategies. *Nature Climate Change*, 3: 621–626. doi:10.1038/nclimate1789

Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., Hughes, A., Silveira, S., DeCarolis, J., Bazillian, M. (2011). OSeMOSYS: the open source energy modeling system: an introduction to its ethos, structure and development. *Energy Policy* 39: 5850–5870.

HSE (2011). [WWW page] Construction of HPPs on the middle Sava River. URL http://www.hse.si/en/projects/hydro/construction-of-hpps-on-the-middle-sava-river (15/01/2015).

HWN (2014). [WWW page] URL http://www.hydroworld.com/articles/2014/03/bosnia-pre-qualifies-firms-to-build-20-mw-vranduk-hydropower-project.html (accessed 21/01/2015).

IEA (2012). Water for Energy – Is energy becoming a thirstier resource? Excerpt from the *World Energy Outlook 2012*. Paris: OECD/IEA.

IPCC (2012). IPCC *Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press.

ISRBC (2009). Sava River Basin Analysis Report. Zagreb, September 2009. URL: http://www.savacommission.org/dms/docs/dokumenti/documents_publications/publications/other_publications/sava_river_basin_analysis_report_high_res.pdf

ISRBC (2010). Sava River Basin Analysis Summary. Zagreb: December 2010.

ISRBC (2013a). Sava River Basin Management Plan – Draft March 2013. URL: http://www.savacommission.org/dms/docs/dokumenti/srbmp_micro_web/srbmp_final/sava_rbmp_draft_eng_03_2013.pdf

ISRBC (2013b). *Sava River Basin Management Plan. Background Paper No. 10 – Climate Change and RBM planning*. URL: http://www.savacommission.org/dms/docs/dokumenti/srbmp_micro_web/backgroundpapers_final/no_10_background_paper_climate_change_and_rbm_planning_.pdf

ISRBC (2013c). *Towards Practical Guidance for Sustainable Sediment Management using the Sava River Basin as a Showcase - Estimation of Sediment Balance for the Sava River.* Zagreb: ISRBC. URL: http://www.savacommission.org/dms/docs/dokumenti/documents_publications/publications/other_publications/balses_final.pdf

ISRBC (2013d). *Sava River Basin Management Plan. Background Paper No. 5 – Significant Water Management Issues.* URL: http://www.savacommission.org/dms/docs/dokumenti/srbmp_micro_web/background_documents/no_5_background_paper_significant_water_management_issues.pdf

ISRBC (2015). International Sava River Basin Commission website. URL: http://www.savacommission.org/

Johst, M., Rothstein, B. (2014). Reduction of cooling water consumption due to photovoltaic and wind electricity feed-in. *Renewable and Sustainable Energy Reviews*, 35: 311-317.

Koch, H., Vögele, S. (2009). Dynamic modelling of water demand, water availability and adaptation strategies for power plants to global change. *Ecological Economics*, 68: 2031-2039.

Koch, H., Võgele, S. (2013). Hydro-climatic conditions and thermoelectric electricity generation - Part I: Development of models. *Energy*, 63: 42-51.

Komatina, D., Grošelj, S. (2015). Transboundary Water Cooperation for Sustainable Development of the Sava River Basin. In: Milačič, R. et at (eds). *The Sava River*. Handbook of Environmental Chemistry, 31, Springer-Verlag Berlin Heidelberg, pp. 1 – 24.

KPMG (2010). Central and Eastern European Hydropower Outlook. URL http://www.kpmg.com/TR/en/IssuesAndInsights/ArticlesPublications/Documents/Central-and-Eastern-European-Hydro-Power-Outlook.pdf (accessed 30/01/2015).

Leflaive, X., et al. (2012), "Water", in OECD, *OECD Environmental Outlook to 2050: The Consequences of Inaction*, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/env_outlook-2012-8-en

Macknick, J., Newmark, R., Heath, G., and Hallett, K.C. (2012). Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. *Environmental Research Letters*, 7: 045802.

Ministry of Agriculture of Croatia (MA-HR), (2012). *IPARD Programme 2007-2013 – Agriculture and Rural Development Plan.* Directorate of Rural Development, EU and International Cooperation. Zagreb, August 2012. URL: http://www.mps.hr/ipard/UserDocsImages/dokumenti/IPARD/IPARD%202012/IPARD%20V%202012%20EN%20FINAL.pdf

ME (2011). Energy Community - Security of Supply Statement for Montenegro. URL https://www.energy-community.org/portal/page/portal/ENC_HOME/DOCS/1218178/Montenegro_-_SoS-_eng11.pdf (accessed 12/10/2014).

ME (2014). National Renewable Energy Action Plan to 2020 of the Republic of Montenegro. December 2014.

Mekonnen, M., and Hoekstra, A. (2012). The blue water footprint of electricity from hydropower. Hydrology and Earth Systems Science. 16: 179–187, doi:10.5194/hess-16-179-2012.

Mekonnen, M., Gerbens-Leenes, P., Hoekstra, A. (2015). The consumptive water footprint of electricity and heat: a global assessment. *Environmental Science: Water Research & Technology*, Royal Society of Chemistry, 1: 285-297.

Meldrum, J., Nettles-Anderson, S., Heath, G., Macknick, J. (2013). Life cycle water use for electricity generation: A review and harmonization of literature estimates. *Environmental Research Letters*, 8: 015031.

MENP-HR (2014). Sixth National Communication and First Biennial Report of the Republic of Croatia under the United Nations Framework Convention on Climate

Change. January 2014. URL:
http://unfccc.int/files/national_reports/annex_i_natcom_/application/pdf/hrv_nc6.pdf

MESP-RS (2010). Initial National Communication of the Republic of Serbia under the United Nations Framework Convention on Climate Change. Belgrade, November 2010. URL: http://unfccc.int/resource/docs/natc/srbnc1.pdf

Ministry of Agriculture and Environmental Protection of the Republic of Serbia (MAEP-RS), (2014). Republic of Serbia – IPARD Programme for 2014-2020. Belgrade. URL: http://www.seio.gov.rs/upload/documents/Vesti/2015/IPARD_2014_2020.pdf

Ministry of Economy of Croatia (ME-HR), (2013). National Action Plan for Renewable Energy Sources to 2020 (English Provisional Translation). October 2013.

Ministry of Energy, Development and Environmental Protection of the Republic of Serbia (MEDEP-RS), (2013). National Renewable Energy Action Plan of the Republic of Serbia. Belgrade, 2013.

Mobley, K.R. (2001). *Plant Engineer's Handbook*. Butterworth-Heinemann.

MSDT-ME (2015). The Second National Communication on Climate Change of Montenegro to the United Nations Framework Convention on Climate Change. Podgorica, May 2015. URL: http://unfccc.int/resource/docs/natc/mnenc02.pdf

MSPCE-BA (2013). Second National Communication of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Change. June 2013. URL: http://unfccc.int/resource/docs/natc/bihnc2.pdf

NRDC (2014). "Power Plant Cooling and Associated Impacts: The Need to Modernize U.S. Power Plants and Protect Our Water Resources and Aquatic Ecosystems". Natural Resources Defence Council Issue Brief, April 2014. URL: http://www.nrdc.org/water/files/power-plant-cooling-ib.pdf (accessed on 08/08/2015).

Peel, M., Finlayson B., McMahon, T. (2007). Updated world map of the Köppen-Geiger climate classification, *Hydrol. Earth Syst. Sci*., 11: 1633-1644.

Perry, J., Vanderklein, E. (1996*). Water Quality: Management of a Natural Resource*. Cambridge (MA): Blackwell Science.

Plappally, A. K., Lienhard, J.H. (2012). Energy requirements for water production, treatment, end use, reclamation, and disposal. *Renewable and Sustainable Energy Reviews*, 16: 4818-4848.

Platts (2012). World Electric Power Plants Database for 2012.

PS (2014). [WWW page] URL http://zagrebnasavi.hr/nova-koncepcija/ (accessed 23/01/2015).

RCC (2013). "Reservoir Granted Concessions for 18 MW Cehotina Hydroelectric Project in Bosnia and Herzegovina". URL: http://www.reservoircapitalcorp.com/i/pdf/2013-01-16_NR.pdf (accessed 14/01/2015).

RCC (2013). Renewable Energy in South East Europe - Hydro & Geothermal Energy. Investors Presentation. URL: http://www.reservoircapitalcorp.com/i/pdf/Nov-2013-REO-Investor-Presentation.pdf (accessed 30/01/2015).

RCERS (2014). [WWW page] Registar of Licences for the Construction of Electric Power Objects. URL: http://www.reers.ba/en/node/367 (accessed 16/01/2015).

Rebetez, M., Dupont, O., Giroud, M. (2009). An analysis of the July 2006 heatwave extent in Europe compared to the record year of 2003. *Theoretical and Applied Climatology 95*(1): 1-7.

ReISS Institute (2014). Provinces of Yugoslavia, 1929-1939 (Figure). Accessed 17October; URL: http://www.reiss-institute.org/articles/yugoslavia-maps-1929-1945/.

Rübbelke, D., Vögele, S. (2011). Impacts of climate change on European critical infrastructures: the case of the power sector. *Environmental Science & Policy*. 14: 53-63, DOI:10.1016/j.envsci.2010.10.007.

Scanlon, B., Duncan, I., Reedy, R. (2013). Drought and the water-energy nexus in Texas. *Environmental Research Letters*, 8: 045033.

SEN (2013). [WWW page]. "Montenegro: Large hydrological projects stopped due to the lack of investors' interest". URL http://serbia-energy.eu/montenegro-large-hydrological-projects-stopped-due-to-the-lack-of-investors-interest/?format=pdf (accessed 30/01/2015).

SI (2010) National Renewable Energy Action Plan 2010-2020 of Slovenia. Ljubljana, July 2010.

Sorg, A., Mosello, B., Shalpykova, G., Allan, A., Hill Clarvis, M., Stoffel, M. (2014). Coping with changing water resources: The case of the Syr Darya river basin in Central Asia. *Environmental Science & Policy*, 43: 68 - 77.

Strasser, L., Howells, M., Alfstad, T., Roger, H., Welsh, M., Lipponen, L. (2014). *Water-Food-Energy-Ecosystems Nexus: Reconciling Different Uses in Transboundary River Basins –*

Draft Methodology for the Nexus Assessment for discussion. UNECE Water Convention, September 2014, Geneva.

Stahl, K. (2001) Hydrological Drought - a Study across Europe *Freiburger Schriften zur Hydrologie*, 15, Institute of Hydrology (Hrsg). URL: http://www.hydrology.uni-freiburg.de/publika/band15.html

Tidwell, V., Kobos, P., Malczynski, L., Klise, G., Castillo, C. (2012). Exploring the Water-Thermoelectric Power Nexus. *Journal of Water Resources Planning and Management*. 138: 491:501.

UN Serbia, European Commission and the World Bank Group (2014). Serbia floods 2014. Belgrade. http://ec.europa.eu/enlargement/pdf/press_corner/floods/20140715-serbia-rna-report.pdf

UNECE (2011). Second Assessment of Transboundary Rivers, Lakes and Groundwaters. United Nations, New York and Geneva.

UNEP, 2005. Severskiy, I., Chervanyov, I., Ponomarenko, Y., Novikova, N.M., Miagkov, S.V., Rautalahti, E. and D. Daler. Aral Sea, GIWA Regional Assessment 24. University of Kalmar, Kalmar, Sweden.

USBR (US Department of Interior - Bureau of Reclamation), (2014). Consumptive Uses and Losses: Provisional Estimate. Arizona Portion of the Upper Colorado River Basin. Calendar Year 2013. Denver, Colorado. October 2014. URL: http://www.usbr.gov/uc/library/envdocs/reports/crs/az/AZreport2013draft.pdf

Williams, C. R., Rasul, M. G. (2008). Feasibility of a Hybrid Cooling System in a Thermal Power Plant. Conference Proceedings, 3rd IASME/WSEAS International Conference on Energy & Environment, University of Cambridge, February 23-25.

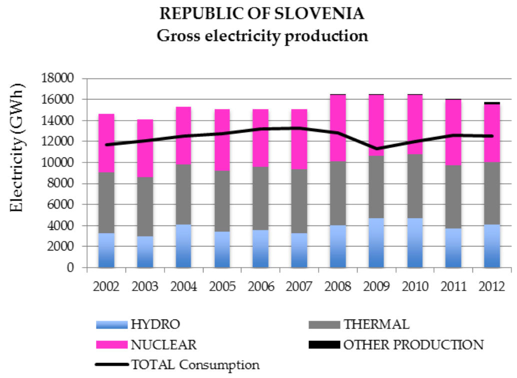
World Bank – WPP (2014). *Water & Climate Adaptation Plan for the Sava River Basin – Draft Final Report* for Consultation. Water Partnership Programme (WPP).

World Bank (2004). Water Energy Nexus in Central Asia – Improving Regional Cooperation in the Syr Darya River Basin. Washington DC: The World Bank, Europe and Central Asia Region.

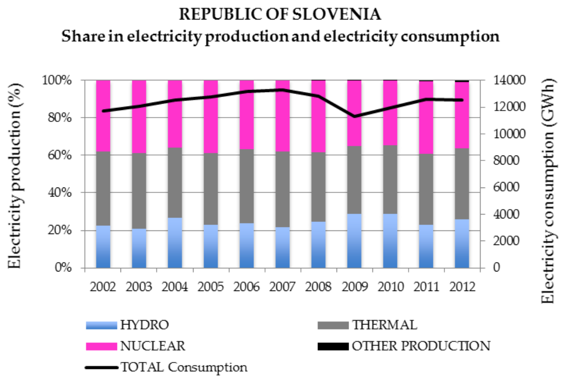
World Bank Group (2015). Bosnia and Herzegovina Partnership: Country Program Snapshot. October 2015. URL: http://pubdocs.worldbank.org/pubdocs/publicdoc/2015/10/779381443795253068/BiH-Snapshot.pdf

ANNEXES

A-1. HISTORIC ELECTRICITY PRODUCTION PER COUNTRY

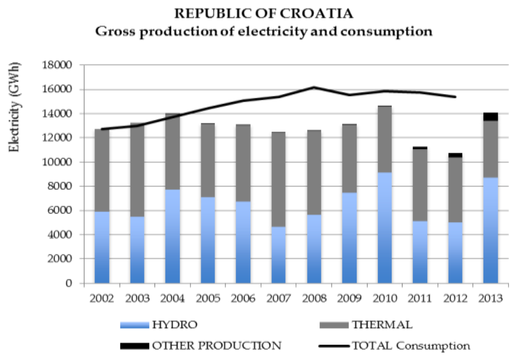


a)

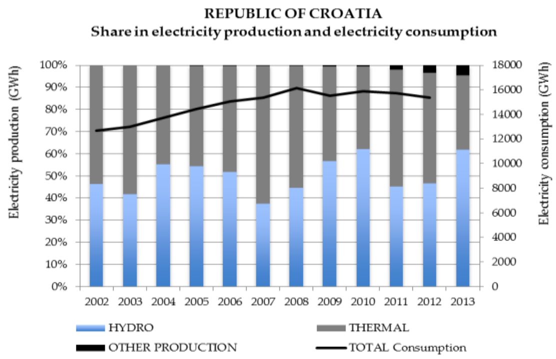


b)

Figure A-1. 1. Gross electricity production and total electricity consumption in Slovenia for the period from 2002-2012. a) Gross electricity production by technology; b) Share of gross electricity production by technology and total consumption of electricity (Statistical Yearbooks 2003 – 2013, Slovenia Statistics Office).

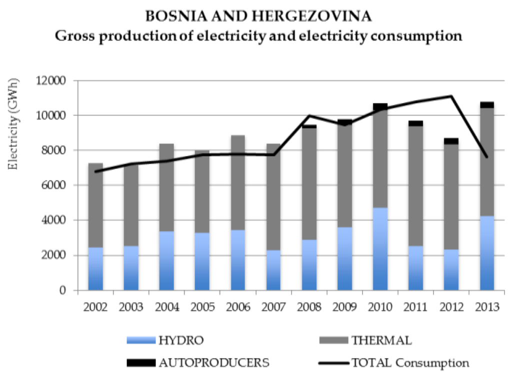


a)

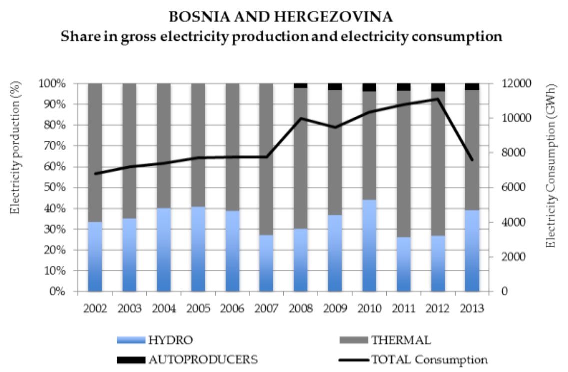


b)

Figure A-1. 2. Gross electricity production and total electricity consumption in Croatia for the period 2002-2013: a) Gross electricity production by technology; b) Share of gross electricity production by technology and total consumption of electricity (Statistical Yearbooks 2003 – 2014, Croatia Bureau of Statistics).

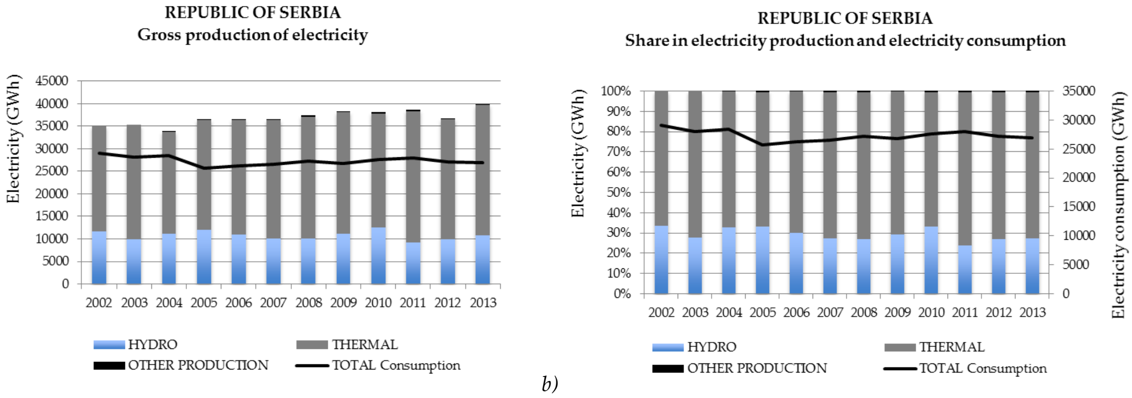


a)



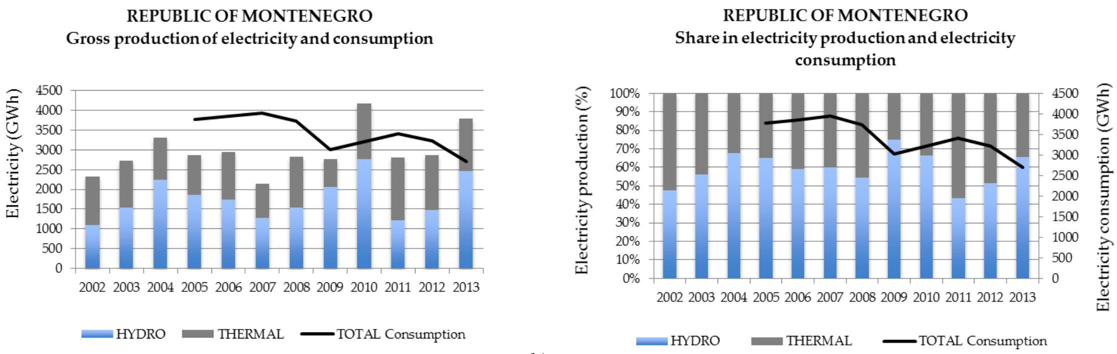
b)

Figure A-1. 3. Gross electricity production and total electricity consumption in Bosnia and Herzegovina for the period 2002-2013: a) Gross electricity production by technology; b) Share of gross electricity production by technology and total consumption of electricity (Statistical Yearbooks 2003 – 2014, Statistics Office of Bosnia and Herzegovina).



a) *b)*

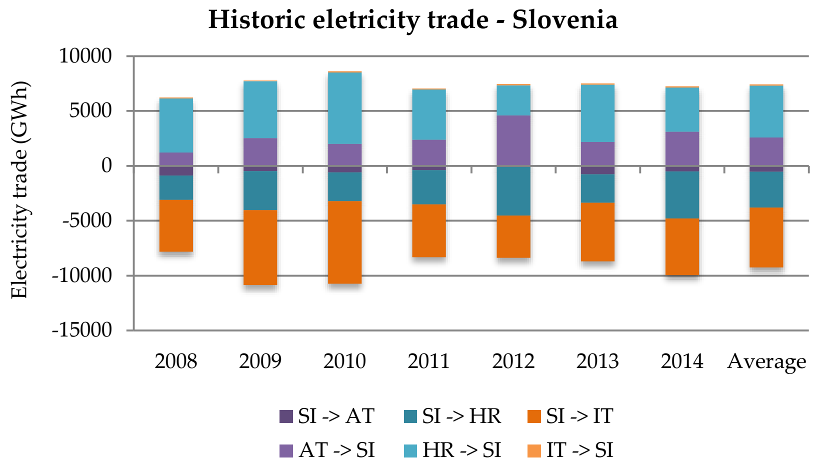
Figure A-1. 4. Gross electricity production and total electricity consumption in Serbia for the period 2002-2013: a) Gross electricity production by technology; b) Share of gross electricity production by technology and total consumption of electricity (Statistical Yearbooks 2003 – 2014, Statistics Office of the Republic of Serbia).

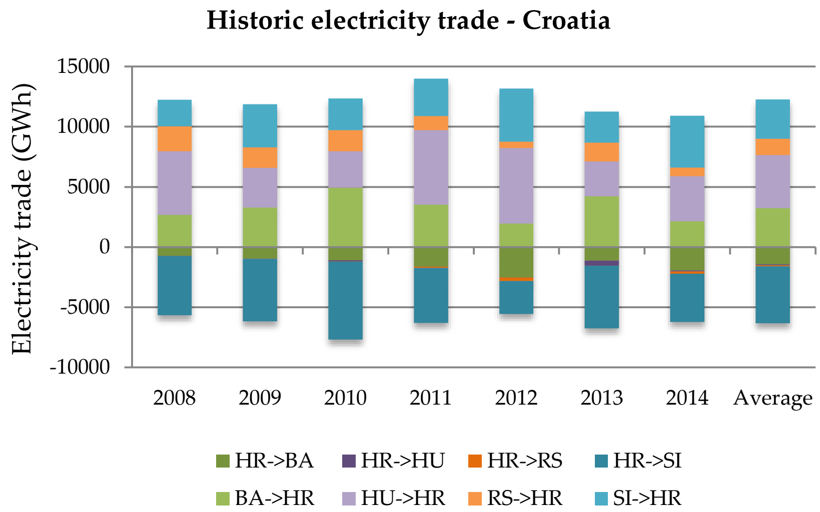


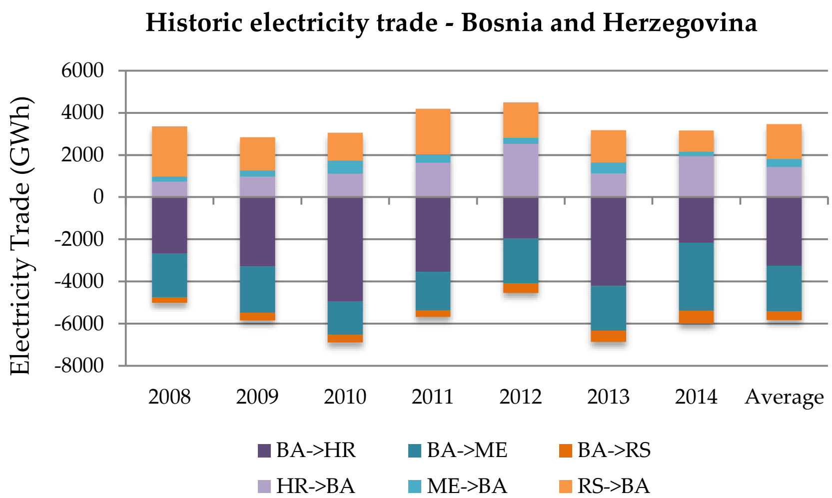
a) *b)*

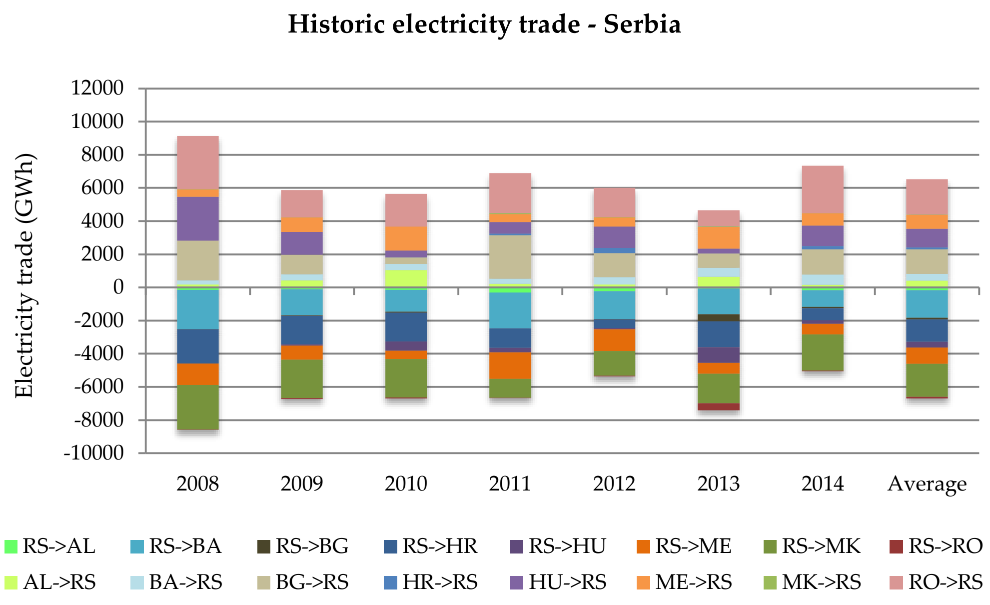
Figure A-1. 5. Gross electricity production and total electricity consumption in Croatia for the period 2002-2013: a) Gross electricity production by technology; b) Share of gross electricity production by technology and total consumption of electricity (Statistical Yearbooks 2003 – 2014, MONSTAT).

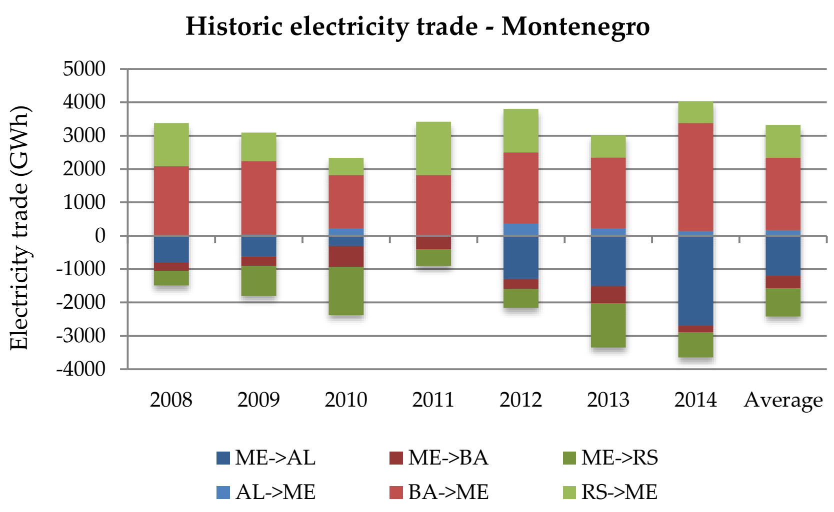
A-2. Historic electricity trade








Historic electricity trade - Serbia
12000
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
Electricity trade (GWh)
2008
2009
2010
2011
2012
2013
2014
Average
RS->AL
RS->BA
RS->BG
RS->HR
RS->HU
RS->ME
RS->MK
RS->RO
AL->RS
BA->RS
BG->RS
HR->RS
HU->RS
ME->RS
MK->RS
RO->RS


Historic electricity trade - Montenegro
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
Electricity trade (GWh)
2008
2009
2010
2011
2012
2013
2014
Average
ME->AL
ME->BA
ME->RS
AL->ME
BA->ME
RS->ME

A-3. POWER PLANTS LIST BY COUNTRY

Table A-3. 1. Existing and planned power generation technologies in Slovenia.

HYDROPOWER PLANTS						
Name of plant	**River**	**Flowing into Sava?**	**Type**	**Capacity (MW)**	**Installation Date**	**Status**
POTOK	in the SRB	YES	HYDRO	0.01	2008	OPR
ZAGA KOFLER	Soča	NO	HYDRO	0.012	1946	OPR
MLIN SUM	Not in SRB	NO	HYDRO	0.012	1956	OPR
CERENSCICA	Not in SRB	NO	HYDRO	0.012	2008	OPR
LADRA	Soča	NO	HYDRO	0.018	1940	OPR
DEMSAR	Poljanska Sora (Sava)	YES	HYDRO	0.02	2009	OPR
ZAGA JESENICE	Sava	YES	HYDRO	0.03	1946	OPR
LOZEKAR	Nd	NO	HYDRO	0.029	1986	OPR
SKERJANEC	Kamnik Bistrica	YES	HYDRO	0.05	1940	OPR
POKRZNIK	Not in SRB	NO	HYDRO	0.051	1988	OPR
ILIRSKA BISTRICA	Reka (Sava)	YES	HYDRO	0.06	1967	OPR
PALENK	Palenk (Savinja)	YES	HYDRO	0.06	1986	OPR
KOSTANJE	Not in SRB	NO	HYDRO	0.058	1975	OPR
VIDEM	Not in SRB	NO	HYDRO	0.062	1986	OPR
JELENK	Jelenk	NO	HYDRO	0.070	1987	OPR
IDRIJA	Not in SRB	NO	HYDRO	0.074	1950	OPR
PECNIK	Peklenska grapa	NO	HYDRO	0.095	1984	OPR
KNEZKE RAVNE	Prošček	NO	HYDRO	0.100	1979	OPR
RUSE DRAVA	Drava	NO	HYDRO	0.106	1940	OPR
CERKLJE	Not in SRB	NO	HYDRO	0.117	1969	OPR
TOLMIN	Tolminka	NO	HYDRO	0.120	1995	OPR
PLANINA HYDRO	Unec	NO	HYDRO	0.136	1989	OPR
KLONTE	Idrijca (Soča)	NO	HYDRO	0.140	2007	OPR
GRADISCE	Vipava	NO	HYDRO	0.150	1989	OPR
MESTO	Idrijca	NO	HYDRO	0.200	1909	OPR
CERSAK	Mura	NO	HYDRO	0.216	1954	OPR
AJBA	Soča	NO	HYDRO	0.250	2008	OPR
SOTESKA	Not in SRB	NO	HYDRO	0.294	1975	OPR
KLAVLARICA	Klavžarica	NO	HYDRO	0.303	2006	OPR
HOBOVSCICA	Poljanska Sora (Sava)	YES	HYDRO	0.38	2008	OPR
PODMELEC	Mohorčev potok	NO	HYDRO	0.420	1930	OPR
CERKNICA-II NO 1	Cerknica (Soča)	NO	HYDRO	0.420	2007	OPR
CERKNO	Zapoška	NO	HYDRO	0.436	1984	OPR
MAROF	Idrijca	NO	HYDRO	0.440	1932	OPR
MOZNICA REBUILD 1	Koritnica	NO	HYDRO	0.448	1961	OPR
SAVA KRANJ 1		YES	HYDRO	0.45	1967	OPR
BACA 1	Mohorčev potok	NO	HYDRO	0.500	1991	OPR
CAS	Drava	NO	HYDRO	0.510	1940	OPR
PAPIRNICA VEVCE	-	NO	HYDRO	0.640	1983	OPR
MRZLA RUPA 1	Idrijca	NO	HYDRO	0.648	1989	OPR
KRAJCARICA	Krajcarica (Soca)	NO	HYDRO	0.780	1996	OPR
KNEZKE RAVNE 2	Prošček	NO	HYDRO	0.810	1993	OPR
TREBUZA	Trebušica	NO	HYDRO	0.950	1985	OPR
MELJE 1	Drava	NO	HYDRO	1.000	2009	OPR
JAVORNIK 1	Idrijca (Soča)	NO	HYDRO	1.260	1984	OPR
LOG 1	Mangrtski potok	NO	HYDRO	1.700	1993	OPR
PLUZNA REBUILD 1	(Gljun) Soča	NO	HYDRO	1.858	1994	OPR
MARIBOR-1	Drava	NO	HYDRO	1.960	1988	OPR
LOMSCICA 1	Lomščica (Tržič Bistrica)	YES	HYDRO	2.00	1991	OPR
HUBELJ 1R	Hubelj	NO	HYDRO	2.100	1992	OPR
BISTRICA ZIROVNCA	Sava	YES	HYDRO	2.67	1998	OPR
SAVICA	Sava Bohinjka	YES	HYDRO	3.08	1949	OPR
RUDNIK S.MEZICA	Meza (Drava)	NO	HYDRO	4.650	1943	OPR
TRZIC 1	Tržič Bistrica	YES	HYDRO	6.64	1988	OPR
GORICANE 1	Soča	NO	HYDRO	8.000	1975	OPR
ZADLASCICA	Zadlascica (Soca)	NO	HYDRO	8.000	1989	OPR
MOSTE	Sava	YES	HYDRO	21.10	1952	OPR
MEDVODE	Sora and Sava	YES	HYDRO	25.00	1953	OPR
DRAVOGRAD	Drava	NO	HYDRO	26.200	1944	OPR
SOLKAN 1	Soča	NO	HYDRO	31.200	1984	OPR
BOSTANJ	Paka (Savinja, Sava)	YES	HYDRO	32.40	2011	OPR
VRHOVO	Sava	YES	HYDRO	34.50	1993	OPR
MAVCICE	Sava	YES	HYDRO	38.20	1986	OPR

BLANCA	Sava	YES	HYDRO	42.50	2011	OPR
VUZENICA	Drava	NO	HYDRO	56.000	1954	OPR
FALA	Drava	NO	HYDRO	57.000	1977	OPR
PLAVE	Soča	NO	HYDRO	57.100	1939	OPR
MARIBORSKI OTOK	Drava	NO	HYDRO	60.000	1948	OPR
VUHRED	Drava	NO	HYDRO	61.200	1958	OPR
OZBALT	Drava	NO	HYDRO	61.200	1962	OPR
DOBLAR	Soča	NO	HYDRO	70.000	1939	OPR
Zlatolicje	Drava	NO	HYDRO	126.000	2012	OPR
FORMIN	Drava	NO	HYDRO	127.000	1978	OPR
AVCE 1	Soča	NO	PS	185.000	2010	OPR
MOSTE II	Sava	YES	HYDRO	5.00	0	CON
RUDNIK S. MEZICA NEW	Meza (Drava)	NO	HYDRO	6.05	0	CON
ZALOG	Goricica	YES	HYDRO	15.70	0	CON
SENTJAKOB	Krka	YES	HYDRO	15.90	0	CON
HRASTJE MOTA	Mura	NO	HYDRO	20.00	2019	
JEVNICA	Sava	YES	HYDRO	22.90	0	PLN
GAMELJNE	Sava	YES	HYDRO	26.50	0	CON
KRESNICE	Sava	YES	HYDRO	27.70	0	PLN
TRBOVLJE SAVA	Sava	YES	HYDRO	27.80	2018	PLN
MOKRICE	Ljubljanica	YES	HYDRO	28.35	2018	PLN
RENKE	Sava	YES	HYDRO	28.60	2022	PLN
TACEN	Sava	YES	HYDRO	32.60	0	PLN
KRSKO HSE 1	Sava	YES	HYDRO	37.56	2014	CON
SUHADOL	Sava	YES	HYDRO	39.30	2018	PLN
BREZICE	Sava	YES	HYDRO	45.30	2018	PLN
PONOVICE	Sava	YES	HYDRO	63.00	0	PLN
KOZJAK PSP 1	Paka	NO	PS	400.00	2018	PLN
THERMAL POWER PLANTS (including nuclear)						
Name of plant	**Type**	**Close to river?**	**Fuel Type**	**Capacity (MW)**	**Installation Year**	**Status**
DOMZALE SEWAGE	IC/H	Kamnisca (Sava)	DGAS	0.22	1990	OPR
MEDVODE IC 1	IC/H	Sora (Sava)	GAS	0.29	1990	OPR
SMARTNO OB SAVI 1	ST	Sava	HFO	0.80	1974	OPR
TUS CELJE IC 1	IC/H	Savinja (Sava)	GAS	1.05	2003	OPR
LJUBLIJANA-BARJE LANDFILL	IC/H	Sava	LGAS	1.20	1995	OPR
SAVINJA-CELJE 1	ST/S	Savinja (Sava)	HFO	1.55	1976	OPR
VRHNIKA IUV 1	ST	Sava	HFO	1.60	0	OPR
KAMNIK 1	ST	Kamnisca (Sava)	HFO	1.60	1970	OPR
NOVO MESTO NOVOLES	ST	Krka (Sava)	HFO	1.90	0	OPR
SPLOSNA BOLN.HOSP IC 1	IC/H	Drava	GAS	2.02	2003	OPR
CELJE WTE 1	ST	Savinja (Sava)	REF	2.10	2010	OPR
SVILA TT MARIBOR	ST	Drava	HFO	2.35	1991	OPR
SKOFA LOKA WWTP IC	IC/H	Sora (Sava)	GAS	3.03	2002	OPR
KRANJ CHP IC 1	IC/H	Sava	GAS	3.03	2004	OPR
POLAJ TRIBOVLJE IC	IC/H	Sava	GAS	3.03	2005	OPR
JESENICE WORKS 3	ST	Sava	-	3.60	1968	OPR
NOVO MESTO KRKA	ST	Krka (Sava)	HFO	4.25	1973	OPR
TEKSTILNA TOVARNA	ST/S	Savinja (Sava)	HFO	5.00	1978	OPR
NAFTA LENDAVA 1	ST	Ledava (Mura	HFO / GAS	7.00	1976	OPR
LJUBLJANA HEATING GT 1	GT/S	Ljubljianica (Sava)	GAS	7.10	1997	OPR
RAVNE KOROSKEM IC	IC/H	Meza	GAS	8.17	1999	OPR
TOVARNA SLA. ORMOZ	ST	Drava	HFO	8.50	1980	OPR
PAPIRNICA RADECE	ST	Sava	HFO	11.20	0	OPR
KRSKO MILL	ST/S	Sava	HFO	38.00	1954	OPR
TRBOVLJE GT 1	GT	Sava	OIL	63.00	1974	OPR
SOSTANJ 5 GT 1	GT/T	Paka (Sava)	GAS	84.00	2007	OPR
TE-TOL CHP 1	ST/S	Sava	COAL	124.00	1966	OPR
TRBOVLJE 4	ST	Sava	COAL	125.00	1968	OPR
BRESTANICA PB4-5	GT	Sava	GAS	228.00	2000	OPR
SOSTANJ 3,4,5	ST	Paka (Sava)	COAL	695.00	1977	OPR
KRSKO		Sava	URANIUM	696.00	1981	OPR
NOVO MESTO IMV GT 1	GT	Krka (Sava)	DIESEL	1.25	0	CON
PLANINA HEATING IC	IC/H	Sava	GAS	4.30	2012	PLN
TE-TOL CHP CC	CC	Sava	GAS	90.00	0	PLN
BRESTANICA VI - IX		Sava	GAS	100.00	2018-2018	PLN
TRBOVLJE 4	ST	Sava	COAL / BIOMASS	125.00	2014	PLN
TRBOVLJE-2 CC 1	CC	Sava	GAS	290.20	2015	PLN
SOSTANJ 6		Sava	COAL	545.00	2015	CON
KRSKO 2		Sava	URANIUM	1,600.00	2025-2030	PLN

OTHER POWER PLANTS						
Name	**Fuel Type**			**Capacity (MW)**	**Installation Year**	**Status**
NEMSCAK IC	BIOGAS			0.16	2002	OPR
MOTVARJEVCI IC	BIOGAS			0.50	2008	OPR
CELJE FAIR PV	PV			0.95	0	OPR
KOLAR POMURJE IC	BIOGAS			1.00	2006	OPR
GORNJI PETROVCI PV	PV			1.00	2010	OPR
LENDAVA IC 1	BIOGAS			1.42	2008	OPR
LENDAVA IC 2	BIOGAS			1.42	2008	OPR
LENDAVA IC 3	BIOGAS			1.42	2008	OPR
NEMSCAK IC 2	BIOGAS			1.70	2006	OPR
MAVCICE PV	PV			6.00	2006	OPR
MERKSCHA CELJE 1	BIOMASS			6.75	2006	OPR
BENEDIKT IC	BIOFUEL			6.75	2010	OPR
BRDO CONGRESS C. PV	PV			20.00	2008	OPR
PTUJ IC	BIOGAS			1.00	0	PLN
VRTOJBA PV	PV			20.00	0	PLN
VOLOVJA REBER	WIND			39.95	0	PLN

Table A-3. 2. Existing and planned power generation technologies in Croatia.

HYDROPOWER PLANTS						
Name of plant	**Type**	**River**	**Flowing into Sava?**	**Capacity (MW)**	**Installation Date**	**Status**
GORSKI KOTAR 1	HYDRO	not in SRB	NO	0.04	1957	OPR
DELNICE 1	HYDRO	not in SRB	NO	0.20	1959	OPR
MZ PLANT	HYDRO	not in SRB	NO	0.30	1982	OPR
KRCIC 1	HYDRO	Krka, south HR	NO	0.35	1988	OPR
SIBENIK VODOVOD 1	HYDRO	not in SRB	NO	0.47	1975	OPR
BRANA	HYDRO	not in SRB	NO	0.63	1973	OPR
RC PLANT	HYDRO	not in SRB	NO	0.68	1978	OPR
LEPENICA 1	PS	not in SRB	NO	0.80	1985	OPR
ZELENI VIR 1	HYDRO	not in SRB	NO	1.70	1921	OPR
ROSKI SLAP	HYDRO	Krka	NO	1.77	1907	OPR
ZAVRELJE	HYDRO	not in SRB	NO	2.00	1953	OPR
OZALJ 1	HYDRO	Kupa	YES	5.50	1908	OPR
GOLUBIC 1	HYDRO	Butišnica	NO	7.50	1981	OPR
FUZINE	PS	Lokvarka and Ličanka	NO	4.60	1957	OPR
JARUGA-I and II	HYDRO	not in SRB	NO	7.78	1903	OPR
SKLOPE	HYDRO	Gacka and Lika	NO	22.50	1970	OPR
MILJACKA	HYDRO	Krka, south HR	NO	24.00	1956	OPR
RIJEKA	HYDRO	Rječina	NO	36.00	1968	OPR
DJALE 1	HYDRO	Cetina	NO	40.80	1989	OPR
PERUCA REBUILD	HYDRO	Celtina (Peruća lake)	NO	60.00	2012	OPR
LESCE	HYDRO	Gojačka Dobra	YES	42.29	2010	OPR
KRALJEVAC	HYDRO	Cetina	NO	46.40	1990	OPR
GOJAK	HYDRO	Dobra and Mrežnica	YES	55.5	2006	OPR
CAKOVEC	HYDRO	Drava basin	NO	77.44	1982	OPR
DUBRAVA	HYDRO	Drava basin	NO	77.78	1989	OPR
VINODOL	HYDRO	Lokvarka and Ličanka	NO	84.00	1952	OPR
VARAZDIN	HYDRO	Drava basin	NO	86.50	1975	OPR
DUBROVNIK-I	HYDRO	Trebisnjica	NO	108.00	1965	CON
SENJ	HYDRO	Gusic jezero, Gacka and Lika	NO	216.00	1965	OPR
ORLOVAC	HYDRO	Ruda	NO	237.00	1974	OPR
VELEBIT	PS	Zrmanja	NO	276.00	1984	OPR
ZAKUCAC	HYDRO	Blato	NO	522.00	1979	OPR
JARUN	HYDRO	Sava	YES	9.31	0	PLN
SANCI	HYDRO	Sava	YES	9.31	0	PLN
PETRUSEVEC	HYDRO	Sava	YES	9.31	0	PLN
IVANJA REKA	HYDRO	Sava	YES	9.31	0	PLN
SISAK	HYDRO	Sava	YES	26.90	0	PLN
PRECKO	HYDRO	Sava	YES	42.00	0	PLN
PODSUSED - ZAPRESIC	HYDRO	Sava	YES	46.00	0	PLN
MOLVE 1&2	HYDRO	Drava (Danube)	NO	108.00	0	PLN

MEDVEDNICA	PS	Brodavec reservoir/Sava	YES	500.00	0	PLN
PERUCA REBUILD	HYDRO	Celtina (Peruća lake)	NO	90.00	2013	PLN
DUBROVNIK-II	HYDRO	Trebisnjica	NO	304.00	2019	PLN
KOSINJ	HYDRO	Lika	NO	52.00	2020	PLN
SENJ-II	HYDRO	Lika	NO	360.00	2020	PLN
OMBLA	HYDRO	Ombla	NO	68.00	2025	PLN
THERMAL POWER PLANTS						
Name of plant	**Type**	**Close to river?**	**Fuel Type**	**Capacity (MW)**	**Installation Year**	**Status**
PLOMIN-A,B	ST	Not in SRB	Coal	335.00	1969	OPR
SISAK REFINERY	ST/S	Kupa / Sava	DIESEL	34.60	1966	OPR
BELISCE BELISCE MILL	ST/S	Karasica or Drava	DIESEL	3.50	1971	OPR
VIKTOR LENAC SHIPYARD IC	IC	Not in SRB	DIESEL	0.74	1975	OPR
P PLANT IC	IC	Not in SRB	DIESEL	6.75	1976	OPR
SISAK REFINERY IC	IC	Kupa / Sava	DIESEL	0.40	1978	OPR
RIJEKA IC	IC	Not in SRB	DIESEL	1.40	1979	OPR
KUTINA PETROCHEMICAL 18	ST	SRB	DIESEL	35.00	1981	OPR
SIBENIK IC 1-9	IC	Not in SRB	DIESEL	7.90	1993	OPR
VINKOVCI IC 1-18	IC	Not in SRB	DIESEL	13.80	1993	OPR
SPLIT IC 1-20	IC	Not in SRB	DIESEL	14.20	1993	OPR
ZADAR IC 1-27	IC	Not in SRB	DIESEL	15.50	1993	OPR
BELISCE BELISCE MILL	ST/S	Karasica or Drava	DIESEL / GAS	16.00	1983	OPR
SLAVONSKI BROD GT	GT	Not in SRB	GAS	13.50	1994	OPR
ZAGREB EL-TO	GT/S	SRB	GAS/OIL	47.80	1998	OPR
ZAGREB TE-TO-K	GT/CP	Sava	GAS/OIL	208.00	2003	OPR
JERTOVEC REPOWER	GT/C	SRB	GAS/OIL	76.00	2012	OPR
RIJEKA TPP	ST	Not in SRB	HFO	320.00	1978	OPR
ZAGREB EL-TO 3,4	ST/S	SRB	HFO / GAS	41.00	1970	OPR
SISAK (A,B)	ST	SRB	HFO / GAS	396.00	1970	OPR
ZAGREB TE-TO-C	ST/S	Sava	HFO / GAS	120.00	1979	OPR
OSIJEK 3	ST/S	Not in SRB	HFO / GAS	45.00	1985	OPR
OSIJEK GT	GT/S	Not in SRB	LFO / GAS	50.00	1976	OPR
PRUDINEK LANDFILL	IC	Neretva	LGAS	3.05	2004	OPR
JASENOVAC	ST/S	Sava	BIOMASS	7.20	2012	CON
SISAK-C GT1	GT/CP	Sava	GAS	160.00	2012	CON
VELIKA GORICA BIOMASS	ST/S	Sava	BIOMASS	22.50	0	DEF
LUKOVO SUGARJE 1	ST	Not in SRB	COAL	700.00	0	DEF
LIKA BIOMASS	ST/S	Not in Sava	BIOMASS	1.00	0	PLN
DONJI MIHOLJAC IC	IC/H	Drava	BGAS	2.00	0	PLN
OVCARA BIOGAS	IC/H	Drava	BGAS	10.00	0	PLN
LEGRAD	ST	Drava	GEO	10.00	0	PLN
SLATINA ENEX	ST	Drava	GEO	10.00	0	PLN
ZAGREB DIOKI IC	IC/H	Sava	GAS	35.00	0	PLN
ZAGREB EL-TO CC (Unit L)	CC	Sava	GAS	120.00	2009	PLN
GRADEC AGROKOR IC	IC/H	in the SRB	BGAS	1.00	2012	PLN
MALA BRANJEVINA DAIRY IC	IC/H	Not in SRB	BGAS	2.00	2012	PLN
DALMACIJA CC	CC	Not in SRB	GAS	400.00	2015	PLN
PLOMIN-C	ST	Not in SRB	COAL	500.00	2016	PLN
OSIJEK 500 CC	CC	Not in SRB	GAS	250.00	2019	PLN
OTHER POWER PLANTS						
Name	**Fuel Type**			**Capacity (MW)**	**Installation Year**	**Status**
STRIZIVOJNA BIOMASS	BIOMASS			3.30	2011	OPR
KRIZOPOTJE PV	PV			0.03	2011	OPR
RAVNE ADRIA-1 WTG 1-7	WIND			5.95	2004	OPR
TRTAR-KRTOLIN WTG 1-14	WIND			11.90	2006	OPR
ORLICE WTG 1-11	WIND			9.60	2010	OPR
VRATARUSA WTG 1-14	WIND			42.00	2010	OPR
VELIKA POPINA ZD6	WIND			9.20	2011	OPR
CRNO BRDO WTG 1-7	WIND			10.50	2011	OPR
POMETENO BRDO WTG 1-16	WIND			17.50	2012	OPR
PONIKVE WTG 1-16	WIND			34.00	2012	OPR
BRUSKA ZD2	WIND			36.00	2012	OPR
BENKOVAC SOLAR	PV			0.95	0	PLN
PROMINA SOLAR 1	PV			60.00	0	PLN
OSIJEK MILL	PV			30.00	0	PLN
BARBAN PV	PV			1.00	2012	PLN
STANKOVCI PV	PV			6.00	2014	PLN
KOMOROVAC WTG	WIND			5.60	0	PLN
PRUTNA WTG	WIND			10.00	0	PLN
DOVANJ WTG	WIND			10.80	0	PLN

SESTANOVAC WTG 1-8	WIND			12.00	0	PLN
OBROVAC ZD2 WTG	WIND			18.00	0	PLN
KRS PADJENE-2 WTG	WIND			30.00	0	PLN
JASENICE WTG 1-24	WIND			31.20	0	PLN
BENKOVAC	WIND			39.00	0	PLN
RUDINE WTG	WIND			45.00	0	PLN
SVILAJA WTG 1-17	WIND			51.00	0	PLN
DUBROVNIK WIND WTG	WIND			52.00	0	PLN
KRS PADJENE-1 WTG	WIND			80.00	0	PLN
KOSTANJE WIND WTG	WIND			12.00	2012	PLN
ZADAR	WIND			36.00	2012	PLN
CRNI VAH WTG 1&2	WIND			4.60	2013	PLN
BUBRIG WTG 1-8	WIND			18.40	2013	PLN
VELIKA GLAVA WTG 1-9	WIND			20.70	2013	PLN
VE ZD4	WIND			9.00	2014	PLN
VE ST1 - 2	WIND			20.00	2014	PLN
JELINAK WTG 1-20	WIND			30.00	2014	PLN
VE ZD2 / ZD3	WIND			36.00	2014	PLN

Table A-3. 3. Existing and planner power generation technologies in Bosnia and Herzegovina.

HYDROPOWER PLANTS						
Name of plant	**River**	**Flowing into Sava?**	**Type**	**Capacity (MW)**	**Installation Date**	**Status**
ZENICA HYDRO 1		NO	HYDRO	0.03	1988	OPR
BOSANSKA KRUPA		NO	HYDRO	0.10	1954	OPR
GLASINAC	Vrbas	YES	HYDRO	0.10	2010	OPR
BUGOJNO		NO	HYDRO	0.11	1950	OPR
BASTASICA		NO	HYDRO	0.12	1985	OPR
BUK 1		NO	HYDRO	0.14	1991	OPR
BIHAC (SLAPOVI)	Una/Sana	YES	HYDRO	0.16	2001	OPR
PRSLJANICA		NO	HYDRO	0.20	2009	OPR
PAKLENIKA 1	Paklenici (Bosna)	YES	HYDRO	0.23	2012	OPR
DERALA	Vrbas	YES	HYDRO	0.30	2009	OPR
PODSTINJE		NO	HYDRO	0.36	2010	OPR
HRID 1	Sarajevo water supply	NO	HYDRO	0.40	1917	OPR
TORLAKOVAC 1		NO	HYDRO	0.43	2008	OPR
SNJEZNICA	Snjeznica	YES	HYDRO	0.50	2002	OPR
GRABLJE 1		NO	HYDRO	0.50	2010	OPR
POGLEDALA		NO	HYDRO	0.52	2006	OPR
CEMERNICA 1		NO	HYDRO	0.54	2009	OPR
RAMA A1	Rama	NO	HYDRO	0.55	1968	OPR
OSANICA-4	Osanica	YES	HYDRO	0.65	2007	OPR
MOSCANI 1		NO	HYDRO	0.70	2006	OPR
PRUSAC 1		NO	HYDRO	0.70	2006	OPR
POTKOZICA		NO	HYDRO	0.70	2009	OPR
RUZNOVAC	Vrbas	YES	HYDRO	0.70	2009	OPR
ZAGRADACKA 1		NO	HYDRO	0.72	2010	OPR
TRESANICA		NO	HYDRO	0.74	2009	OPR
SASTAVCI	Vrbas	YES	HYDRO	0.79	2005	OPR
DUBOKI POTOK	Vrbas	YES	HYDRO	0.90	2005	OPR
VLASENICA 1	Tisca	YES	HYDRO	0.90	1949	OPR
DUSCICA RIVER 1		NO	HYDRO	1.00	2010	OPR
DELIBASINO SELO		NO	HYDRO	1.02	1910	OPR
OSANICA-1	Osanica	YES	HYDRO	1.08	1998	OPR
BOTUN 1	Kozica	YES	HYDRO	1.24	2004	OPR
MUJADA 1		NO	HYDRO	1.28	2009	OPR
CRIMA 1		NO	HYDRO	1.30	2011	OPR
CARDAK		NO	HYDRO	1.31	2011	OPR
JEZERNICA 1	Jezernica	YES	HYDRO	1.38	2004	OPR
JELICI	Vrbas	YES	HYDRO	1.41	2005	OPR
MUJAKOVICI 1	Jezernica	YES	HYDRO	1.63	2005	OPR
DUBRAVA NERETVA	Kozicka Rijeka	YES	HYDRO	1.86	2008	OPR
LUKE SRPSKA	Cehotina	YES	HYDRO	2.00	2010	OPR
TISCA	Drinjaca	YES	HYDRO	2.12	1989	OPR
MODRAC DAM 1	Spreca	YES	HYDRO	2.20	1998	OPR
TRESANICA-4		NO	HYDRO	2.62	2009	OPR
MAJDAN 1	Kozica	YES	HYDRO	2.80	2005	OPR
SUCESKA-1 NO	Lim	YES	HYDRO	2.90	2009	OPR
MESICI	Praca	YES	HYDRO	3.00	1950	OPR
STUBICA 1	Trebizat	NO	HYDRO	3.00	2012	OPR

MODO OKO 1		NO	HYDRO	3.75	2012	OPR
POLJANICE		NO	HYDRO	3.80	2009	OPR
GOROVNIK USCE		NO	HYDRO	3.93	2012	OPR
BISTRICA-B5A NO 1	Bistrica	YES	HYDRO	3.93	2010	OPR
KOCUSA 1		NO	HYDRO	4.78	2010	OPR
KRAVICA 1	Kravica (Jadar, Drina)	YES	HYDRO	5.00	2011	OPR
NOVAKOVICI	Ugar	YES	HYDRO	5.43	2011	OPR
BOGATICI	Zeljeznica	YES	HYDRO	7.00	1947	OPR
STRZANJ 1		NO	HYDRO	7.30	2012	OPR
BUSKO BLATO		NO	HYDRO	7.60	1974	OPR
TREBINJE-II	Trebisnjica	NO	HYDRO	8.00	1981	OPR
PEC MLINI	Tihaljina	NO	HYDRO	30.00	2004	OPR
JAJCE-II	Vrbas	YES	HYDRO	30.15	1954	OPR
JAJCE	Vrbas (Pliva)	YES	HYDRO	48.27	1957	OPR
MOSTARSKO BLATO	Neretva	NO	HYDRO	60.00	2010	PLN
MOSTAR	Neretva	NO	HYDRO	75.00	1987	OPR
DUBROVNIK II - G2	Trebisnjica	NO	HYDRO	108.00	1965	OPR
BOCAC	Vrbas	YES	HYDRO	110.00	1981	OPR
GRABOVICA	Neretva	NO	HYDRO	114.00	1982	OPR
RAMA	Rama	NO	HYDRO	160.00	1968	OPR
TREBINJE	Trebisnjica	NO	HYDRO	180.00	1968	OPR
JABLANICA	Neretva	NO	HYDRO	181.10	1955	OPR
SALAKOVAC	Neretva	NO	HYDRO	210.00	1982	OPR
VISEGRAD	Drina	YES	HYDRO	315.00	1989	OPR
CAPLJINA	Neretva	NO	PS	440.00	1979	OPR
POLJANSKI POTOK	Poliansk Potok	NO	HYDRO	0.04	0	PLN
KASUMI	Vrbas	YES	HYDRO	0.04	0	PLN
BILA VODA 1	Vrbas (Bila Voda)	YES	HYDRO	0.06	0	PLN
IPOTA	Vrbas	YES	HYDRO	0.08	0	PLN
TRESANICA-1	Tresanica	NO	HYDRO	0.29	0	PLN
PROLAZ	Drina (Janjina)	YES	HYDRO	0.35	0	PLN
POZELEVKA		NO	HYDRO	0.37	0	PLN
RUSTE		NO	HYDRO	0.37	0	PLN
PLAVUZI	Crni Potok	NO	HYDRO	0.40	0	PLN
PAVLOVAC	Vrbas (Crkvena)	YES	HYDRO	0.44	0	PLN
BROVA	Brova	NO	HYDRO	0.50	0	PLN
MILINOVAC		NO	HYDRO	0.50	0	PLN
PECINA		NO	HYDRO	0.60	0	PLN
MOSCANICA-4 NO 1	Una (Mostanica)	YES	HYDRO	0.63	0	PLN
DABAR MINI		NO	HYDRO	0.65	0	PLN
POZARNA	Pozarna	NO	HYDRO	0.70	0	PLN
KOLINA-4	Drina (Kolina)	YES	HYDRO	0.72	0	PLN
VELIKI DUBOKI POTOC	Neretva	NO	HYDRO	0.74	0	PLN
BOSTANICA-USCE	Bosna	YES	HYDRO	0.82	0	PLN
KONJIC MINI 1		NO	HYDRO	0.99	0	PLN
CUDE	Stupcanica	NO	HYDRO	1.00	0	PLN
RUJEVICA-USCE		NO	HYDRO	1.00	0	PLN
GOSTOVIC-1	Bosna (Gostovic)	YES	HYDRO	1.07	0	PLN
MALA NERETVICA-USCE	Neretvika	NO	HYDRO	1.11	0	PLN
GOROVNIK		NO	HYDRO	1.24	0	PLN
HATIRAJ	Una (Bliha/Sana)	YES	HYDRO	1.44	0	PLN
MOSCANICA-2	Drina	YES	HYDRO	1.47	0	PLN
DVANAESTI KILOMETAR		NO	HYDRO	1.50	0	PLN
DIVIC	Drina	YES	HYDRO	1.50	0	PLN
OBASCOCA		NO	HYDRO	1.59	0	PLN
JABUSNICA	Jabunisca	NO	HYDRO	1.65	2017	PLN
PETROVICI	Trebisnijica	NO	HYDRO	1.70	0	PLN
DONJI OBALJI		NO	HYDRO	1.87	0	PLN
LUKAC T3		NO	HYDRO	2.00	0	PLN
JABUSNICA-3	Jabusnica	NO	HYDRO	2.12	2016	CON
CRNA RIJEKA	Una (Crna Rijeka/Sana)	YES	HYDRO	2.30	0	PLN
VOLUJAK RIVER	Prozorcica	NO	HYDRO	3.00	0	PLN
MOKRONOGE MINI	Una (Unac)	YES	HYDRO	3.30	2013	PLN
SRIJANSKI MOST		NO	HYDRO	3.53	0	PLN
BRIONI	Cehotina	YES	HYDRO	3.60	0	PLN
GODIJENO	Cehotina (Drina)	YES	HYDRO	3.65	0	PLN
BISTRICA-JANJINI	Drina (Bistrica)	YES	HYDRO	4.10	2017	PLN
ZAPECE	Vrbas (Ugar)	YES	HYDRO	4.10	2017	PLN
PODHUM		NO	HYDRO	4.53	0	PLN
HRELJAVA	Cehotina (Drina)	YES	HYDRO	4.80	0	PLN
MEDNA SANA	Una (Sana)	YES	HYDRO	4.90	0	PLN
MESICI-NOVA	Drina (Praca)	YES	HYDRO	4.90	2017	PLN
KLOKUN	Adriatic Basin	NO	HYDRO	5.00	2015	PLN
KLJAJIEI		NO	HYDRO	5.90	0	PLN

PRVNICE	Cehotina	YES	HYDRO	6.10	0	PLN
UNA KOSTELA	Una	YES	HYDRO	6.46	0	PLN
USTRIPACA	Drina	YES	HYDRO	6.90	2015	PLN
BISTRICA-B2A	Drina (Bistrica)	YES	HYDRO	7.94	2017	PLN
FALOVICI	Cehotina	YES	HYDRO	9.26	0	PLN
DUB	Drina (Ratiknica)	YES	HYDRO	9.40	2016	PLN
VRLETINA KOSA	Vrbas (Ugar)	YES	HYDRO	11.20	2018	PLN
IVIK	Vrbas (Ugar)	YES	HYDRO	11.20	2018	PLN
BABINO SELO	Vrbas	YES	HYDRO	11.50	0	PLN
VINAC	Vrbas	YES	HYDRO	11.50	0	PLN
UGAR USCE	Vrbas (Ugar)	YES	HYDRO	11.60	2018	PLN
ČAPLJE	Una (Sana)	YES	HYDRO	11.63	0	PLN
HAN SKELA	Vrbas	YES	HYDRO	12.00	0	PLN
KOSJEREVO	Vrbas	YES	HYDRO	13.00	0	PLN
JANJICI	Bosna	YES	HYDRO	13.30	2017	PLN
KOVANICI	Bosna	YES	HYDRO	13.30	2019	PLN
KRUSEVO and ZELENI VIR	Bosna (Bioštica/Krivaja)	YES	HYDRO	13.33	0	PLN
CIJEVNA-3	Vrbas	YES	HYDRO	13.80	2015	PLN
LAKTASI	Vrbas	YES	HYDRO	16.00	0	PLN
NOVOSELIJA	Vrbas	YES	HYDRO	16.40	0	PLN
RAZBOJ	Vrbas	YES	HYDRO	17.00	0	PLN
VRANDUK	Bosna	YES	HYDRO	19.63	2018	PLN
VIKOC	Cehotina	YES	HYDRO	23.30	0	PLN
TRN	Vrbas	YES	HYDRO	24.00	0	PLN
MHE NEREVTICA (15 sHPPs)	Neretva	NO	HYDRO	26.00	0	PLN
NERETVICE	Neretvika	NO	HYDRO	26.20	2017	PLN
GLAVATICEVO	Neretva	NO	HYDRO	28.50	0	PLN
JANJSKE OTOKE	Drina (Pliva)	YES	HYDRO	29.60	0	PLN
KOZLUK	Drina	YES	HYDRO	33.60	0	PLN
ULOG	Neretvika	NO	HYDRO	35.00	2015	PLN
LJUBUCA	Neretva	NO	HYDRO	36.00	0	PLN
BILECA	Trebinsjica	NO	HYDRO	36.00	2020	PLN
MRSOVO	Drina (Lim)	YES	HYDRO	36.80	2017	PLN
PAUNCI	Drina	YES	HYDRO	37.00	2026	PLN
BANJA LUKA NISKA	Vrbas	YES	HYDRO	37.20	0	PLN
SUTJESKA	Drina RB	YES	HYDRO	42.00	2017	PLN
FOCA (SRBJINE)	Drina	YES	HYDRO	44.00	2018	PLN
KRUPA	Vrbas	YES	HYDRO	48.50	0	PLN
KABLIC	Bistrica (Adriatic Basin)	NO	PS	52.00	2019	PLN
NEVESINJE	Trebinsjica	NO	HYDRO	60.00	2020	PLN
USTIKOLINA	Drina	YES	HYDRO	60.48	2018	PLN
VRILO	Šuica	NO	HYDRO	64.00	2014	PLN
CIJEVNA 1,2,4,5,6	Vrbas	YES	HYDRO	68.00	0	PLN
RMANJ (UNAC)	Una	YES	HYDRO	74.00	0	PLN
VRHPOLJE	Una (Sana)	YES	HYDRO	80.00	0	PLN
DRINA I	Drina	YES	HYDRO	93.00	0	PLN
DRINA II	Drina	YES	HYDRO	93.00	0	PLN
DRINA III	Drina	YES	HYDRO	93.00	0	PLN
BUK BIJELA	Drina	YES	HYDRO	94.00	2018	PLN
BJELIMICI 1		NO	HYDRO	100.00	0	PLN
GORNJA DRINA	Drina	YES	HYDRO	114.60	2015	PLN
DUBRAVICA	Drina	YES	HYDRO	122.00	0	PLN
TEGARE	Drina	YES	HYDRO	124.00	0	PLN
ROGACICA	Drina	YES	HYDRO	140.00	0	PLN
DABAR	Trebinsjica	NO	HYDRO	159.00	2018	PLN
DRUBOVNIK 2 - 50% HR	Trebisnjica	NO	HYDRO	304	0	PLN
BJELIMICI PHP		NO	PS	600.00	0	PLN
			TOTAL PLANNED CAPACITY (MW)	**3,390.33**		

THERMAL POWER PLANTS						
Name of plant	**Type**	**Close to river? Name of the River**	**Fuel Type**	**Capacity (MW)**	**Installation Year**	**Status**
GACKO	ST	NO	Coal	300.00	1982	OPR
UGLJEVIK	ST	Drina	Coal	300.00	1985	OPR
KAKANJ	ST	Bosna	Coal	450.00	1956	OPR
TUZLA	ST/S	in SRB	Coal	715.00	1966	OPR
MOSTAR WORKS	ST/S	Neretva	Coal	4.00	0	OPR
LUKAVAC SODA FACTORY	ST	Vrbas	Coal	7.80	0	OPR
BIRAC WORKS 1&2	ST/S	Rijeka (Jadar, Drina)	Coal	25.30	0	OPR
MAGLAJ PULP MILL	ST	Bosna	Coal	49.00	0	OPR
BANJA LUKA PULP MILL	ST	Vrbas	Coal	89.30	1958	OPR
BJELJINA MILL	ST	Dasnica (Sava)	Coal	8.00	1979	OPR
DRVAR PAPER MILL	ST/S	Unac (Una)	Coal/BFG	8.50	0	OPR

ZENICA STEEL WORKS	ST	Bosna	Coal/Oil	39.54	1959	OPR
VRBAS MILL	ST	Vbras	Coal/Oil	8.80	1977	OPR
BOSANSKI BROD	ST	Sava	HFO	34.50	0	OPR
PRIJEDOR FACTORY	ST/S	Sana (Una)	HFO	17.00	1967	OPR
MODRICA REFINERY	ST	Bosna	HFO	3.00	1972	OPR
KAKANJ CCGT	CC	in SRB	Gas	100.00	2020	PLN
KONGORA	ST	Not in SRB	Coal	550.00	2017	PLN
GRACANICA - Bugojno and mine	ST	Not in SRB	Coal	300.00	2021	PLN
KAKANJ 8	ST	in SRB	Coal	300.00	2019	PLN
TUZLA 7 - CHP	ST	in SRB	Coal	450.00	2018	PLN
TUZLA-B2	ST	in SRB	Coal	450.00	2023	PLN
ZENICA CHP GT1	GT/CP	Bosna	Gas	384.00	2015	PLN
BANOVICI	ST	Litva (Bosna)	Coal	300.00	2017	PLN
STANARI	ST	Ostruznja (Radnja, Sava)	Coal	300.00	2016	PLN
KAMENGRAD	ST	Sana (Una)	Coal	215.00	2017	PLN
GLINICA	ST	Glina (Kupa)	Coal	500.00	after 2025	PLN
UGLJEVIK-3 NO 1	ST	Drina	Coal	600.00	2018	CON
MILJEVINA (FOCA)		Drina sub-basin	Coal	140.00	0	PLN
			TOTAL PLN CAPACITY (MW)	**4,589.00**		

OTHER POWER PLANTS

Name	Fuel Type			Capacity (MW)	Installation Year	Status
GREEN POWER PLANT	SOLAR			1.00	0	PLN
MESIHOVINA WTG 1-22	WIND			55.00	2014	CON
TRUSINA	WIND			51.00	2016	CON
BOROVA GLAVA-1 WTG	WIND			52.00	0	PLN
POKLECANI WIND WTH	WIND			72.00	0	PLN
WF Kamena	WIND			42.00	0	PLN
WF Merdžan Glava	WIND			72.00	0	PLN
WF Sveta Gora , Mali Grad Poljica	WIND			48.00	0	PLN
WF Mokronoge	WIND			70.00	0	PLN
WF Planinica	WIND			28.00	0	PLN
WF Velja Međa	WIND			18.00	0	PLN
WF Ivan Sedlo	WIND			20.00	0	PLN
WF Srdani 30 MW	WIND			30.00	0	PLN
WF Crkvine	WIND			24.00	0	PLN
GRADINA BIH WTG 1-35	WIND			70.00	2014	PLN
PAKLINE-LJUBUSA-KUPRES	WIND			408.00	2014	PLN
BALJCI	WIND			48.00	2015	PLN
JELOVACA	WIND			36.00	2015	PLN
PODVELEZJE-2 WTG 1-15	WIND			48.00	2016	PLN
WF Debelo Brdo	WIND			54.60	2016	PLN
ORLOVACA	WIND			42.00	2016	PLN
IVOVIK	WIND			84.00	2016	PLN
MUCEVACA	WIND			59.80	2016	PLN
VLASIC	WIND			50.00	2016	PLN
GALICA	WIND			50.00	2016	PLN
VELIKA VLAJNA WIND WTG	WIND			32.00	2017	PLN

Table A-3. 4. Existing and planned power generation technologies in Serbia.

HYDROPOWER PLANTS

Name of plant	River	Flowing into Sava?	Type	Capacity (MW)	Installation Date	Status
JAGNILO	Pek (Danube)	NO	CONV	0.05	1954	OPR
VUCJE	Veternica (Morava)	NO	CONV	0.28	1903	OPR
POD GRADOM	Detinja	NO	CONV	0.30	1904	OPR
MORAVICA	Moravica	NO	CONV	0.16	1911	OPR
TURICA	into Morava	NO	CONV	0.40	1927	OPR
JELASNICA	Vranjska Reka (Morava)	NO	CONV	0.50	1928	OPR
SVETA PETKA NISAVA	Nisava	NO	CONV	0.40	1931	OPR
SICEVO	Nisava	NO	CONV	0.44	1931	OPR
GAMZIGRAD	Timok (Danube)	NO	CONV	0.20	1909	OPR
TEMAC 1-3	Temska (Morava)	NO	CONV	0.78	1940	OPR
PEC MILL	Drin	NO	CONV	0.15	1950	OPR
VLASINSKE HPPs (Vrla I - IV)	Vrla (South Morava)	NO	CONV	129.00	1951	OPR

RASKA (SOPOCANI)	Raska (Ibar)	NO	CONV	6.32	1953	OPR
MEDJUVRSJE	Morava	NO	CONV	7.00	1953	OPR
OVCAR BANJA 1	Morava	NO	CONV	6.00	1954	OPR
KOSJERIC 1	Detinja (West Morava)	NO	CONV	0.16	1956	OPR
ARILJE 1	Veliki Rzav (Golijska Moravica)	NO	CONV	0.13	1962	OPR
ARANDJELOVAC 1	close to Lug	NO	CONV	0.15	1983	OPR
BOGUTOVAC	Ibar (West Morava)	NO	CONV	0.26	1983	OPR
RADALJSKA REKA 1	Zapadna Morava	NO	CONV	0.25	1986	OPR
VISOCICA 1	Visocica	NO	CONV	0.17	1987	OPR
PIROT	Nisava	NO	CONV	80.00	1990	OPR
SOKOLOVICA	Timok	NO	CONV	3.09	1948	OPR
LAKE BOVAN 1	South Morava	NO	CONV	0.25	2006	OPR
VRUTCI MINI 1	Detinja	NO	CONV	0.40	2009	OPR
POSTICA	Vlasina (South Morava)	NO	CONV	0.60	2010	OPR
STUDENICA MONASTERY	Studenica (Ibar)	NO	CONV	0.09	2011	OPR
PRVONEK	Vranjska Reka (Morava)	NO	CONV	1.02	2011	OPR
DJERDAP-II NO 1	Danube	NO	CONV	270.00	1985	OPR
DJERDAP-I	Danube	NO	CONV	1,058.00	1972	OPR
OZRENICA 1	into Drina	YES	CONV	0.01	1961	OPR
MLIN SELJASNICA 1	Lim	YES	CONV	0.03	1954	OPR
VRELO 1	Drina	YES	CONV	0.06	1927	OPR
SPAZOJEVICI 1	Rzav (Drina)	YES	CONV	0.14	1961	OPR
SELJASNICA 1	Lim	YES	CONV	0.93	1952	OPR
KRATOVSKA REKA	Lim (Uvac)	YES	CONV	1.16	1989	OPR
BISTRICA EPS A1	Lim	YES	CONV	1.32	1958	OPR
KOKIN BROD 1	Uvac	YES	CONV	22.54	1960	OPR
UVAC 1	Uvac	YES	CONV	36.00	1979	OPR
POTPEC	Lim (Uvac)	YES	CONV	51.00	1967	OPR
ZVORNIK 1	Drina	YES	CONV	92.80	1955	OPR
BISTRICA EPS 1	Lim	YES	CONV	102.60	1960	OPR
BAJINA BASTA REBUILD 1	Drina	YES	CONV	105.60	2011	OPR
BAJINA BASTA PSP	Drina	YES	PS	614.00	1982	OPR
GRUZA RESERVOIR	Lepenica (Great Morava)	NO	CONV	0.04	0	PLN
LAKE VUCKOVICA	Danube	NO	CONV	0.20	2012	PLN
ZAVOJ	Visocica or Temska	NO	CONV	0.35	0	PLN
MALA VRLA-1	Vrla (South Morava)	NO	CONV	0.46	0	PLN
JEZERO	South Morava	NO	CONV	1.00	0	PLN
BOVAN 1	South Morava	NO	CONV	1.50	0	PLN
BANJICA	Nisava	NO	CONV	2.50	0	PLN
CELIJE	West Morava	NO	CONV	4.00	0	PLN
ARILJE EXT	Moravica (West Morava)	NO	CONV	7.10	0	PLN
VRUTCI	Detinja	NO	CONV	31.80	0	PLN
RIBARICE	Gazidova lake (Ibar)	NO	CONV	46.70	0	PLN
DJERDAP-III NO 1	Danube	NO	PS	1,200.00	0	PLN
BRODAVERO-1,2	Lim	YES	CONV	58.41	2015	PLN
BAJINA BASTA REBUILD 2	Drina	YES	CONV	316.80	2012	CON
BISTRICA PSP	Lim	YES	PS	680.00	2020	PLN
THERMAL POWER PLANTS						
Name of plant	**Type**	**Close to river?**	**Fuel Type**	**Capacity (MW)**	**Installation Year**	**Status**
SVETOZAREVO CABLE FACTORY 1	ST	Great Morava	COAL	8.00	0	OPR
BAC MILL 1	ST	Tisa / Danube	HFO	7.50	0	OPR
KOVACICA MILL 1	ST	Tisa	HFO	7.50	0	OPR
ZABALJ MILL 1	ST	Jegricka (Tisa)	HFO	7.50	0	OPR
SENTA MILL 1	ST	Tisa	COAL	8.90	1961	OPR
KOVIN MILL 1	ST	Danube	HFO	9.40	1961	OPR
CRVENKA MILL	ST	Veliki (Moravica)	HFO	10.30	1965	OPR
KRAGUJEVAC AUTO FACTORY 2	ST	Lepenica (Morava)	COAL	30.00	1966	OPR
PANCEVO REFINERY 1	ST/S	Danube	HFO	12.00	1966	OPR
KOSTOLAC-A,B	ST/S	Danube	COAL	921.00	1967	OPR
MORAVA 1	ST	Morava	COAL	108.00	1969	OPR
ODZACI PLANT IC 1	IC	Danube	OIL	2.25	1980	OPR
NOVI SAD AGROVO IC 1	IC	Danube	DIESEL	7.14	1981	OPR
NOVI SAD	ST/S	Danube	HFO / GAS	245.00	1981	OPR
ZRENJANIN 1	ST/S	Tisa	GAS / OIL	120.00	1989	OPR
VELVET FARM IC	IC	Tisa	MGAS	0.64	2011	OPR
BEOGRAD MILL 1	ST	Sava	HFO	5.60	0	OPR
LOZNICA PULP MILL 1	ST	Drina	COAL	54.00	1956	OPR
KOLUBARA	ST	Kolubara	COAL	245.00	1956	OPR
SREMSKA MITROVICA 1	ST/S	Sava	COAL	18.50	1963	OPR

BEOGRAD GT 1	GT/S	Sava	GAS / NAP OIL	96.00	1965	OPR
NIKOLA TESLA-A	ST	Sava	COAL	1,502.00	1970	OPR
SREMSKA MITROVICA 3	ST/S	Sava	HFO / GAS	45.00	1979	OPR
NIKOLA TESLA-B NO 1	ST	Sava	COAL	1,160.00	1983	OPR
SABAC MILL 1	ST	Sava	COAL	2.40	1984	OPR
PANCEVO REFINERY 3	ST/S	Danube	OIL / RGAS	12.00	0	PLN
KRALJEVO	ST/S	Ibar (West Morava)	REF	24.00	0	PLN
KOSTOLAC-B NO 3	ST	Danube	COAL	350.00	2019	PLN
NOVI SAD-2 CC 1	CC	Danube	GAS	900.00	0	DEF
LOZNICA IPP CC	CC	Drina	GAS	110.00	2012	PLN
STAVALJ	ST	Grabovica/Jablanica (Drina)	COAL	350.00	2017	PLN
KOLUBARA-B NO 1	ST/S	Kolubara (Sava)	COAL	750.00	2017	PLN
NIKOLA TESLA-B NO 3	ST	Sava	COAL	740.00	2017	PLN
OTHER POWER PLANTS						
Name	**Fuel Type**			**Capacity (MW)**	**Installation Year**	**Status**
LA PICCOLINA VETRO-1 WTG 1&2	WIND			6.00	0	PLN
KULA WTG 1-3	WIND			9.00	0	PLN
RAM VELIKOVO-1 WTG	WIND			9.00	0	PLN
RAM VELIKOVO-2 WTG	WIND			9.00	0	PLN
BELO BLATO WTG	WIND			20.00	0	PLN
PANCEVO WTG	WIND			50.00	0	PLN
VRSAC PLANDISTE WTG	WIND			102.00	0	PLN
BELA ANTA WTG 1-60	WIND			120.00	0	PLN
LA PICCOLINA VETRO-2 WTG	WIND			120.00	0	PLN
KOVIN CIBUK WTG	WIND			170.00	2014	PLN
KOVIN WELLBURY WTG 1-94	WIND			188.00	0	PLN
DOLOVO WTG	WIND			350.00	0	PLN
CAJETINA PV	SOLAR PV			1.00	2012	CON
VELIKE BILJANICA PV	SOLAR PV			0.95	0	PLN
VRANJE SOLAR PV	SOLAR PV			10.00	0	PLN
SOJAPROTEIN BECEJ	BIOMASS - ST/S			9.00	0	PLN
VICTORIA OIL SID	BIOMASS - ST/S			9.00	0	PLN
SENTA ALLTECH IC	BGAS - IC/H			1.40	2009	OPR
KRALJEVO ENTRADE IC	BGAS - IC/H			3.20	0	PLN

Table A-3. 5. Existing and planned power generation technologies in Montenegro.

HYDROPOWER PLANTS						
Name of plant	**River**	**Flowing into Sava?**	**Type**	**Capacity (MW)**	**Installation Year**	**Status**
PODGORICA	Moraca	NO	HYDRO	0.25	1937	OPR
RIJEKA MUSOVICA		NO	HYDRO	1.36	1949	OPR
RIJEKA CRNOJEVIC		NO	HYDRO	0.18	1950	OPR
SLAP ZETE	Zeta	NO	HYDRO	1.47	1951	OPR
GLAVA ZETE	Zeta	NO	HYDRO	5.29	1954	OPR
LIJEVA RIJEKA		NO	HYDRO	7.66	1956	OPR
PERUCICA 1/2	Zeta	NO	HYDRO	76.00	1960	OPR
PERUCICA 3/4/5	Zeta	NO	HYDRO	114.00	1962	OPR
PERUCICA 6	Zeta	NO	HYDRO	58.50	1977	OPR
PERUCICA 7	Zeta	NO	HYDRO	58.50	1978	OPR
SAVNIK	Savnik (Komarnica)	YES	HYDRO	0.18	0	OPR
PIVA		YES	HYDRO	360.00	1976	OPR
BIJELA	Bijela (Piva)	YES	HYDRO	1.40	0	PLN
BOKA (RISAN)		NO	HYDRO	345.00	0	PLN
BUKOVICA	Bukovica (Piva)	YES	HYDRO	3.20	0	PLN
DJURICKA	Djuricka	NO	HYDRO	1.40	0	PLN
GRLJA 1&2		NO	HYDRO	3.12	0	PLN
KOMARACA	Komaraca	NO	HYDRO	4.00	0	PLN
KOMARNICA	Piva	YES	HYDRO	172.00	2022	PLN
HPP na Moraci	Moraca	NO	HYDRO	238.40	2021	PLN
KRASTICA		NO	HYDRO	0.80	0	PLN

LAKE KRUPAC		NO	HYDRO	0.80	0	PLN
LAKE SLANO		NO	HYDRO	5.00	0	PLN
LJUTICA	Tara	YES	HYDRO	224.00		
MURINSKA		NO	HYDRO	2.40	0	PLN
PERUCICA 8	Zeta	NO	HYDRO	58.50	2018	PLN
SJEVERNICA A-1		NO	HYDRO	0.94	0	PLN
TREPACKA		NO	HYDRO	8.30	0	PLN
TUSINA	Tusina (Piva)	YES	HYDRO	0.50	0	PLN
VELICKA	Velicka	NO	HYDRO	0.30	0	PLN
VRBNICA	Vrbnica (Piva)	YES	HYDRO	2.80	0	PLN
THERMAL POWER PLANTS						
Name of plant	**Type**	**Close to river?**	**Fuel Type**	**Capacity (MW)**	**Installation Year**	**Status**
PLJEVLJA 1	ST	SRB	Coal	225.00	1982	OPR
BERANE THERMAL	ST		Coal	110.00	0	PLN
MAOCE 1	ST	SRB	Coal	350.00	0	PLN
BERANE BIOMASS	ST/S		BIOMASS	2.00	0	PLN
PLJEVLJA 2	ST/S		Coal	225.00	2020	PLN
OTHER POWER PLANTS						
Name	**Fuel Type**			**Capacity (MW)**	**Installation Year**	**Status**
MOZUR WTG 1-23	WND			46.00	2017	PLN
KRNOVO WTG I	WND			50.00	2017	PLN
KRNOVO WTG II	WND			22.00	2017	PLN
OTHER I	WND			7.50	2018	PLN
OTHER II	WND			25.70	2020	PLN
OTHER III	WND			17.10	2025	PLN
OTHER IV	WND			21.40	2030	PLN
PV ME2030 Strategy	PV			1,5 - 31,5	2015-2030	PLN
ME2030 Strategy	Waste			10.00	2020	PLN
ME2030 Strategy	Other Biomass			0,4 - 39,0	2015 - 2030	PLN

A-4. Reference Scenario Results – generation per country

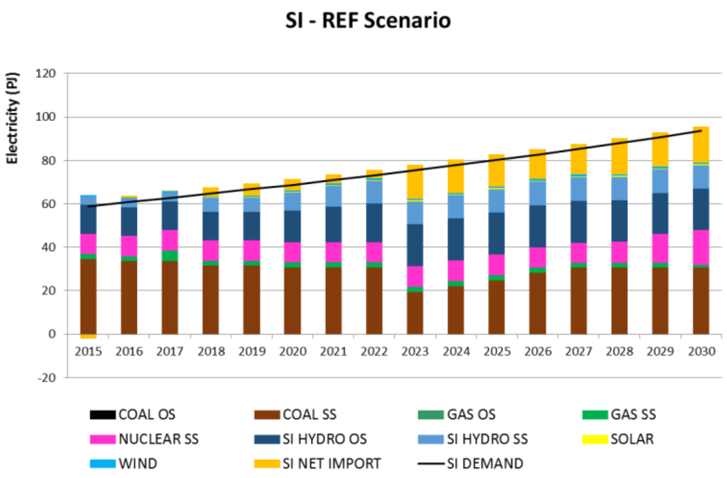


Figure A-4. 1. Electricity generation by technology type for the REF Scenario for Slovenia.

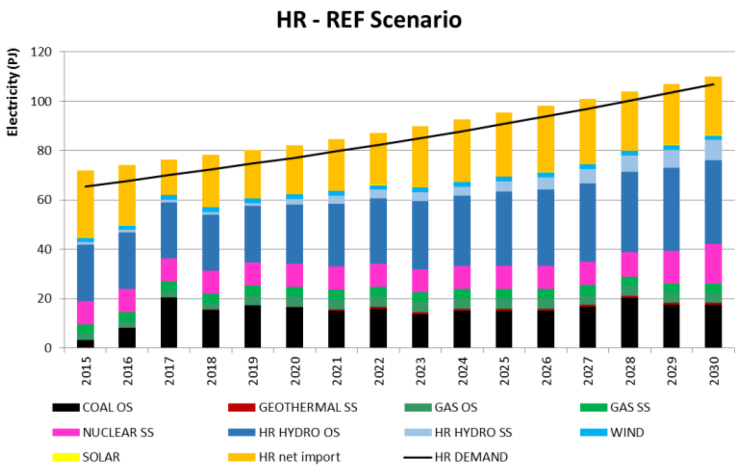


Figure A-4. 2. Electricity generation by technology type for the REF Scenario for Croatia.

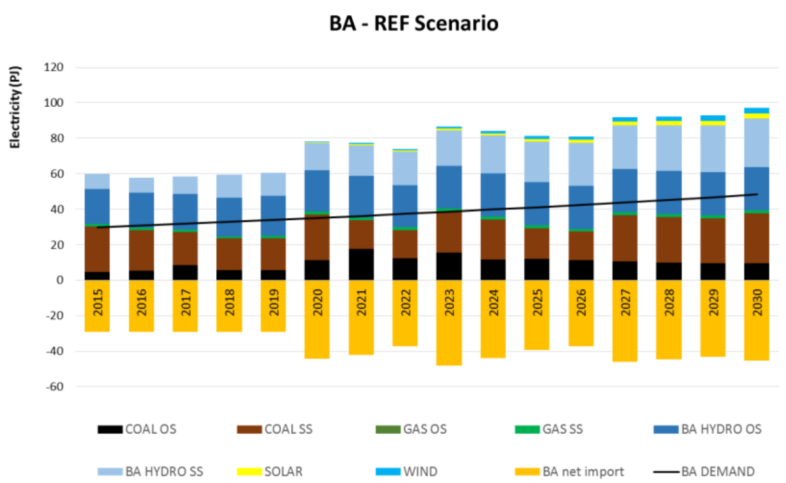


Figure A-4. 3. Electricity generation by technology type for the REF Scenario for Bosnia and Herzegovina.

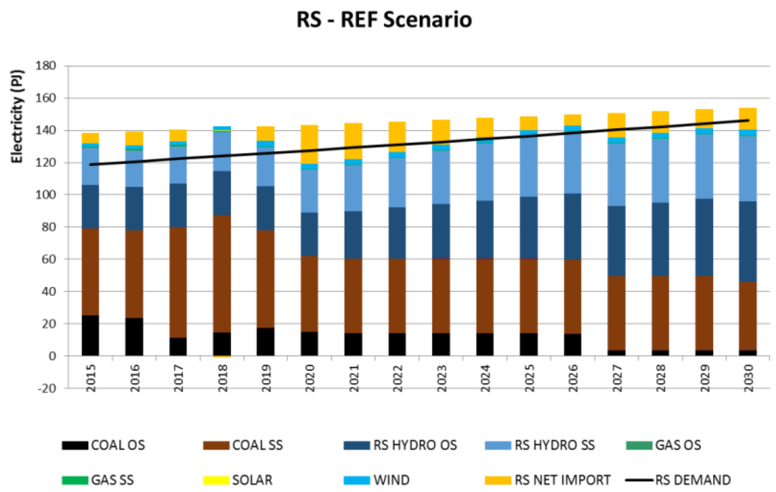


Figure A-4. 4. Electricity generation by technology type for the REF Scenario for Serbia.

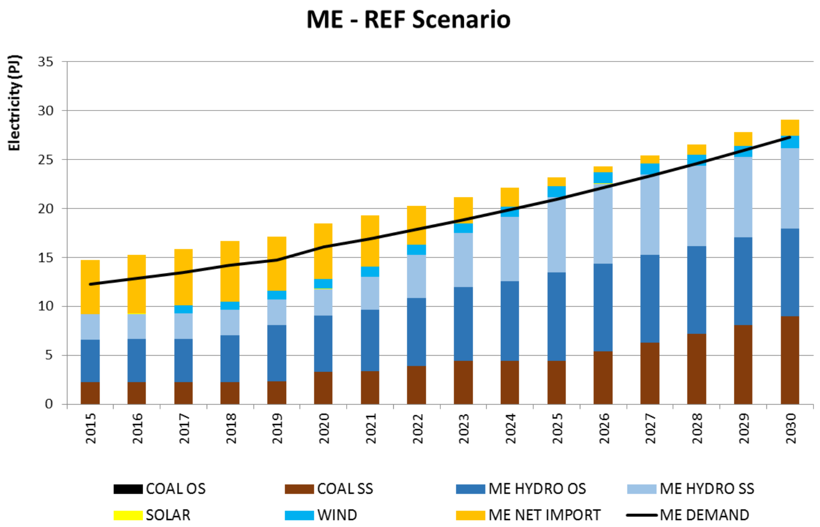


Figure A-4. 5. Electricity generation by technology type for the REF Scenario for Montenegro.

A-5. ELECTRICITY TRADE IN THE SRB COUNTRIES FOR THE REF SCENARIO

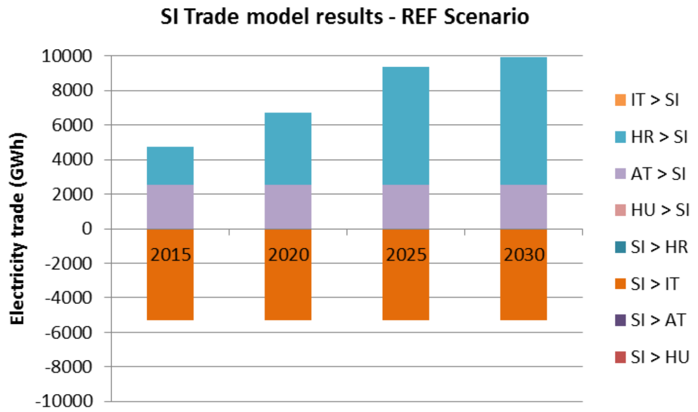


Figure A-5. 1. Electricity trade for Slovenia in the REF Scenario for the years 2015, 2020, 2025 and 2030.

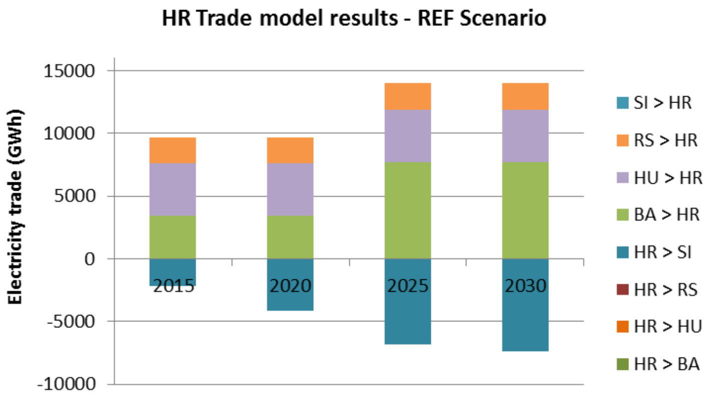


Figure A-5. 2. Electricity trade for Croatia in the REF Scenario for the years 2015, 2020, 2025 and 2030

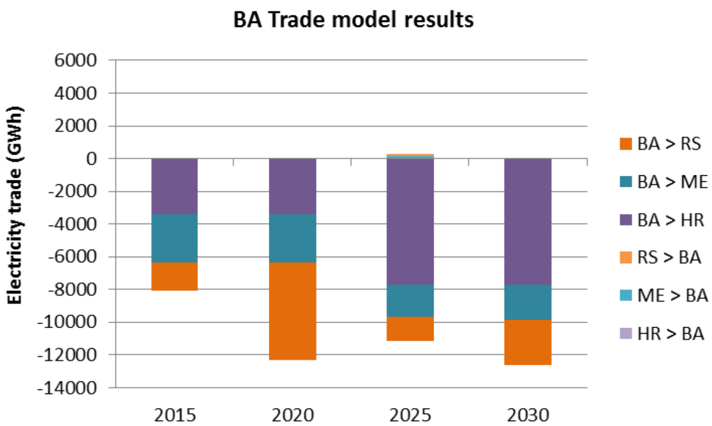


Figure A-5. 3. Electricity trade for Bosnia and Herzegovina in the REF Scenario for the years 2015, 2020, 2025 and 2030.

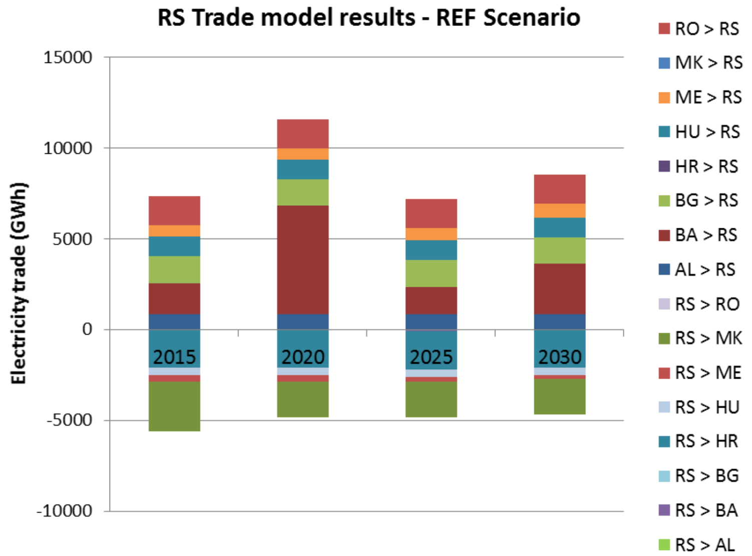


Figure A-5. 4. Electricity trade for Serbia in the REF Scenario for the years 2015, 2020, 2025 and 2030.

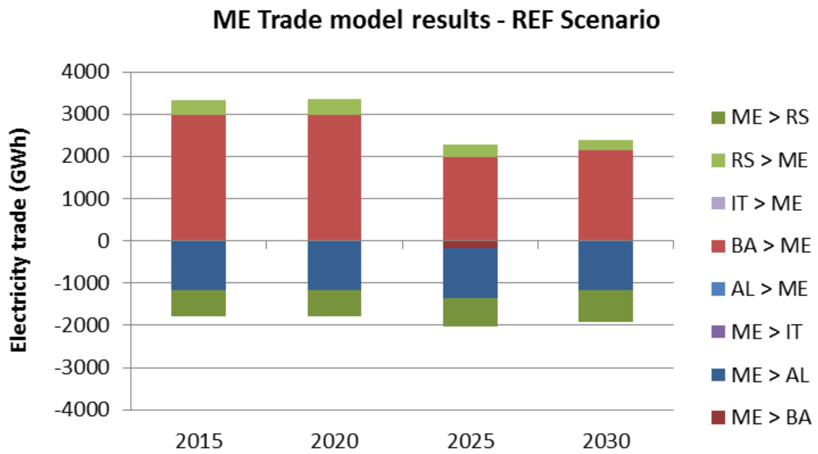


Figure A-5. 5. Electricity trade for Montenegro in the REF Scenario for the years 2015, 2020, 2025 and 2030.