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Dispa-SET model for unit commitment in the Western Balkans

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Milić Bakić, a student at the University of Piraeus at the Graduate Program of Energy: Strategy, Law & Economics, who wrote this Master's thesis with the title Dispa-SET model for unit commitment in the Western Balkans under supervision of the Professor Athanasios Dagoumas, is a scholarship holder from the Hellenic Petroleum program for the academic year 2018-2020 and dedicates this thesis to his beloved family.

Contents

Introduction

Energy plays a significant role in human wellbeing and it has an enormous influence on the global economy and development in general. From the moment when the first Oil Crises happened in the early 1970s it was clear that reforms in Energy Sector must occur. In order to answer better on the challenges in the power systems, researchers and scientists use different energy model and energy system optimization tools.

The first signs of energy models occurred during the Second World War but more fruitful period was the period of 70s of the 20th century. From that point on energy modelling never stopped developing. Energy modelling witnessed huge development in the 1990s and at the beginning of 21st century because of the need from those models to answer on various issues.

It is generally accepted that there are two types of energy system modelling software: Proprietary and Open source. At the beginning energy models were mainly proprietary and very often results as well as the code were not available. Open source gave a completely new dimension to the energy modelling because software, their code and results became available to everyone and it created community that works together on development of different models.

Nowadays, there is a huge variety of different open source energy system models. They are written in different programming languages such as Python, General Algebraic Modelling System (GAMS) and Visual Basic for Applications (VBA). Thanks to the data availability for the Western Balkans region, in this Master thesis Dispa-SET model has been used. Dispa-SET is an open source model for Unit Commitment and Economic Dispatch of the European power system.

The aim of this research is to study the power system of the Western Balkans, which includes power systems of Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, Serbia and Kosovo and to examine evolution of these power systems under different scenarios. For that purpose three scenarios for three different years, i.e. 2015, 2020 and 2030 were created and in total 21 simulations were carried out. First 7 simulations covered the reference year 2015, which is used for calculations and comparison of later scenarios. The first simulation in 2015 is carried out for all 6 Western Balkans countries together, while 6 other simulations are carried out for each country individually. Scenarios for the years 2020 and 2030 include increase of power capacities coming from small hydropower plants, solar, wind and biomass power plants. Power systems of each one of the six countries were upgraded by adding additional power capacities so that in total all six countries would have 20%, i.e. 32%, of their total generation capacities coming from the renewables. First simulation for both years is carried out for the region of the Western Balkans in interconnected mode, where all six countries exchange energy between them but there is no exchange with other neighbouring countries. The rest of simulations in both 2020 and 2030 are carried out for each country in islanded mode, which means that there was no power exchange with any of their neighbouring countries.

The thesis is structured in four different chapters. The first chapter covers literature review with focus on the evolution of energy models, which is followed by the description of the most popular open source energy models. The second chapter is dedicated to the description and formulation of the Dispa-SET model. In this chapter the objective function is defined. The third chapter deals with the introduction to the Western Balkans region, which is followed by the progress of the European integration of the region and description of the power systems of the Western Balkans. In the last chapter simulation scenarios and results from the simulations for three different years, i.e. 2015, 2020 and 2030 were presented. In the conclusions the results are further discussed with insight for further research.

1. Energy System models and their application

1.1. Introduction

Energy plays a significant role in human wellbeing and it has an enormous influence on the global economy and development in general. From the moment when the first Oil Crises happened in the early 1970s it was clear that reforms must occur in Energy Sector. Need for reforms was even more strengthened by the fact that last decades of twentieth century brought growth in population and development in industry. Those two factors are directly proportional to the increased demand of energy. The trend of further growth in energy consumption and population continues to happen even more intensively in twenty-first century. Current energy systems, starting with production of energy from primary source to the final energy services, are not sustainable any more. Concerns about global warming caused by greenhouse gas emission, air quality in urban areas, and scarcity in fossil fuel reserves create a path towards the change of the current form of the power systems [1]. Till now human needs are met without keeping the balance with nature and it seems that in order for energy systems to face those challenges there is a need for combination of options that will decrease energy demand and make energy generation more green and sustainable, in general. As a conclusion from study review in paper [1], Energy system modelling and energy system optimization can be seen as really effective, powerful and useful tool for problem solving in power system sector and they are especially useful for policymakers because the huge amount of scenario analyses can lead to establishment of better policies.

1.2. Evolution of Energy system models

Signs of the very first energy system models can be traced back even in the period of the Second World War [2] but more fruitful period for energy system models started with period of 1970s. As it is stated in [3], the energy system models and computer models in general represent a critical tool that is being used for examination of the future decision under a variety of different assumptions and hypothesis. The period when the first oil crises happened was the period when policy makers needed to answer on many issues and challenges that concerned the energy sector. Thanks to these events the first versions of energy system models were born in order to answer on a question - what kind of impact the crises could have on economic development. The development of the energy systems models can also be linked to the rising importance of scenario planning throughout the twentieth century [2]. Increase in computing power led to further development in energy system modelling in

1980s [5] and motivation for even further development of the energy models has never stopped. In the 1990s and at the beginning of twenty-first century, climate change problems as well as local pollution were the main interest in energy system modelling because of the high impact of energy production on those problems [4]. Nowadays researches' motivation to build and develop energy models is even stronger as result of many requirements that are put in front of the contemporary energy systems. Initially energy system models were focused on energy security and costs but because of the climate change issues, climate policy arose as the significant driving force for large number of new studies [5]. When energy systems models were initially developed, power plants were either baseload or dispatchable at will, i.e. able to ramp up or down to match demand as needed [2], but during the last decades, beside the penetration of renewable energy resources that have variable nature, some new concepts of energy planning and management have emerged such as decentralized planning, waste recycling, integrated energy planning, energy conservation through improved technologies and energy forecasting that made energy system even more complexed [6].

1.3. Open source models

It is generally accepted that there are two types of energy system modelling software: Proprietary and Open source. At their beginning energy system models were mainly proprietary, closed and they were not shared with the others [7]. The models creation and development were carried out by government agencies, and large, vertically-integrated utilities that did not have any obligation to reveal their modelling assumptions or methodologies [8]. So, purpose of the energy system models in that period was to help governments to manage energy systems, which sometimes led to mismanagement.

In order to better understand the differences between the types of software in [9] definitions and characteristics of both were given.

The term Proprietary Software is used to refer to software that has restrictions in its use, modification and restrictions on distributing, coping and publishing any version of software, i.e. modified or not modified version of software. All the restrictions are written in details in the software license. Breaking the rules as consequence can result in penalties in many countries. This kind of software is known as commercial, as well as non-open or non-free software.

Open source software is software that is distributed with source code and it gives opportunity to users to read or modify it. Open source software license gives users rights to freely use the software for any purposes, to view and use the source code, to make modifications and copies, to distribute their own versions for free or for a fee. To summarize, open source software gives permit to anyone to view source code, use and modify software without any obligation to pay anything to the issuer of the license.

In the same paper [9], Free Software are also defined as a software that can be studied, used and modified without any restrictions. In [10], Richard M. Stallman gives the definition of Free Software. This term is often misunderstood because it has nothing to do with price but with a freedom. Indeed, freedom is the key word that describes Free Software because it gives freedom to a particular user to run the software for any purposes, to modify the code in order to make it more tailored for user’s need, to distribute copies or modified versions of it, so that the community can benefit from user’s improvements. The main difference between Open Source and Free Software is in the license type. Free License, also known as reciprocal license, obliges the user that in the case of distributing a modified application the source code must remain open source. In case of Open Source license user has the opportunity to convert an open source code into closed software [9].

Really important question that is put in front of researchers is which type of software they should use. Many authors agreed that open source software will always win in this race. There is little or no difference between open source software and the proprietary software when it comes about quality [13]. The reason why open source are highly efficient is network of volunteer programmers, who are constantly developing more and more open source software, making them highly complex products and products of equal if not better quality than the competing commercial products [11]. Motivation for programmers to volunteer on development of Open Source Community can include learning, career concerns or satisfying functional needs [15]. Successful open source software projects can even pose a threat of creative destruction to proprietary software [12]. The most important is that this type of projects allow public participation.

1.4. Data in the models

Data being an input and output represents a vital part of energy system modelling. However, collection and updating the data is seen as costly and really demanding job. While there is positive trend in numbers of open source energy system models, still there are issues with data transparency and openness [14]. Open data can be defined as data that can be freely used by everyone without any restrictions and plays supporting role in the modelling process and it can enhance public engagement into energy issues [15]. This kind of data is collected from different sources. Some data is available from transparent government documents but mainly data is collected through different institutions like non-profit, industry or research institutions. There are several reasons that show the benefits of having freely access to data. Those reasons are presented in [16] and they are the following ones: improvement of scientific research, more effective collaboration across the science-policy boundary and increased productivity through collaborative burden sharing, profound relevance to societal debates, etc. Open models and data are necessity when it comes about fulfilling the fundamental scientific principles such as transparency, peer review and reproducibility. Those principles are in direct correlation with increase of quality of science. Researchers are just human beings and errors can occur and in such cases peer reviews can significantly improve those mishaps. Open data would create space for academia and government to interact and work together even more on answering the huge challenges. Transparency would make modelling of huge and complex systems even easier, where beside engineers professionals from different backgrounds, such as economics, social studies and environmentalists would work together. If researchers have access to source code and data, then the precious researchers' time is not wasted and researchers can focus on further improvement of existing models. World Bank's Open Data Initiative [15], Open Power System Data [19] and the EU Regulation on Wholesale Energy Market Integrity and Transparency (REMIT) that requires from participants to publish electricity market data [16], are just some of the good examples of open data practices.

1.5. Examples of open source models

It is common practice in energy system modelling that only the results are published but that kind of models are not matter of concern in this thesis. In the following section focus will be on the open source models and their applications. Beside some commercial products like NEPLAN, PowerWorld or PSS/E, there are several models that are free to download and use, and RETScreen, HOMER, BCHP Screening Tool, EnergyPLAN, Invert, ORCED, ENPEP-BALANCE, COMPOSE, SIVAEL, MiniCAM, STREAM are just some of them [17]. The problem with these models is the fact that there is no possibility to get the source code because those models are not open source models.

The number of open source models that were created has grown over the last years. Open source community received greater attention as more and more publically available energy models are shared via GitHub, which create space for users from different backgrounds and organisations to work together on a project [7]. At the website of Open Energy Modelling Initiative: openmod [22] the list of energy models published under open source licenses can be found. Most of them are written in Python programming language. Beside Python the list of the three most common programming or modelling languages includes General Algebraic Modelling System (GAMS) and Visual Basic for Applications (VBA) [7]. Short explanation of some open source energy system models will follow.

1.5.1. Balmorel

Balmorel is an open source model that was developed by the Danish Energy Research Program in 2001 [17]. The model was firstly created to analyse the Baltic Sea Region but in recent years it expanded to more countries, such as Canada, Ghana, Mauritius and China. Balmorel is a model that optimises generation, transmission and consumption of electricity and heat, finding the optimal way to satisfy the energy demand maximising social welfare, consumers' utility minus producers' cost of electricity and district heat generation, storage, transmission and distribution [18]. The model is written in General Algebraic Modelling System (GAMS) modelling language which requires a valid GAMS license in order for Balmorel to be run.

1.5.2. MatPower

MatPower, being created in 1997, is one of the oldest Open Source tool used for optimisation of energy power systems [9]. It is specifically used for the power flow and optimal power flow and it was developed by Engineering Research Centre [20]. Power flow and optimal power flow are important for improvement of system performances and for the management of losses. MatPower is a powerful package that consists of MATLAB m-files, written in code that is simple to understand and modify and at the same time designed to give the best performance while calculating optimal power flow [9]. Since the MatPower is written in MATLAB, a valid MATLAB licences is required from the user in order to run the MatPower.

1.5.3. PyPower

PyPower belongs to the group of first open source models written in Python. It was developed by Richard Lincoln in 2009 and it actually represents a translation of MatPower, which was written in Matlab, into Python [8]. Development of this model stopped in 2014 but in 2016 three more independent models were built on the basis of PyPower. Those are PyPSA, pandapower and GridCal. While GridCal offered a graphical user interface and it added new algorithms for power flow, pandapower further developed the modelling of distribution networks [8].

1.5.4. PyPSA

Python for Power System Analysis (PyPSA) is a free software made for simulations and optimisations of modern power systems over multiple periods [23]. It was developed at the

Frankfurt Institute for Advanced Studies. Using PyPSA it is possible to do power flow calculations and linearized optimal load flow and from the very beginning it was written with variable renewables, storage and sector coupling in mind, so that it can perform without any problem with large networks. PyPSA is powerful enough to do the unit commitment of conventional generators, variable renewable generators, storage units, all combinations of direct and alternating current electricity networks, and the coupling of electricity to other energy sectors, such as transport, gas and heating [23]. Being free software gives freedom to users to read, modify and distribute the code. PyPSA-EU is good example how a model can be further developed if it is free and accessible to everyone. This model is the first open model of the full European system at such a high spatial resolution because it covers full ENTSO-E area [24].

1.5.5. PSAT

The Power System Analysis Toolbox (PSAT), founded by Dr Federico Milano in 2002, was one of the pioneers in free and open source software for power system modelling [7]. Power flow, optimal power flow, time domain simulation, Phasor Measurement Unit placement, conversion of data files from several formats, one-line diagram editor were just some of the features of this Software. Unfortunately, after bad results in community contribution Dr F. Milano decided to stop this open source project. In 2013, Dr F. Milano started a new project called DOME, which is Power System Modelling tool completely written in Python [7]. After low level of community contribution he realized the importance of choosing the right programming language. There are several reasons that make Python a good choice for programming language. First of all Python is free and open source based on well-structured classes, its syntax is simple, elegant and compact, it has huge variety of libraries, etc. The main idea on which DOME was created was the modularity and reusability of the code. DOME can solve power flow analysis, optimal power flow, time domain simulation including quasi-static one and small signal stability.

1.5.6. Switch

Switch is a modern platform for planning power system with high share of renewable energy, storage and/or demand response [22]. It can perform power system studies such as investment planning, production cost simulation, or economic and policy analyses; it also includes unit commitment, part-load efficiency, fuel supply curves, planning and operating reserves, storage, demand response, hydroelectric networks, and policy constrains [25]. Its objective is to minimize the power plants present costs, transmission capacity, fuel and per-ton carbon dioxide adder [26]. Switch is written in Python and thanks to the open source licences there is an easy access to code and its distribution is easy. The model can be solved using Pyomo, which includes most commercial and open-source solvers. Switch has been successfully applied to power systems of the United States, Canada, Mexico, Chile, China, Japan, East Africa, Kenya and Peru [25].

1.5.7. TEMOA

TEMOA stands for Tools for Energy Model Optimization and Analysis and it is an open source framework. The general design philosophy of TEMOA is to make the model just complex enough to answer specific questions, but no more [27]. The main component of TEMOA is an energy economy optimization model that minimizes the system-wide cost of energy supply by the deployment and utilization of energy technologies over a user-specified time horizon [28]. The model features can be found on TEMOA website [29] and they are the following: Flexible time slicing by season and time-of-day; variable length model time periods; technology vintaging; separate technology loan periods and lifetimes; global and technology-specific discount rates; and capability to perform modelling to generate alternatives. The model is written in Python and in order to be solved Pyomo, open source Python library, should be used.

1.5.8. Calliope

Calliope is a multi-scale framework to build energy system models, designed to analyse systems with high spatial and temporal resolution [30]. Its main focus is on planning energy system at the different scale range. Beside the ability to handle high spatial and temporal resolution, main feature of Calliope is the easy run on high-performance computing systems. It provides both a command line interface and an API for programmatic use, which is useful for the users familiar with Python but at the same time it is appealing for the users that have no Python experience [30]. As the previous examples, Calliope is also based on Python. It has been used in several studies that included countries like Great Britain and South Africa.

1.5.9. Ficus

Ficus is a mixed integer linear optimisation model for capacity expansion planning and unit commitment [31]. Its objective is optimal power flow which will take into consideration all processes, storage units, commodity imports, and commodity exports in order to satisfy demand with minimal costs [32]. This model is also written in Python, it can be solved using Pyomo and it can be redistributed and modified.

1.5.10. OSeMOSYS

Open Source Energy Modelling System (OSeMOSYS) is a framework for long-term energy system models implemented in GNU MathProg and it was released in 2009 [8]. The idea of this project is to facilitate modelling and education through easy to read interface and free software philosophy [34], which allows freely modification of the code for the needs of a research. This was the first energy system optimisation modelling framework which code, environment and solver are fully open source [35]. The OSeMOSYS code is known as straightforward, elegant and transparent [33]. The OseMOSYS team developed a close relationship with two United Nation agencies, UNDESA and UNDP, which helped OSeMOSYS to be adopted by governments for their energy systems planning and South Africa, Bolivia and Cyprus are just some of the best examples [8].

The results given in the paper [7] show that available Open Source models are indeed mature enough for serious use based on their comparison with commercial or proprietary ones. Although, many of those open source models have high quality and accessibility standards very few of them focus on Western Balkans. Dispa-SET model is the most appropriate to be used in case of the Western Balkans since the application of Dispa-SET model on this region already exists. Dispa-SET model will be further explained in the following chapter.

2. Dispa-SET model description

2.1. Introduction to Dispa-SET

For the purpose of the thesis Dispa-SET model has been used. Dispa-SET is an open source model for the Unit Commitment and Economic Dispatch of the European power system [36]. This model, which is focused on balancing and flexibility problems in European grids, is developed within the Joint Research Centre of the European Union Commission, in collaboration with the University of Liège and the KU Leuven in Belgium [37]. The goal of the Dispa-SET model is to optimise the short-term operation of large-scale power systems, with high level of details and at an hourly time step resolution, solving the unit commitment problem. The objective function of this model minimizes the total costs of the power system, which consist of start-up, shut-down, fixed, variable, ramping, transmission-related and load-shedding costs [36]. It is written in Gams and Python (Pyomo) and it uses input data in form of .csv and .xlsx files. Dispa-SET is primarily designed to run with GAMS and valid GAMS user licence is needed. Optimisation problem is defined either as Linear Programming (LP) or Mixed-Integer Linear Programming problem (MILP) depending on the level of accuracy and complexity. The main advantage of Dispa-SET model is ability to optimise a regional multi-zonal power system with high level of details at the unit level, taking into account the minimum and maximum efficiencies, minimum up and down times, start-up times, ramping rates, minimum part loads and CO_2 intensities of conventional power plants, the level in the accumulation reservoirs and pumped hydropower plants as well as the availability factors of all types of renewable energy sources [38].

The following description of the model is based on the detailed description that can be found at the Dispa-SET website [39] and Dispa-SET Joint Research Centre technical report [40].

2.1.1. Countries

For the purpose of this Master thesis only six countries of the Western Balkans region have been examined. Dispa-SET model uses ISO 3166-1 standard to describe each country. The list of examined countries is defined down below in the Table 1.

Table 1. *List of examined countries*

Code	Country
AL	Albania
BA	Bosnia and Herzegovina
ME	Montenegro
MK	North Macedonia
SR	Serbia
XK	Kosovo

Source: Author's work based on [40]

2.1.2. Input Data

Input data has significant influence on the quality of the optimisation results. The data is collected from various resources, such as reports, technical documentations, books, articles etc. Input Data is stored in Dispa-SET folder database and it must follow two rules in order to be valid for simulation. All input data that is written at hourly basis should be register following the timestamp relative to the Coordinated Universal time zone (UTC time zone). Data should be written using a specific convention because non-compliance with the rules will result in discarding of the data in pre-processing phase.

2.1.3. Technologies

The technologies that are recognised by Dispa-SET model are given down below in the Table 2. The model would not be able to recognise the technology type if it is not set using the same name as in the Table 2. and therefore the data will be discarded at the pre-processing stage. Symbol Y in column VRES indicates that the technology is variable renewable technology, while the same symbol in the column Storage means that the technology can accumulate energy.

Table 2. *Dispa-SET technologies*

Technology	Description	VRES	Storage
COMC	Combined cycle	N	N
GTUR	Gas turbine	N	N
HDAM	Conventional hydro dam	N	Y
HROR	Hydro run-of-river	Y	N
HPHS	Pumped hydro storage	N	Y
ICEN	Internal combustion engine	N	N
PHOT	Solar photovoltaic	Y	N
STUR	Steam turbine	N	N
WTOF	Offshore wind turbine	Y	N
WTON	Onshore wind turbine	Y	N
CAES	Compressed air energy storage	N	Y
BATS	Stationary batteries	N	Y
BEVS	Battery-powered electric vehicles	N	Y
THMS	Thermal storage	N	Y
P2GS	Power-to-gas storage	N	Y

Source: Author's work based on [40]

2.1.4. Fuel types

Limited number of different fuel types are considered by the Dispa-SET. The Table 3. shows fuel types that the model can distinguish.

Table 3. *Fuel types*

Fuel	Examples
BIO	Bagasse, Biodiesel, Gas From Biomass, Gasification, Biomass, Briquettes, Cattle Residues, Rice Hulls Or Padi Husk, Straw, Wood Gas (From Wood Gasification), Wood Waste Liquids
GAS	Blast Furnace Gas, Boiler Natural Gas, Butane, Coal Bed Methane, Coke Oven Gas, Flare Gas, Gas(Generic) Methane, Mine Gas, Natural Gas, Propane, Refinery Gas, Sour Gas, Synthetic Natural Gas, Top Gas, Voc Gas & Vapor, Waste Gas, Wellhead Gas
GEO	Geothermal steam
HRD	Anthracite, Bituminous Coal, Coker By-Product, Coal Gas, Coke, Coal (Generic), Coal-Oil Mixture, Coal And Pet Coke Mi, Coal Tar Oil, Anthracite Coal Waste, Coal-Water Mixture, Gob, Imported Coal, Other Solids, Soft Coal, Anthracite Silt, Steam Coal, Subbituminous, Pelletized Synthetic Fuel From Coal, Bituminous Coal Waste
HYD	Hydrogen
LIG	Lignite black, Lignite brown, lignite
NUC	U, Pu
OIL	Crude Oil, Distillate Oil, Diesel Fuel, Furnace Fuel, Fuel Oil, Gas Oil, Furnace Fuel, Gasoline, Heavy Oil Mixture, Jet Fuel, Kerosene, Light Fuel Oil, Liquefied Propane Gas, Methanol, Naphtha, Gas From Fuel Oil Gasification, Fuel Oil, Other Liquid, Orimulsion, Petroleum Coke, Petroleum Coke Synthetic Gas, Black Liquor, Residual Oils, Re-Refined Motor Oil, Oil Shale, Tar, Topped Crude Oil, Waste Oil
PEA	Peat Moss
SUN	Solar Energy
WAT	Hydro Energy
WIN	Wind Energy
WST	Digester Gas, Gas From Refuse Gasification, Hazardous Waste, Industrial Waste, Landfill Gas, Poultry Litter, Manure, Medical Waste, Refused Derived Fuel, Refuse, Waste Paper and Waste Plastic, Refinery Waste, Tires, Agricultural Waste, Waste Coal, Waste Water Sludge, Waste

Source: Author’s work based on [40]

2.1.5. Power plants data

Input data about power plants consists of general and technical details of the power plant. Power plant database may contain as many fields as desired but there are some fields that are required by Dispa-SET. In the Table 4. down below common fields that are required for all units are listed.

Table 4. *Input data*

Description	Field name	Units
Unit name	Unit	
Commissioning year	Year	
Technology	Technology	
Primary fuel	Fuel	
Zone	Zone	
Capacity	Power Capacity	MW
Efficiency	Efficiency	%
Efficiency at the minimum load	MinEfficiency	%
CO_2 Intensity	CO2Intensity	TCO2/MWh
Minimum load	PartLoadMin	%
Ramp up rate	RampUpRate	%/min
Ramp down rate	RampDownRate	%/min
Start-up time	StartUpTime	h
Minimum up time	MinUpTime	h
Minimum down time	MinDownTime	h
No load cost	NoLoadCost	EUR/h
Start-up cost	StartUpCost	EUR
Ramping cost	RampingCost	EUR/MW
Presence of CHP	CHP	y/n

Source: Author's work based on [40]

Beside the information that are common for every energy unit, some additional data are required for combined heat and power (CHP) units and storage units. Those are storage capacity, self-discharge rate, maximum charging power, charging efficiency for storage units, while for CHP information such as CHP Type, power-to-heat ratio, power loss factor, maximum heat production, capacity of heat storage, percentage of storage heat losses per time step are required.

2.1.6. Generation from renewable energy resources

Generation from renewable energy sources have variable nature and energy generated from renewables must be fed to the grid or it will be curtailed. The reason for this is fact that till now there is no existing technology that could store this energy. Availability factor indicates availability of these technologies to generate energy and it has value range from 0 to 1. When availability factor is equal to 0 that means that there is no generation, while when the factor is equal to 1 power generation is in full swing.

2.1.7. Outage factor

This factor indicates power plant outages. Current version of Dispa-SET does not make differences between planned, i.e. scheduled outages because of the maintenance reasons, and unplanned outages. Just like the availability factor, the outages factor can have values between 0 and 1, where 0 means that there is no outage and 1 there is full outage.

2.1.8. Interconnections

Dispa-SET model makes differences between two types of interconnections: interconnections happening between the simulated zone and interconnection happening between the simulated zone and rest of the world.

2.1.8.1. Net transfer capacities

Net transfer capacities (NTC) is amount of commercially exchanged energy between the two interconnected neighbouring countries in the simulated zone. Dispa-SET does not cover DC power flows or more complexed grid simulations. Net transfer capacity values are fluctuating in time and that is why it is necessary to have the information about Net transfer capacities at the hourly basis. Since the Net transfer capacities between two countries are not always symmetrical it is really important to provide information about exchanged capacities between two countries in both direction, otherwise non-provided capacities will be seen as there is no capacity exchange in that direction.

2.1.8.2. Historical physical flows

The flows between country and rest of the world must be provided as exogenous input and they are named as historical physical flows. Although the name would suggest that there is no possibility to change this input data, there is possibility for users to define this flow. This data represents aggregated amount of energy exchanged between examined country and other countries that do not belong to the simulated zones. Non-provided flows are consider to be zero, while when there is no any historical flows, the examining power system is seen as an islanded one.

2.2. Model description

The main idea of Dispa-SET model is to represent with high level of detail unit commitment problem of the European Power System, as it was previously stated. The unit commitment problem solved by Dispa-SET model represents just a simplified version of a problem that operators needs to face in a wholesale day-ahead power market. The available versions of the model present the demand side as an aggregated input for each node, while the transmission network is presented as a transport problem between the nodes.

The unit commitment problem has two parts. Scheduling the start-up, operation and shut down of the available generation units would be the first part, while second part would be allocation of the total power demand among the available generation units in such a way that the overall power system costs are minimised. In order to model the start-up and shut down of the units and to present commitment status of the units in different periods, use of binary variables is required. Second part of the unit commitment problem, also known as economic dispatch problem, determines the continuous output of each generation unit in the system. That is why the model is formulated as a mixed-integer linear program (MILP).

Since the Dispa-SET model is used to optimise quite a big interconnected system, such as European one, compact formulation of the model is needed so that the solver speed can be increased.

2.2.1. Data, sets and parameters of the model

Dispa-SET uses three types of data: sets, parameters and optimisation variables. Sets are building blocks of the optimisation model and they are listed in the Table 5. Parameters represent coefficients that correspond to the exogenous data provided to the model.

Parameters used in the model are listed in the Table 6. Optimisation variables, also known as decision variables, are the variables that need to be adjusted to minimise the objective function. They are listed in the Table 7.

Table 5. *Sets of the model*

Name	Description
f	Fuel types
h	Hours
i	Time step in the current optimization horizon
l	Transmission lines between nodes
mk	{DA: Day-Ahead, 2U: Reserve up, 2D: Reserve Down}
n	Zones within each country (currently one zone, or node, per country)
p	Pollutants
t	Power generation technologies
tr	Renewable power generation technologies
u	Units
s(u)	Storage units (including hydro reservoirs)
chp(u)	CHP units

Source: Author's work based on [40]

Table 6. *Parameters of the model*

Name	Units	Description
AvailabilityFactor(u,i)	%	Percentage of nominal capacity available
CHPPowerLossFactor(u)	%	Power loss when generating heat
CHPPowerToHeat(u)	%	Nominal power-to-heat factor
CHPMaxHeat(chp)	MW	Maximum heat capacity of chp plant
CHPType	/	CHP Type
CommittedInitial(u)	/	Initial commitment status
CostFixed(u)	EUR/h	Fixed costs
CostLoadShedding(n,h)	EUR/MWh	Shedding costs
CostRampDown(u)	EUR/MW	Ramp-down costs
CostRampUp(u)	EUR/MW	Ramp-up costs
CostShutDown(u)	EUR/u	Shut-down costs for one unit
CostStartUp(u)	EUR/u	Start-up costs for one unit
CostVariableH(u,i)	EUR/MWh	Variable costs
CostHeatSlack(chp,h)	EUR/MWh	Cost of supplying heat via other means
Curtailment(n)	/	Curtailment {binary: 1 allowed}
Demand(mk,n,i)	MW	Hourly demand in each zone
Efficiency(u)	%	Power plant efficiency
EmissionMaximum(n,p)	EUR/tP	Emission limit per zone for pollutant p
EmissionRate(u,p)	tP/MW	Emission rate of pollutant p from unit u
Fuel(u,f)	/	Fuel type used by unit u {binary: 1 u uses f}

HeatDemand(chp,h)	MWh/u	Heat demand profile for chp units
K_QuickStart(n)	/	Part of the reserve that can be provided By offline quickstart units
LineNode(l,n)	/	Line-zone incidence matrix {-1,+1}
LoadShedding(n,h)	MW	Load that may be shed per zone in 1 hour
Location(u,n)	/	Location {binary: 1 u located in n}
Nunits(u)	/	Number of units inside the cluster
OutageFactor(u,h)	%	Outage factor (100 % = full outage) per hour
PartLoadMin(u)	%	Percentage of minimum nominal capacity
PowerCapacity(u)	MW/u	Installed capacity
PowerInitial(u)	MW/u	Power output before initial period
PowerMinStable(u)	MW/u	Minimum power for stable generation
PowerMustRun(u)	MW	Minimum power output
PriceTransmission(l,h)	EUR/MWh	Price of transmission between zones
QuickStartPower(u,h)	MW/h/u	Available max capacity for tertiary reserve
RampDownMaximum(u)	MW/h/u	Ramp down limit
RampShutDownMaximum(u)	MW/h/u	Shut-down ramp limit
RampStartUpMaximum(u)	MW/h/u	Start-up ramp limit
RampUpMaximum(u)	MW/h/u	Ramp up limit
Reserve(t)	/	Reserve provider {binary}
StorageCapacity(s)	MWh/u	Storage capacity (reservoirs)
StorageChargingCapacity(s)	MW/u	Maximum charging capacity
StorageChargingEfficiency(s)	%	Charging efficiency
StorageDischargeEfficiency(s)	%	Discharge efficiency
StorageInflow(s,h)	MWh/u	Storage inflows
StorageInitial(s)	MWh	Storage level before initial period
StorageMinimum(s)	MWh/u	Minimum storage level
StorageOutflow(s,h)	MWh/u	Storage outflows (spills)
StorageProfile(u,h)	MWh	Storage long-term level profile
Technology(u,t)	/	Technology type {binary: 1: u belongs to t}
TimeDownMinimum(u)	h	Minimum down time
TimeUpMinimum(u)	h	Minimum up time
VOLL()	EUR/MWh	Value of lost load

Source: Author’s work based on [40]

Table 7. *Optimisation variables*

Name	Units	Description
Committed(u,h)	/	Unit committed at hour h {1,0}
CostStartUpH(u,h)	EUR	Cost of starting up
CostShutDownH(u,h)	EUR	Cost of shutting down
CostRampUpH(u,h)	EUR	Ramping cost
CostRampDownH(u,h)	EUR	Ramping cost
CurtailedPower(n,h)	MW	Curtailed power at node n
Flow(l,h)	MW	Flow through lines
Heat(chp,h)	MW	Heat output by chp plant
HeatSlack(chp,h)	MW	Heat satisfied by other sources
Power(u,h)	MW	Power output
PowerMaximum(u,h)	MW	Power output
PowerMinimum(u,h)	MW	Power output
Reserve_2U(u,h)	MW	Spinning reserve up
Reserve_2D(u,h)	MW	Spinning reserve down
Reserve_3U(u,h)	MW	Non spinning quick start reserve up
ShedLoad(n,h)	MW	Shed load
StorageInput(s,h)	MWh	Charging input for storage units
StorageLevel(s,h)	MWh	Storage level of charge
Spillage(s,h)	MWh	Spillage from water reservoirs
SystemCost(h)	EUR	Total system cost
LL_MaxPower(n,h)	MW	Deficit in terms of maximum power
LL_RampUp(u,h)	MW	Deficit in terms of ramping up for each plant
LL_RampDown(u,h)	MW	Deficit in terms of ramping down
LL_MinPower(n,h)	MW	Power exceeding the demand
LL_2U(n,h)	MW	Deficit in reserve up
LL_3U(n,h)	MW	Deficit in reserve up - non spinning
LL_2D(n,h)	MW	Deficit in reserve down

Source: Author's work based on [40]

2.2.2. Objective function

The aim of the unit commitment problem is minimisation of the total power system costs. Total costs are given in the equation (1), which is the sum of different types of costs: start-up, shut-down, fixed, variable, ramping, transmission-related and load shedding costs. Fixed costs depend on whether the unit is on or off, variable depend on the power output of the unit. Start-up and shut-down costs are the costs that occurred because of the start-up, i.e. shut-down of the unit. Ramping unit up or down will result in adding ramping up and ramping down costs in total costs equation. Transmission costs depend on the flow energy through the lines, while loss of load represents the cost that happened when the power generation exceeds the demand or cannot match it.

$$SystemCost = min \sum_{u,n,i} [CostStartUp_{u,i} + CostShutDown_{u,i} + CostFixed_u \cdot Committed_{u,i} \quad (1)$$

$$+ CostVariable_{u,i} \cdot Power_{u,i} + CostRampUp_{u,i} + CostRampDown_{u,i}$$

$$+ PriceTransmission_{i,l} \cdot Flow_{i,l} + \left(CostLoadShedding_{i,n} \cdot ShedLoad_{i,n}\right)$$

$$+ \sum_{chp} CostHeatSlack_{chp,i} \cdot HeatSlack_{chp,i}$$

$$+ \sum_{chp} CostVariable_{chp,i} \cdot CHPPowerLossFactor_{chp} \cdot Heat_{chp,i}$$

$$+ VOLL_{Power} \cdot \left(LL_{MaxPower,i,n} + LL_{MinPower,i,n}\right)$$

$$+ VOLL_{Reserve} \cdot \left(LL_{2U,i,n} + LL_{2D,i,n} + LL_{3U,i,n}\right)$$

$$+ VOLL_{Ramp} \cdot \left(LL_{RampUp,u,i} + LL_{RampDown,u,i}\right)]$$

The equation (2) represents the equation for variable production costs. As it can been noticed, variable costs depend on fuel and emission prices corrected by the efficiency, which is constant for levels of output in this version of model, and the emission rate of the unit. It also includes mark-up parameter, which is used for calibration and validation purposes.

$$CostVariable_{u,h} = Markup_{u,h} + \sum_{n,f} \left(\frac{Fuel_{u,f} \cdot FuelPrice_{n,f,h} \cdot Location_{u,n}}{Efficiency_u} \right) \quad (2)$$

$$+ \sum_{p} \left(EmissionRate_{u,p} \cdot PermitPrice_p \right)$$

Dispa-SET model uses 3 integers formulations of the up and down status for all units. Equation (3) shows how the number of start-ups and shut-downs is computed at each time step.

$$Committed_{u,i} - Committed_{u,i-1} = StartUp_{u,i} - ShutDown_{u,i} \quad (3)$$

Cost of start-up and shut-down are positive variables and equations (4) and (5) show their calculation, respectively.

$$CostStartUp_{u,i} = CostStartUp_u \cdot StartUp_{u,i} \quad (4)$$

$$CostShutDown_{u,i} = CostShutDown_u \cdot ShutDown_{u,i} \quad (5)$$

Ramping costs are also positive variable and their calculations are presented hereunder in the equation (6) and (7).

$$CostRampUp_{u,i} \geq CostRampUp_u \cdot \left(Power_{u,i} - Power_{u,i-1}\right) \quad (6)$$

$$CostRampDown_{u,i} \geq CostRampDown_u \cdot \left(Power_{u,i-1} - Power_{u,i}\right) \quad (7)$$

In the current version of the Dispa-SET model all other costs are considered as exogenous parameters.

2.2.3. Constraints

The main constrain of the Dispa-SET model is that supply-demand balance has to be fulfilled for each time step and every zone. This restriction is written in the equation (8) hereunder. As it is written in the equation (8), the sum of all the power produced by all the units presented in the node, including the power generated by the storage units, the power injected from the neighbouring nodes, and the curtailed power from intermittent sources is equal to the load in the node, plus the power consumed for energy storage, minus the load interrupted and the load shed.

$$\begin{aligned}\sum_{u} Power_{u,i} \cdot Location_{u,n} + \sum_{l} Flow_{l,i} \cdot LineNode_{l,n} \\ = Demand_{DA,n,h} + \sum_{r} StorageInput_{s,h} \cdot Location_{s,n} - ShedLoad_{n,i} \\ -LL_{MaxPower_{n,i}} + LL_{MinPower_{n,i}}\end{aligned} \tag{8}$$

Beside this production-demand balance, there are also reserve constraints that must be met in each node. Three types of reserve constraints need to be taken into consideration. Those are: Upward secondary reserve (2U) is a reserve that can be covered by spinning units only; downward secondary reserve (2D) is a reserve that can only be covered by spinning units; and upwards tertiary reserve (3U) that can be covered by quick-start offline units or spinning units. Those constraints, as well as constrains about emission, heat production, heat storage, network and load shedding are presented with high level of detail at the Dispa-SET website [39] and in their technical report [40].

3. The Western Balkans region

3.1. Introduction

The Western Balkans is a political and geographical term coined to refer to Albania and the territory of the former Yugoslavia, expect Slovenia [41]. For the purpose of this Master thesis six countries of the Western Balkan region, which are not European Union (EU) members yet, will be examined using Dispa-SET model. All six of the countries have European Union integration highly on their foreign policy agenda. Before examining power systems of those six countries a short overview of their path towards European Union will be given down below.

3.2. Progress of the European integration of the region

In June 1999 European Union launched the Stabilisation and Association Process, which was the European Union's policy towards the Western Balkans. The aim of this policy is to create progressive partnership and stability in the region, which in the end will result in granting countries full membership status. The Stabilisation and Association Process was even more strengthened at the Thessaloniki Summit in June 2003 and from that point on Stabilisation and Association Agreement represents the legal foundation for relations with the EU [42]. After a period of not so dynamic process of European integration of the Western Balkans, on 5 February 2020 European Commission presented a new enlargement methodology that is applicable on the countries that will start the negotiation process. Countries that have already started a negotiation process would be able to choose if they want to continue with the negotiations under new methodology. The methodology is described as more dynamic, credible and predictable [87].

3.2.1. Albania

Estimated number of inhabitants in Albania on January 1, 2019 was 2 862 427, according to Institute of Statistics [47]. The capital of Albania is Tirana. Albania applied for EU membership on 28 April 2009 and in 2014, under the Greek EU presidency, the country was granted the candidate status [44]. From that moment, Commission suggested opening accession negotiations with Albania several times. In June 2018 the Council agreed upon the creation of path towards accession negotiations with Albania [48]. Despite recommendations, opening of accession negotiations did not happen during the last meeting of the European Council 17-

18 October 2019 and it decided to revert to the issue of enlargement before the EU-Western Balkan summit in May 2020, which will take place in Zagreb, Croatia [49]. This decision was commented by the Commission chef Jean-Claude Juncker and EU Council president Donald Tusk as a "historic mistake" [50]. Country became part of the North Atlantic Treaty Organisation (NATO) in 2009.

3.2.2. Bosnia and Herzegovina

The last available report from the Agency for Statistics of Bosnia and Herzegovina estimates that there are 3 511 372 inhabitants living in Bosnia and Herzegovina in 2016 [51]. The capital of the country is Sarajevo. Bosnia and Herzegovina is a potential candidate country that negotiated and signed the Stabilisation and Association Agreement in 2008 [44]. The Stabilisation and Association Agreement entered into force on 1 June 2015 [52]. In 2016 county membership application has been submitted. The country made little progress on the road of accession and developments in four fundamental areas. Rule of law and fundamental rights, public administration and economic development have to be implemented urgently as it is stated in the country report by European Parliament for 2018 [53]. The country accession to NATO is under negotiations since 2008.

3.2.3. Montenegro

Montenegro is the smallest nation when it comes about population among the all six examined countries. According to the last report of the estimated number of population carried out by Montenegrin Statistical Office in 2018, Montenegro had 622 227 inhabitants. The capital and the biggest city of the country is Podgorica. Among all the countries in the region Montenegro is in the leading position on its path towards European Union accession [43]. It started its European integration in December 2008. In 2010 it was granted status of candidate country and in June 2012 it opened the accession negotiations [44]. At present, Montenegro has opened 32 of a total of 35 negotiation chapters, and provisionally it has closed three chapters [45]. In the new Western Balkan Strategy published by the Commission is stated that Montenegro could join the EU by 2025 [44]. Montenegro joined the NATO on 5 June 2017 [46]. Despite the ongoing development there is lot of work ahead of Montenegro when it comes when about fighting against corruption and organised crime, respect for the rule of law and media freedom [43].

3.2.4. North Macedonia

According to the Statistical Yearbook of the Republic of North Macedonia for 2019 [54] estimated number of inhabitants is 2 074 502. The capital city of the country is Skopje. The country send the application for EU memberships in 2004 and in December 2005 it was granted status of a candidate country [44]. The long dispute with Greece over the use of name Macedonia resulted in situation that North Macedonia was not able to open accession negotiations [55]. The issue was successfully solved when the Prespa agreement on the country's new name – North Macedonia enter in the force in 2019 [44]. This was a huge step forward for European and Atlantic integration of this nation. It is expected that soon North Macedonia will become 30th member of NATO [83]. Discussion about the opening of accession negotiations with North Macedonia during the last meeting of the European Council 17-18 October 2019 did not have positive result and it is expected that the issue of the EU enlargement will be discussed before the EU-Western Balkan summit in May 2020 [49].

3.2.5. Serbia

Statistical Office of the Republic of Serbia [56] estimates that in 2018 there were 6 982 604 inhabitants living in Serbia. Belgrade is the capital and the biggest city of the country and region. Serbia started their application for EU membership in December 2009 and in March 2012 it was granted status of candidate country [44]. Process of accession negotiations started in 2014 when the two chapters were opened. Till today, Serbia opened 18 out of 35 chapters and it closed two chapters [57][86]. Montenegro and Serbia are the only countries out of the six examined ones to have opened accession negotiations with the EU. The EU Commission published new Western Balkans strategy in 2018 where it was stated that the country could enter the EU by 2025, just like Montenegro. While there is a long way to go for Serbia towards the EU membership, the dialogue and normalization of the relations with Kosovo is seen as one of the most serious issues before entering the EU.

3.2.6. Kosovo[1]

Kosovo has 1 798 506 inhabitants, based on the Statistical Yearbook of the Republic of Kosovo for 2018 [58]. Kosovo unilaterally declared its independence from Serbia in 2008 and just like Bosnia and Herzegovina has a status of a potential candidate for EU accession [44]. In the

[1] UN Security Council Resolution 1244 (1999).

region Serbia and Bosnia and Herzegovina have not recognized Kosovo's independence, while among EU Member States Greece, Cyprus, Romania, Slovakia and Spain are the ones that have not recognized independence of Kosovo [59]. The Stabilisation and Association Agreement, signed on 26 February, went into force on 1 April 2016 [60]. Although, the country has status of potential candidate, in order for Kosovo to become full member of the EU, dialogue and stabilization of relations with Serbia must occur.

3.3. The Western Balkans power systems

The Wester Balkans region is facing significant energy challenges because of the need for decarbonised energy generation and infrastructure damage during the 1990s [61]. Most of the power plants in the Wester Balkans are in need of improvement of their production efficiency [62]. Main fuel that has been used for energy production in Wester Balkans is coal, which has harmful effect on human health and in general there is a need for diversification of energy production. Together with lignite, hydro energy is intensively used for energy production in Western Balkans. Together those two types of energy resources amounts to more than 90% of power generation [37].

Those countries will need to adopt and implement regulations and EU directions, during the European integration process and when they become members [63]. Many researches show that this region has high potential in generation electricity from Renewable energy resources, mainly wind, solar and biomass [64-66].

A brief description of Western Balkans countries' power systems will follow with main focus on energy mix and type of power plants that exist in the countries.

3.3.1. Power system of Albania

History of Albanian Electric Power System started in 1957 [68]. Albanian Power System is highly dependent on hydropower. In 2015 its installed capacity was 1448 MW, out of which 1 350 MW are from hydropower plants and 98 MW are from thermal power plants [69]. Hydrological conditions plays significant role in Albanian Power system since more than 95% of electricity generation is covered by hydropower plants and because of this high dependency on hydropower plants hours-long blackouts happened in 2005 and 2006 due to low water flow [67]. Drin, the largest river in Albania, hosts the biggest power plants in the country: Fierzë with 500 MW, Komani with 600 MW and Vau I Dejës with 250 MW of installed capacity [70].

Fierze has four aggregates with installed capacity of 125 MW, Koman has four aggregates, as well, all of them with 150MW installed capacity and Vau I Dejës has five aggregates with 50MW installed capacity each.

Albanian power system is presented in the figure 1.

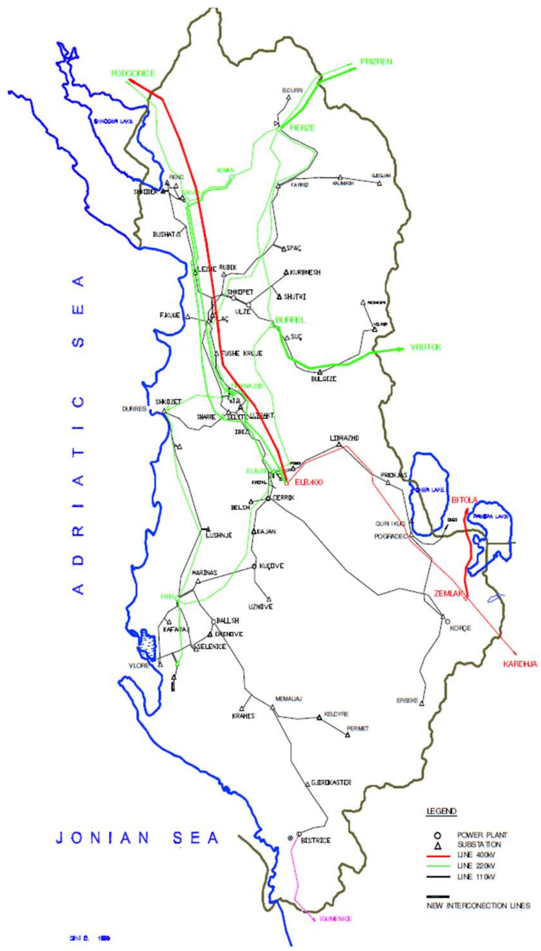

Figure 1. Albanian Power System [68], source OST

From 1971 Albanian Power System is connected with Montenegrin Power System via 220kV line Vau Dejes-Podgorica and there is one more interconnection 400kV line Tirana – Podgorica. From 1974 Albania is connected with Greece via 154kV line Bistrica-Igumenica. In 1985 new 400kV line Elbasani-Kardia was built between Albania and Greece and in 1998 Fierza-Prizren 220kV line between Albania and Kosovo was finished [68]. In the future 400kV line with North Macedonia is expected to be constructed.

Generation of electricity by source in Albania is presented in the Figure 2. for the period from 1990-2017.

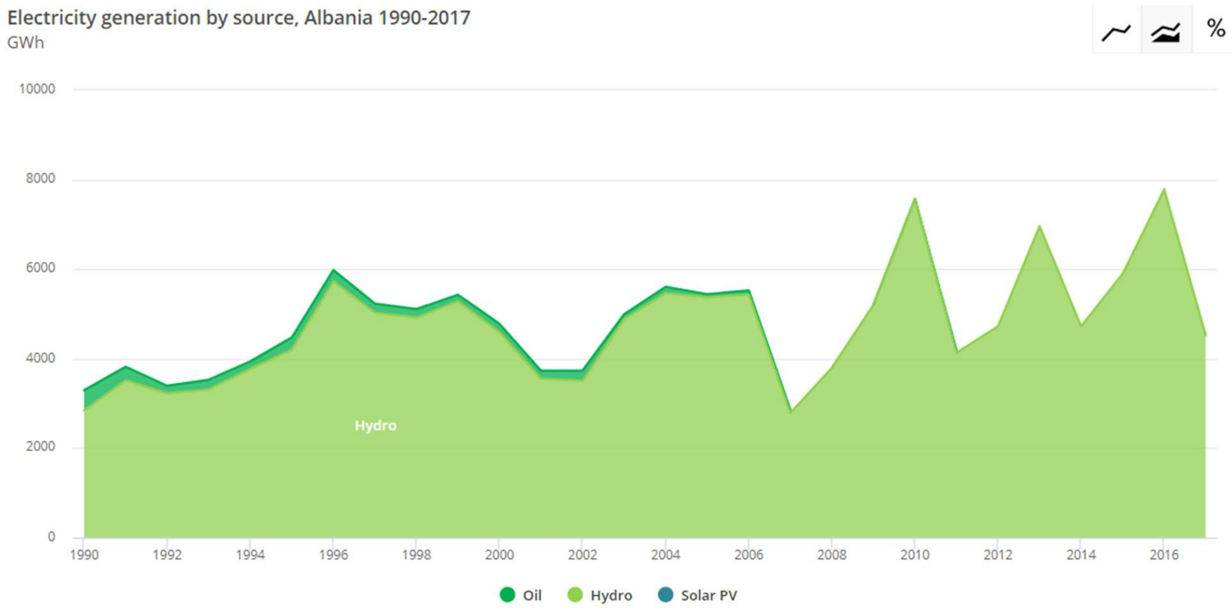

Figure 2. Electricity generation in Albania, source IEA

Net generation given in the report for 2015 [69] was 1 243 000 MWh higher than the average generation in period 1985-2015 and it equals 5 865 670 MWh, which was completely covered by hydropower plants. In the same report it can be seen that total consumption for electricity is increasing and in 2015 it equals 7 265 525 MWh, including customers in the unregulated market.

3.3.2. Power system of Bosnia and Herzegovina

Electricity generation in Bosnia and Herzegovina is based on national resource and it is generated by thermal and hydropower plants.

Total installed capacity of the country is 3 665 MW, out of which 2 106 MW are hydropower plants and 1 559 MW are from five thermal power plants. Only 1.4 % of the total electricity generation in the country in 2009 was covered by small hydropower plants [71]. Hydro potential of Bosnia and Hercegovina is more than 6 000 MW but only one third has been used till today [72]. The biggest hydropower plants in the country include power plants: Čapljina with 430 MW, Višegrad with 315 MW, Salakovac with 210 MW, Jablanica with 180 MW, Trebinje I with 176 MW and Rama with 160 MW. In the country five thermal power plants are operating: Tuzla with 723 MW, Kakanj with 450 MW, Gacko with 300 MW, Stanari with 300 MW and Ugljevik with 300 MW.

Generation of electricity in Bosnia and Herzegovina by source is presented in the Figure 3. for the period from 1990-2017. In 2018, total electricity generation in Bosnia and Herzegovina was 17 873 GWh. Most of the electricity was generated in thermal power plants, 10 954 GWh to be exact, while hydropower plants produced 35% of total production, i.e. 6 300 GWh. Total consumption in 2018 was 13 294 GWh [73].

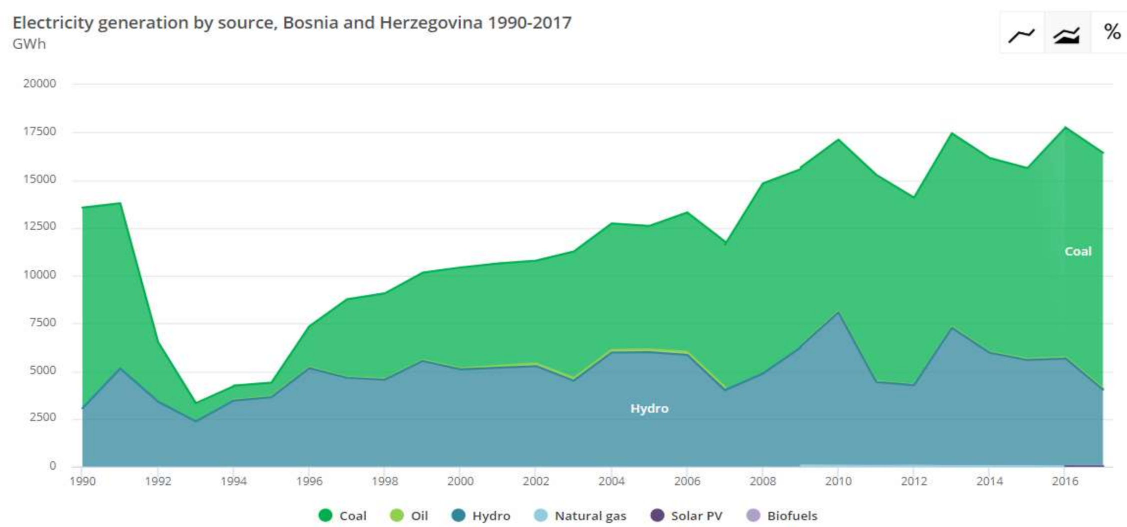

Figure 3. Electricity generation in Bosnia and Hercegovina, source IEA

Since country is a net exporter of electrical energy, good interconnection with the neighbouring counties has a significant role. That is why the system has 400 and 220 kV lines with all its neighbours, i.e. Croatia, Serbia and Montenegro, as it can be seen in the Figure 4.

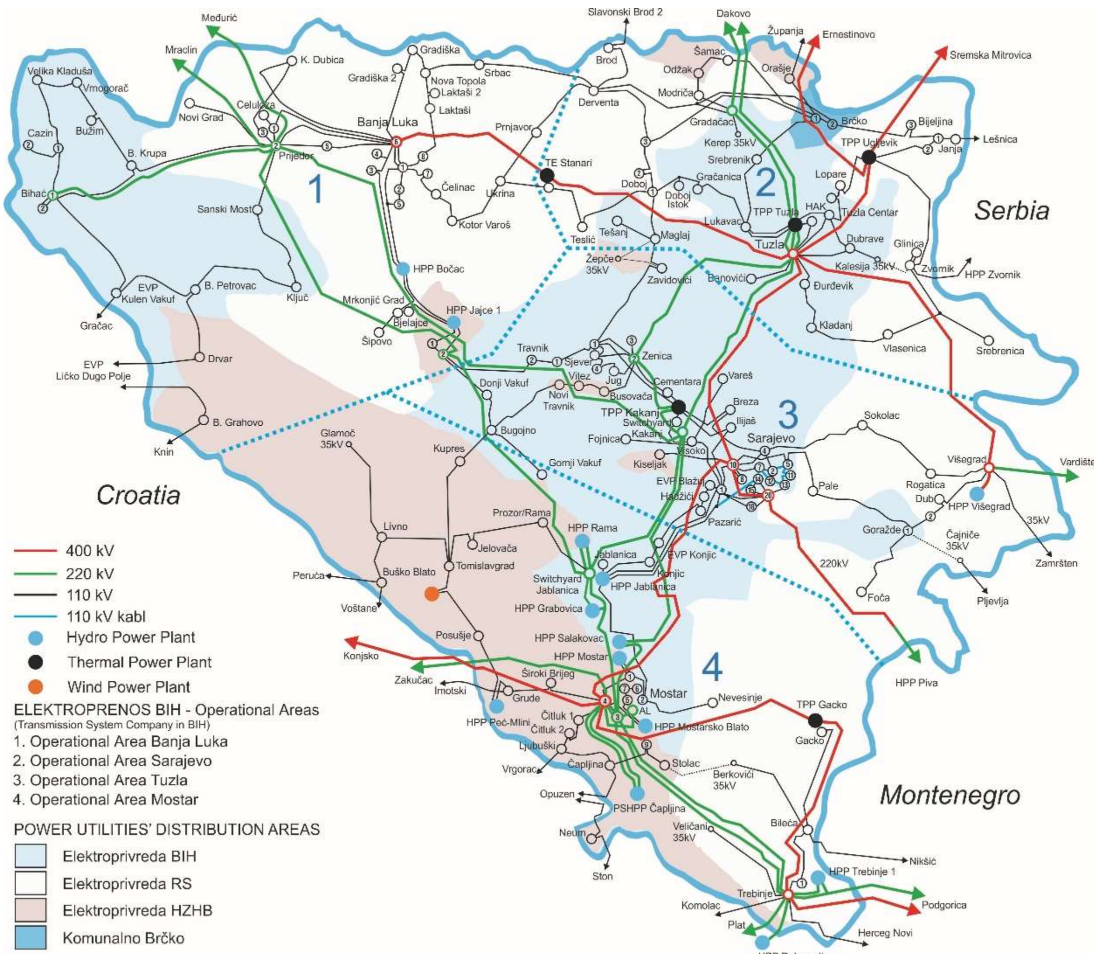

Figure 4. Power system of Bosnia and Herzegovina, source: derk.ba

3.3.3. Power System of Montenegro

Power System of Montenegro is the smallest power system in the region. Power generation is manly based on use of hydro and thermal power. In recent years several wind power plants have been installed.

Total installed capacity of the country is 874 MW [76]. The majority of energy is produced at the Piva hydropower plant, Perućica hydropower plant and Pljevlja coal-fired thermal power plant [75]. Hydropower plant Perućica started its operation in 1960 and it has 7 aggregates with total installed capacity of 307 MW [76]. Hydropower plant Piva was built in 1976 and its installed capacity is 342 MW. Thermal power plant Pljevlja started its operation in 1982 and after a reconstruction its installed capacity is 225 MW.

Montenegro has a good interconnection with its neighbours. Power system of Montenegro is presented in the Figure 5.

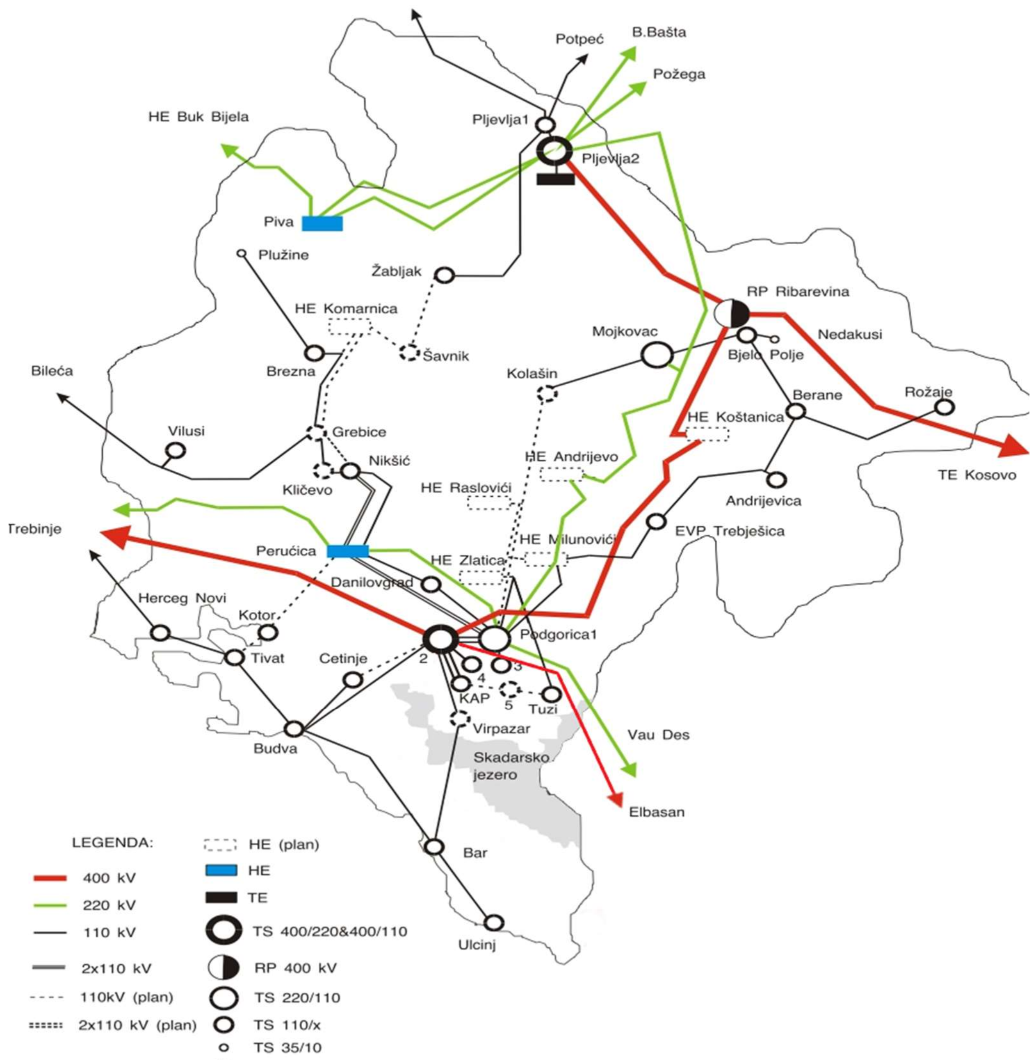

Figure 5. Power System of Montenegro, source CGES

With power system of Serbia it is connected via 220 kV line, Pljevlja-Bajina Bašta and Pljevlja-Požega, and one 110 kV, connecting Pljevlja – Potpeć. With Kosovo Montenegro has one 400 kV line, connecting Ribarevine-Peć. Montenegro and Bosnia and Herzegovina are connected with one 400 kV line, connecting Podgorica-Trebinje, two 220 kV lines, connecting power plant Perućica-Trebinje and power plant Piva-Sarajevo, and two 110 kV lines connecting Herceg Novi-Trebinje and Vilusi-Bileća. Albanian and Montenegrin power systems are connected by 400 kV line Podgorica-Tirana/Elbasan and 220 kV line between Podgorica and Vau Dejës [77].

Generation of electricity by source for the period from 2005-2017 in Montenegro is presented in the Figure 6.

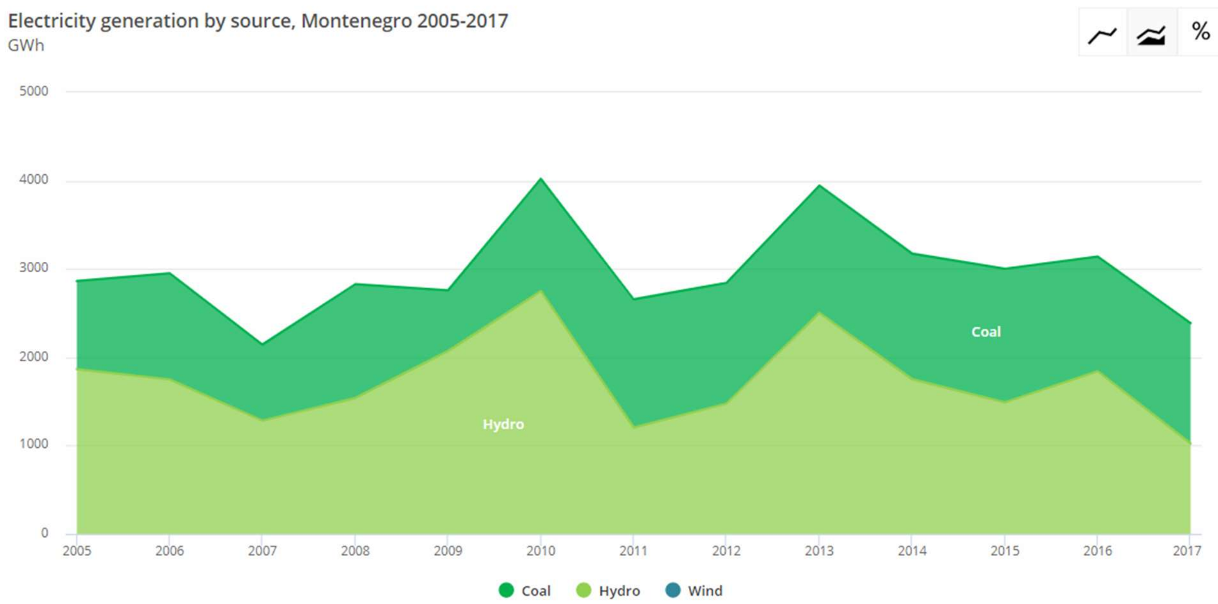

Figure 6. Electricity generation in Montenegro, source IEA

Based on report of energy balance for year 2018 [74], Montenegrin power system generated 3 787 GWh. The most electricity was generated by hydropower plants, including small power plants, i.e. 2 220 GWh to be exact, thermal units generated 1 400 GWh and there was 167 GWh produced by wind power plants. Consumption in 2018 in Montenegro was 3 479 GWh.

3.3.4. Power system of North Macedonia

Like in the case of already examined countries, electricity generation in North Macedonia is mainly based on use of coal and hydropower.

Based on the Annual Report of the Energy and Water Services Regulatory Commission of North Macedonia for 2018 [78], total installed capacity of the electricity generation plants is 2 076 MW. Most of it represents thermal power plants, i.e. 1 034 MW. Power system of North Macedonia has three thermal power plants, which have important role in covering the base load of the country's demand. The greatest producing capacity in North Macedonia is thermal power plant Bitola with its three blocks and total installed capacity of 699 MW [79]. There is also a thermal power plant Oslomej near Kičevo with installed capacity of 125 MW and thermal power plant Negotino with installed capacity of 210 MW that is used as cold reserve. Electricity is generated in 10 hydropower plants with total installed capacity if 586,65 MW. System of three hydropower plants including power plants Vrutok, Vrben and Raven has installed capacity of 200 MW. Other significant hydropower plants are Tikveš, with installed capacity of 113 MW and Kozjak, with installed capacity of 82 MW. Based on the report [78] installed capacities also include wind power plants, photovoltaic power plants, small hydropower plants, biogas thermal power plants and combined heat and power plants.

Transmission network of North Macedonia is given in the Figure 7.

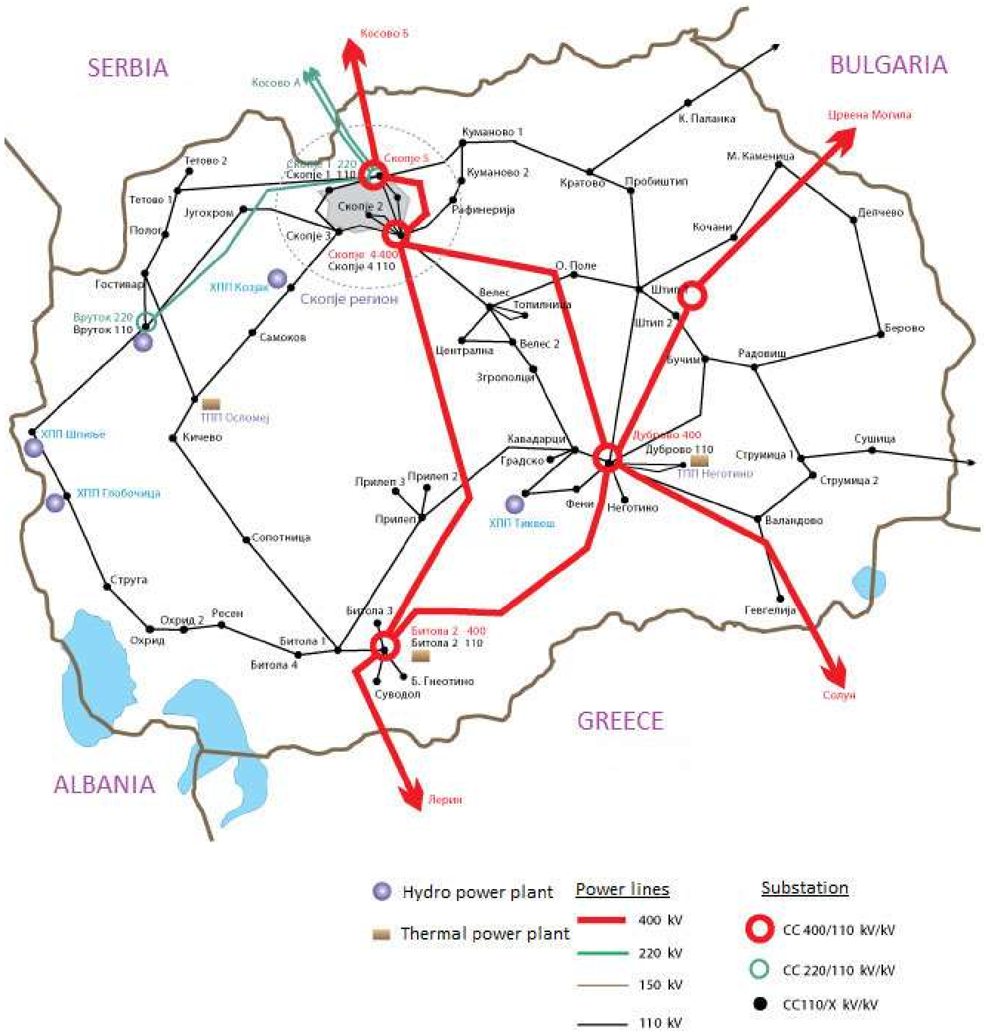

Figure 7. Power System of North Macedonia, source ERC

North Macedonia is interconnected with its neighbours with 400 kV lines, except with Albania. Interconnection with Albania is planned via new 400 kV line Bitola-Elbasan and it is expected that it will be finished in 2023 [78]. North Macedonia is connected with 400 kV lines with Greece connecting Bitola-Meliti and Dubrovo-Thessaloniki. With Serbia there is 400 kV line connecting Štip-Vranje and 400 kV line Skopje-Ferizaj (Uroševac), which connects Kosovo and North Macedonia [78].

Generation of electricity by source for the period from 1990-2017 in North Macedonia is given in the Figure 8.

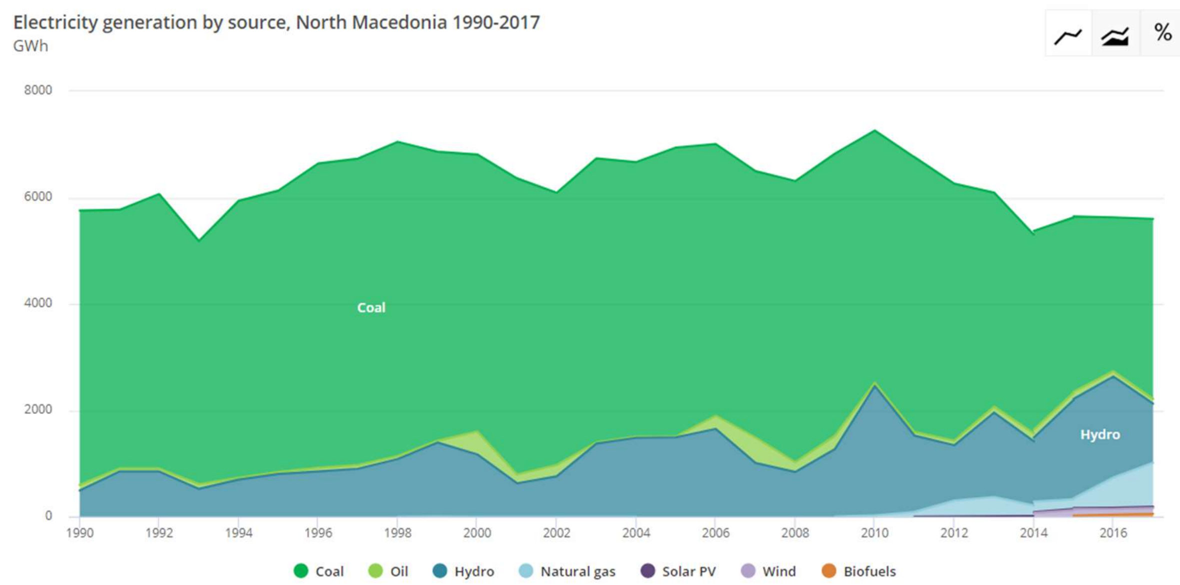

Figure 8. Electricity generation in North Macedonia, source IEA

Based on the report [78], in 2018 North Macedonia generated in total 5 447 GWh which is 1.29 % higher than in 2017. Most of it was generated by thermal power plants, 2 703 GWh to be exact while hydro power plants generated 1 460 GWh. Consumption in North Macedonia in 2018 was 6 365 GWh.

3.3.5. Power system of Serbia

Power system of Serbia is the biggest and the most robust in the region. Electricity generation is based on hydropower plants and coal-fired power plants.

In the Annual report for 2018 Energy Agency of the Republic of Serbia [79] stated that total installed capacity of Serbian power system is 8 088 MW, including small power plants of independent producers. Dominant electricity producer in Serbia PE EPS is the owner of 95.3 % of installed capacities in Serbia. Thermal production units have installed capacity of 4 386 MW, while 2 936 MW are installed in hydropower plants. Beside them electricity is generated with combined heat and power plants, wind power plants and in 17 small hydropower plants. The biggest installed hydropower plants are Đerdap 1 and 2 with total installed capacity of 1 369 MW and they represent 18% of energy production. List of bigger power plants in Serbia includes: hydropower plant Bajina Bašta with 420 MW, hydropower plant Vlasina with 129 MW and hydropower plant Mali Zvornik with 110 MW of installed capacity. Serbian power system also has reversible hydropower plant which is part of hydropower plant Bajina Bašta and its capacity is 614 MW [81]. Thermal power plants Nikola Tesla A and B have installed capacity of 2 787 MW and they have important role in the power system of Serbia since they represent 50% of electricity generation. Thermal power plants Kostolac A and B are also important for normal function of the Serbian power system, since their installed capacity is 921 MW.

Transmission network of Serbian power system is presented in the Figure 9.

Figure 9. Power System of Serbia (without Kosovo), source EMS

Serbia as regional power centre has a good connection with its neighbours. With most of them it is connected via 400 kV transmission lines. There are 400 kV transmission lines between Serbia and Bosnia and Herzegovina, Croatia, Hungary, Romania, Bulgaria, North Macedonia and Kosovo. With Montenegro, Serbia is connected via 220 kV and 110 kV lines. Serbia also has 220 kV lines with Bosnia and Herzegovina and Kosovo.

Generation of electricity in Serbia by source for period from 1990-2017 is presented in the Figure 10.

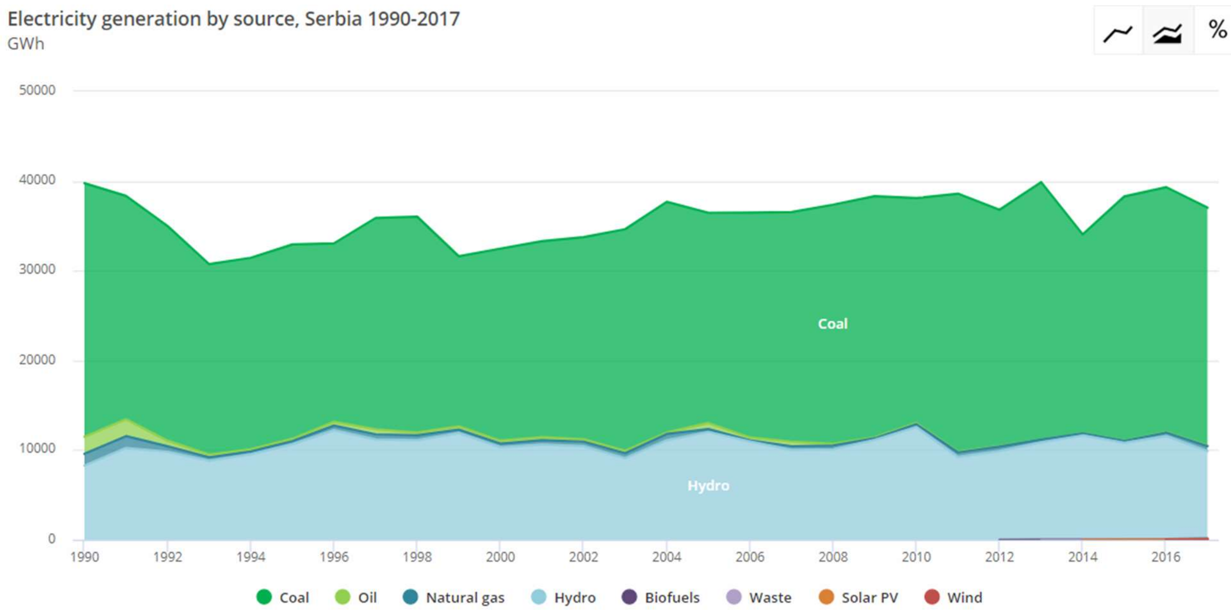

Figure 10. Electricity generation in Serbia, source IEA

Based on the Annual report for 2018 Energy Agency of the Republic of Serbia [79], power system of Serbia generated 34 950 GWh, out of which 22 954 GWh were generated in thermal power plants and 11 031 GWh were generated in hydropower plants. Final consumption for 2018 was 29 660 GWh.

3.3.6. Power system of Kosovo

Kosovo is Western Balkans country that has abundant resources of high calorific coal. It also possesses the fifth largest global reserves of coal [82]. With no surprise main fuel that is used for generation of electricity in Kosovo is coal.

Based on the annual report from 2017 by Energy Regulatory Office of Kosovo [83], the country had an installed generating capacity of 1 560 MW but the operating capacity is significantly lower and it equals 1 037 MW. The majority of production capacity is covered by thermal power plants with 92.5% lignite, while the rest is covered by hydropower, wind and solar power plants. Kosovo with its production has significant resources to cover domestic need for energy but also to be an exporter of energy. The biggest generating units in the country are Kosovo A and Kosovo B thermal power plants, with 800 and 678 MW installed capacity, respectively. Both of the power plants are more than 40 years old and reconstruction or change is needed and that is the reason that the plants' capacities are lower than the installed.

Hydropower plants, wind and photovoltaic power plants represent in total 77.5 MW of production capacities.

Transmission network of power system of Kosovo is presented in the Figure 11.

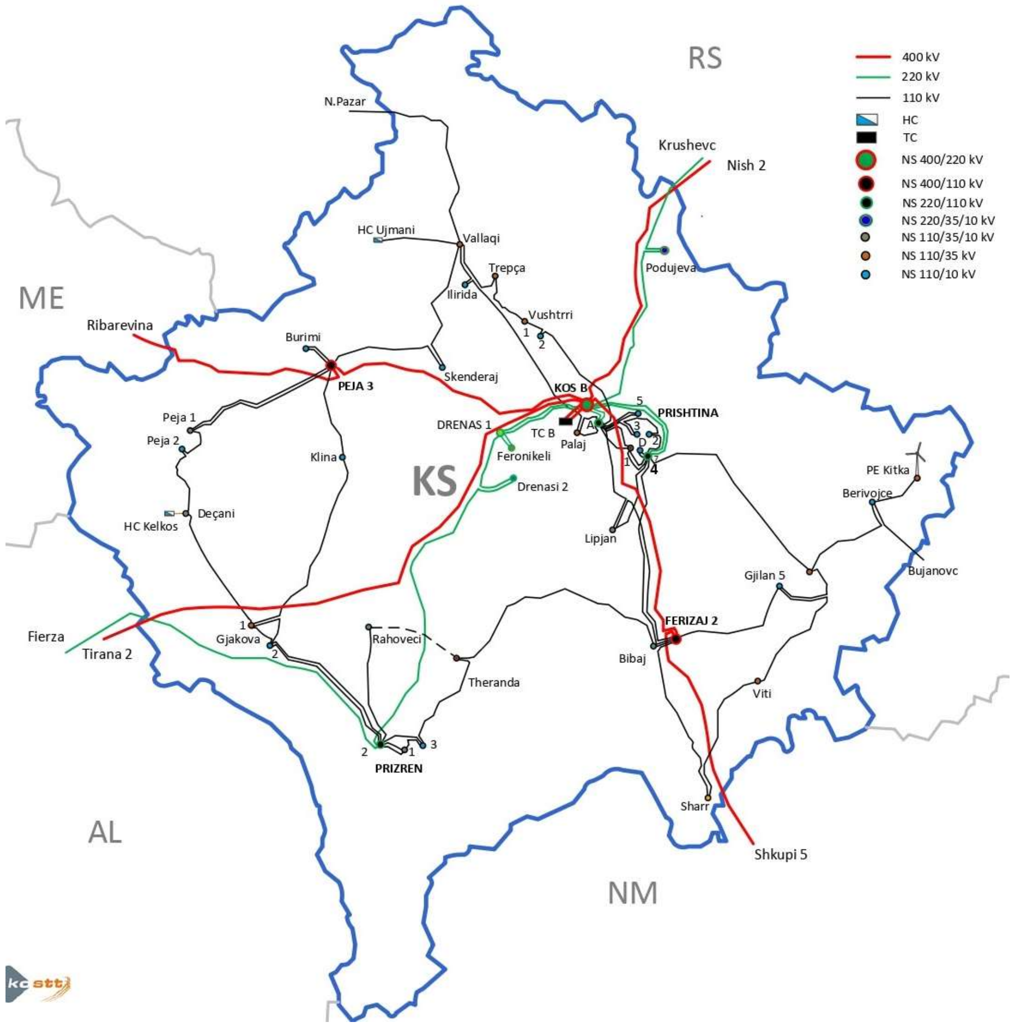

Figure 11. Power System of Kosovo, source KOSTT

Kosovo has good interconnection with countries in the region. High voltage transmission power lines exist with all neighbouring countries. There are 400 kV lines connecting Kosovo with Albania, Montenegro, North Macedonia and Serbia. Kosovo is connected with Albania and Serbia also with 220 kV line and with Serbia it has two more lines of 110 kV.

Generation of electricity in Kosovo by source for period from 2000-2017 is presented in the Figure 12.

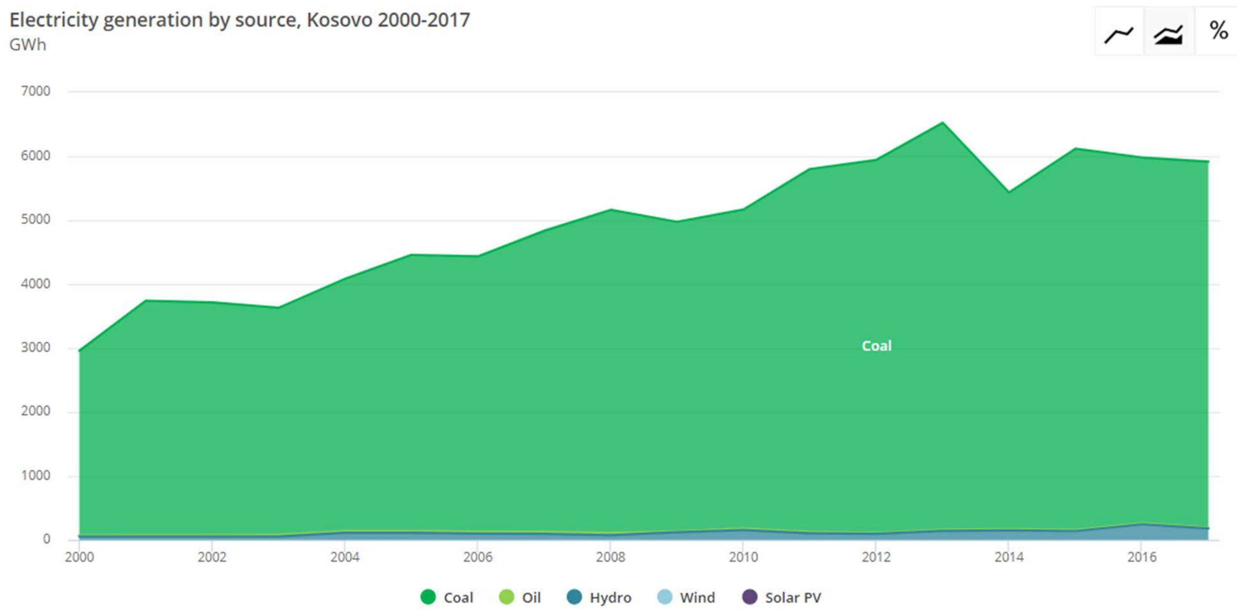

Figure 12. Electricity generation in Kosovo, source IEA

As it is stated in the annual report from 2017 by Energy Regulatory Office of Kosovo [83], total production of electricity was 5 300 GWh and it was by 9,01% decreased from the level in 2016. The total demand in 2017 was 5 686 GWh and it was increased by 6,43% from 2016 level.

4. Dispa-SET model simulation scenarios

4.1. Introduction

As it has already been explained in the chapter 3.2. European integration of the region is set as a main goal in the foreign policy of the six countries that are examined in this Master thesis. Countries that have aspiration to become European Union members will need to adopt European Union legislation framework, which includes numbers of different legislations and regulations, directives and decisions in different spheres, from human rights to climate strategies.

Key targets of the of the European Union energy and climate strategy are presented in 2020 climate and energy package and 2030 climate and energy framework [84]. The idea behind these targets is reduction of greenhouse gas emissions, as well as increase in both, the share of renewable energy and energy efficiency. Achieving those targets towards a low-carbon economy will create many benefits, such as increase in European Union energy security, competitiveness and sustainability and at the same time this green growth will create more job opportunities [84].

The 2020 climate and energy package represents a set of binding legislations, which will ensure that the European Union will meet its climate and energy targets for the year 2020 [84]. Key targets in this package suggest that 20% of energy should come from renewables, 20% cut in greenhouse emissions from the 1990 levels and 20% improvement in energy efficiency. In order for European Union region to meet the target of 20% of energy coming from renewables different targets are set for different countries, based on their potential to produce energy from renewables, i.e. from 10% in Malta to 49% in Sweden but in all the EU share of the renewable energy must be 20%.

The 2030 climate and energy framework was adopted by the European Council in October 2014 and it includes targets and objectives for the period from 2021 to 2030 [84]. The targets for renewables and energy efficiency were revised upwards in 2018 [84]. Key targets for 2030 include at least 32% share of renewable energy, at least 32.5% improvement in energy efficiency and at least 40% cuts in greenhouse emissions from the 1990 level.

Inspired by the EU binding targets in share of the renewable energy that were presented in 2020 climate and energy package and 2030 climate and energy framework, three alternative simulation scenarios for Western Balkan countries have been created.

Those three different scenarios that have been created are the following ones:

- Reference scenario for the year 2015,
- Scenario for the year 2020,
- Scenario for the year 2030.

The year 2015 has been chosen as a reference year due to Dispa-SET data availability. The reference scenario was run without any changes in the power systems. The results from the simulations for the reference year were used as a base values on which the changes for the other two scenarios have been calculated. For this scenario following 7 subcases have been simulated:

1. The Western Balkans power system in integrated mode with existence of power exchange with the neighbouring countries,
2. Power system of Albania as part of an integrated system but simulated alone,
3. Power system of Bosnia and Herzegovina as part of an integrated system but simulated alone,
4. Power system of Montenegro as part of an integrated system but simulated alone,
5. Power system of North Macedonia as part of an integrated system but simulated alone,
6. Power system of Serbia as part of an integrated system but simulated alone,
7. Power system of Kosovo as part of an integrated system but simulated alone.

Scenario for the year 2020 was created on the basis of EU 2020 climate and energy package. The main idea of this case is to expand installed capacity of power systems of the region so that the installed power capacities coming from renewables in the region would represent 20%. Values from the reference scenario were taken as the base values.

Scenario for the year 2030 is inspired by the suggestions given in the 2030 climate and energy framework. Capacities of power systems of the region have been expanded by adding new renewable capacities. The goal was to add capacities so that the renewables would represent 32% of the total installed capacity. Values from the reference scenario were taken as the base values.

Last two scenarios, i.e. scenarios for 2020 and 2030, examine the expansion of the Western Balkans power systems by adding renewables. Each of those two scenarios have 7 subcases that simulate:

1. Expanded Western Balkans power system in integrated mode with existence of power exchange among the six countries but without power exchange with the neighbouring countries,

2. Expanded power system of Albania in islanded mode, i.e. with no power exchange with any of the neighbouring countries,
3. Expanded power system of Bosnia and Herzegovina in islanded mode, i.e. with no power exchange with any of the neighbouring countries,
4. Expanded power system of Montenegro in islanded mode, i.e. with no power exchange with any of the neighbouring countries,
5. Expanded power system of North Macedonia in islanded mode, i.e. with no power exchange with any of the neighbouring countries,
6. Expanded power system of Serbia in islanded mode, i.e. with no power exchange with any of the neighbouring countries,
7. Expanded power system of Kosovo in islanded mode, i.e. with no power exchange with any of the neighbouring countries.

The Renewable Energy Snapshots carried out by United Nations Development Programme (UNDP) [85], were an additional motivation to increase the share of renewables in Western Balkans. The Snapshots show that this region has a huge potential when it comes about generation from renewable sources but at the same time percentages of renewables contributing to energy mix of the six examined countries in 2014 were really low. Percentages go as low as 0.5 in case of Serbia till 4.2 in case of North Macedonia, which represents the highest percentage of renewables in the Western Balkans in 2014 [85].

Explanation of simulations results of power systems in Western Balkans for 2015, 2020 and 2030 will follow. The data which was used for simulation is provided by the Dispa-SET model.

4.2. Reference year

Year 2015 was taken as a reference case in this Master thesis due to data availability. Simulation for 2015 was run without changing input data that is available in Dispa-SET model for Western Balkans region. Following subchapters will describe the results after optimization of the power systems. For 2015 seven simulations were carried out. The first simulation includes all six countries and their power exchange with the neighbouring countries while the rest of the simulations are carried out for each country individually.

4.2.1. Reference scenario: the Western Balkans

Total installed capacity of the region in 2015 is 15 878.6 MW. After the simulation it can be concluded that the main types of power plants used for the electricity generation are hydropower and lignite. Coal sums up to 7 419 MW, hydropower 7 796 MW, gas 353 MW, oil 98 MW and small hydro 213 MW of the total installed capacities. As it can be seen in the figure 13, power plants that use water and lignite for generation of electricity represent 49% and 47% respectively, while renewable energy in the whole region represents just 1.4% and it is 100% covered by the small hydropower plants.

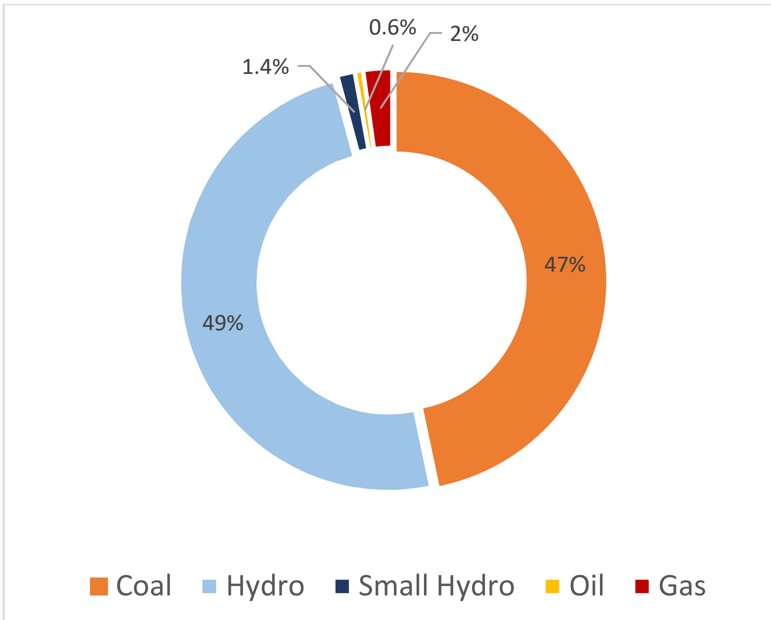

Figure 13. Generation capacities of the Western Balkans for year 2015, source author's work

As it can be seen in the figure 14. electricity demand of the Western Balkans region was the highest during the winter months, which can be explained by the fact that the electricity is intensively used for heating in the region. The lowest demand for energy generation in the whole region was on May 4 and it equals 5 045 MW, while the highest level was on December 31 and it equals 13 514 MW.

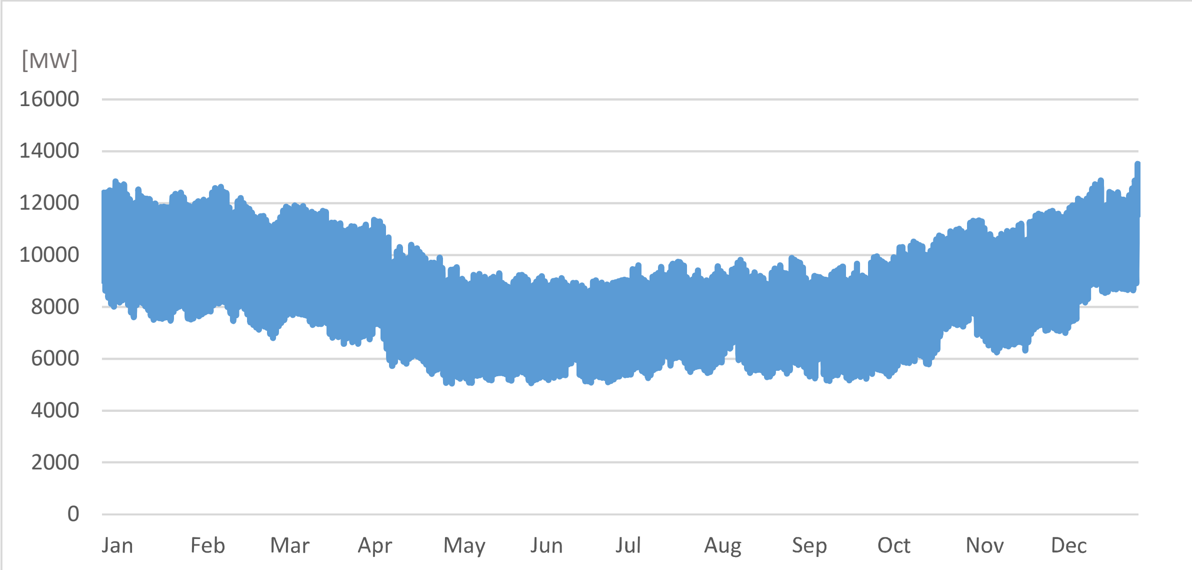

Figure 14. Power demand in the Western Balkans for year 2015, source author's work

After the simulation for 2015 the average value of total power system costs for the whole region of Western Balkans was 170 672 EUR.

Results after the simulation show that the total energy generated of the integrated Western Balkans region is 76 127 GWh. The most energy in 2015 in this region was generated by power plants that burn lignite, i.e. 47 573 GWh. Hydropower plants, including small hydropower plants, generated 28 554 GWh. In 2015, there are no installed capacities that use energy coming from the Sun, wind and biomass for electricity generation and that is why they do not contribute to the energy mix.

4.2.2. Reference scenario: Albania

According to data provided by Dispa-SET model, in 2015 the total installed capacity of Albanian power system is 1 895 MW. Main type of energy used for electricity production in Albanian power system is hydropower. In the figure 15. Generation capacities of Albanian power system are presented. Out of 1 895 MW of the total installed capacity, 1 713 MW is hydropower which accounts 90.4% of the whole system. Beside hydropower there is a combined cycle unit with installed capacity of 98 MW that runs on oil. Renewable sources are 100% covered by the small hydropower plants that amount to 84.64 MW, i.e. just 4.5% of the total installed capacity.

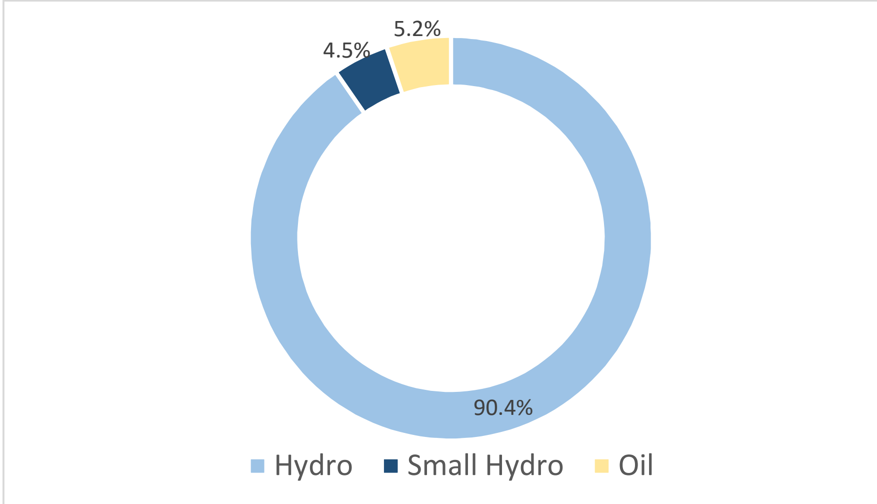

Figure 15. Generation capacities of Albania for year 2015, source author's work

Demand of the Albanian power system is presented in the figure 16. The lowest level of demand in 2015 happened on February 18, when it was 397 MW. The maximum demand happened on December 31 and it was 1 717 MW.

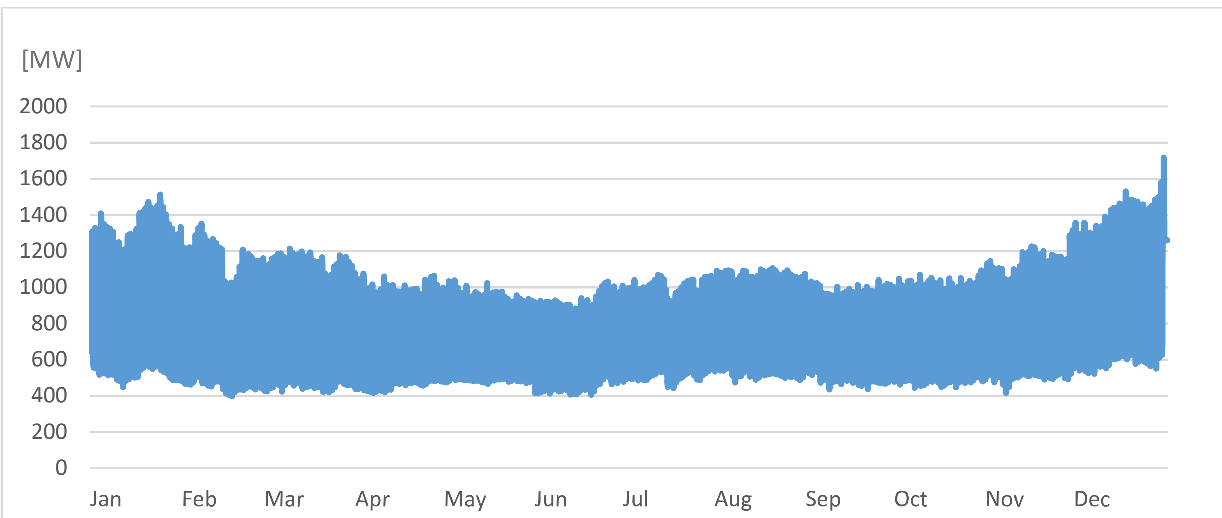

Figure 16. Power demand in Albania for year 2015, source author's work

Results after the simulation show that the total energy generated in Albania is 6 926 GWh. Hydropower plants, including small hydropower plants, were mainly used for electricity generation and together they generated 6 774 GWh. Unit that runs on oil contributed to the Albanian energy mix with 152 GWh. In 2015, there are no installed capacities that use energy coming from the sun, wind and biomass for electricity generation and that is why they do not contribute to the Albanian energy mix.

4.2.3. Reference scenario: Bosnia and Herzegovina

Power system of Bosnia and Herzegovina is the second largest in the region and in 2015 its installed capacity is 3 622 MW. Electricity could be generated in hydropower plants or coal burning power plants, as it is shown in the figure 17. Out of 3 622 MW of the total installed capacity hydropower plants amount to 2 038 MW, while 1 534 MW of the total installed capacity are covered by the thermal power plants that burn lignite. In percentages they represent 56.3% and 42.3% of the total installed capacities, respectively. Only 1.4% represent generation coming from the renewable sources, i.e. 50.6 MW of the total installed capacity.

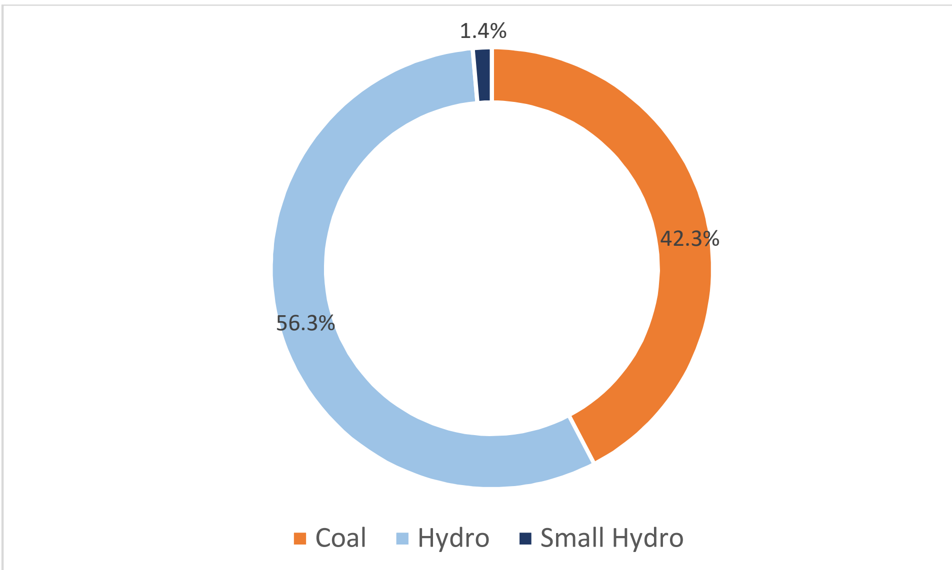

Figure 17. Generation capacities of Bosnia and Herzegovina for year 2015, source author's work

Demand on an hourly basis for Bosnia and Herzegovina is presented in the figure 18. Generation is slightly lower during summer months. The minimum value of energy demand was recorded during April 30 and it was 858 MW. The maximum happened during the winter, on December 31, and it equals 2 105 MW.

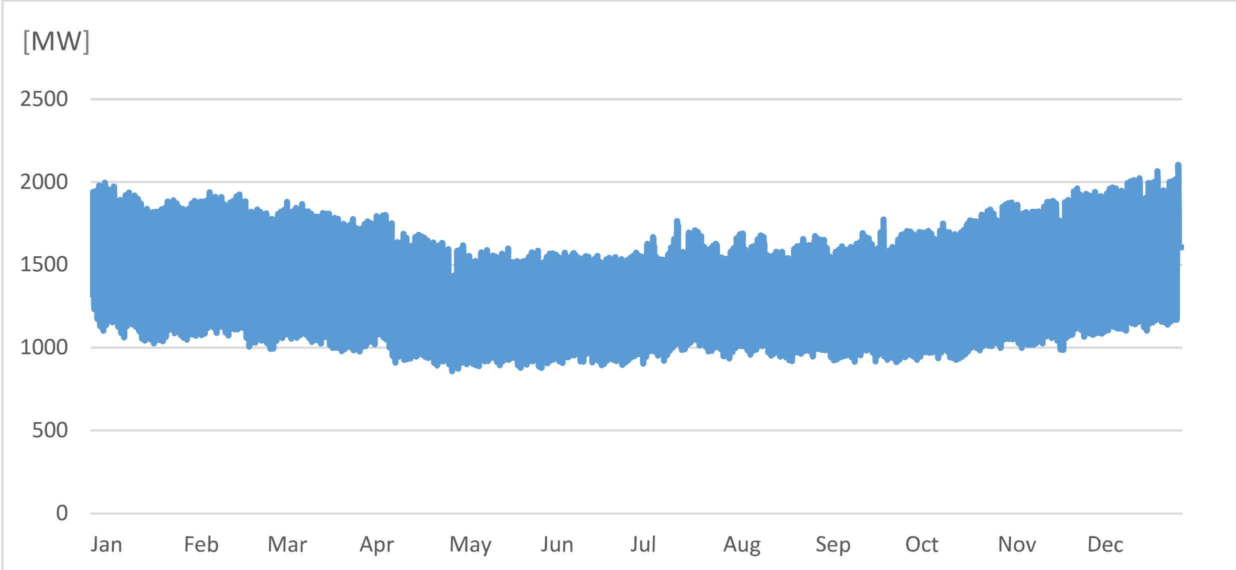

Figure 18. Power demand in Bosnia and Herzegovina for year 2015, source author's work

The total energy generated in the power system of Bosnia and Herzegovina is 12 365 GWh. The most energy in 2015 in Bosnia and Herzegovina was generated by hydropower plants, including small hydropower plants, and it amounts to 6 597 GWh. The rest of energy, i.e. 5 767 GWh was generated in thermal power plants that burn lignite. In 2015, there are no installed capacities that use energy coming from the sun, wind and biomass for electricity generation and that is why they do not contribute to the energy mix of Bosnia and Herzegovina in 2015.

4.2.4. Reference scenario: Montenegro

The power system of Montenegro is the smallest in the region. Installed capacity of Montenegrin power system in 2015, according to the Dispa-SET available data, was 892 MW. As it was the case with many countries in this region, two main types of fuel used for the electricity generation are water and coal. Generation capacities of Montenegro are presented in the figure 19. Hydropower has the installed capacity of 670 MW, which represents 75.1% of the total installed capacity, while coal has the installed capacity of 210 MW, which represents 23.6% of the total installed capacity. Renewable sources are only presented in the form of small hydropower plants, which total capacity amounts to 12 MW that is just 1.3% of the total installed capacity of Montenegrin power system.

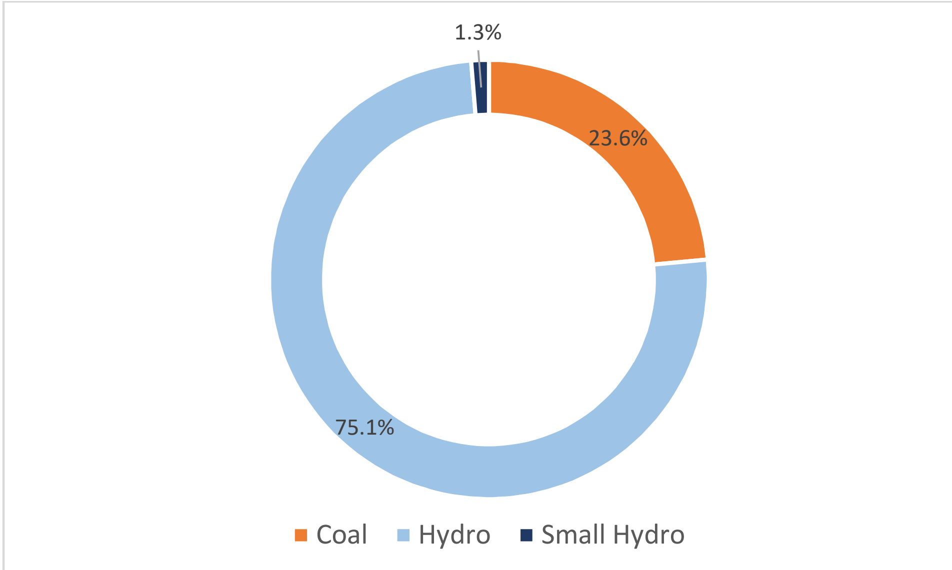

Figure 19. Generation capacities of Montenegro for year 2015, source author's work

Power demand in Montenegro on an hourly basis for 2015 is presented in the figure 20. The minimum power used for generation happened on August 31 and it was 210.7 MW. The maximum power demand occurred on July 22 and it equals 583 MW.

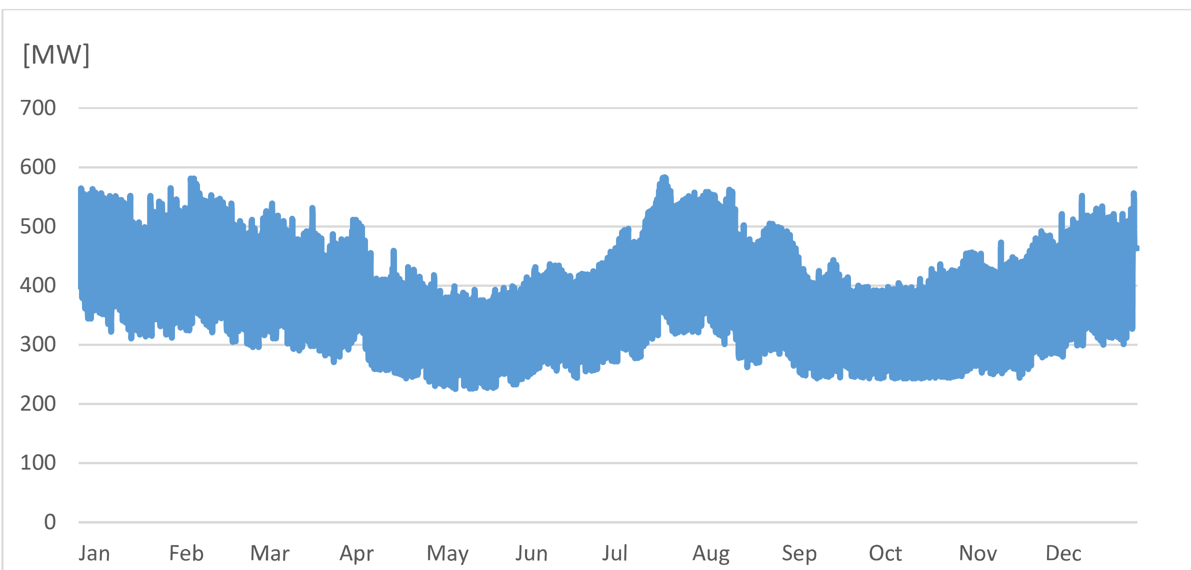

Figure 20. Power demand in Montenegro for year 2015, source author's work

Montenegrin power system generated 3 237 GWh of energy. The most energy in 2015 in Montenegro was generated by hydropower plants, including small hydropower plants, and it amounts to 1 680 GWh. The rest of energy, i.e. 1 556 GWh was generated in thermal power plants that burn lignite. In 2015, there are no installed capacities that use energy coming from the sun, wind and biomass for electricity generation and that is why they do not contribute to the energy mix of Montenegro in 2015.

4.2.5. Reference scenario: North Macedonia

According to the available Dispa-SET model data, installed capacity of power system of North Macedonia in 2015 is 1 372 MW. Electricity production consists of production by hydropower and thermal power plants that burn lignite. Generation capacities of North Macedonia is presented in the figure 21. As it is shown, capacities consist of 824 MW coming from thermal power plants that burn lignite, i.e. 60.1% of the total installed capacity. Hydropower represents 37.6% of the total installed capacity, i.e. 516 MW. Renewable sources are presented in the form of small hydropower plants and they contribute to the total installed capacity with 32 MW, which represents just 2.3% of the total installed capacity of the power system of North Macedonia.

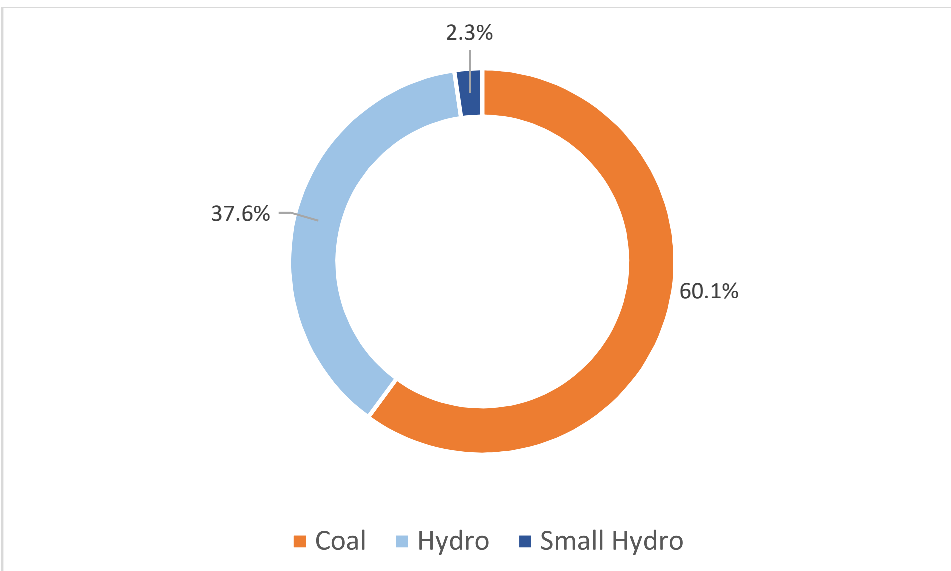

Figure 21. Generation capacities of North Macedonia for year 2015, source author's work

Demand for electricity in North Macedonia for 2015 on hourly basis is presented in the figure 22. The minimum power demand happened on June 2 and it was 530 MW. The maximum power demand happened on January 9 and it equals 1 439 MW.

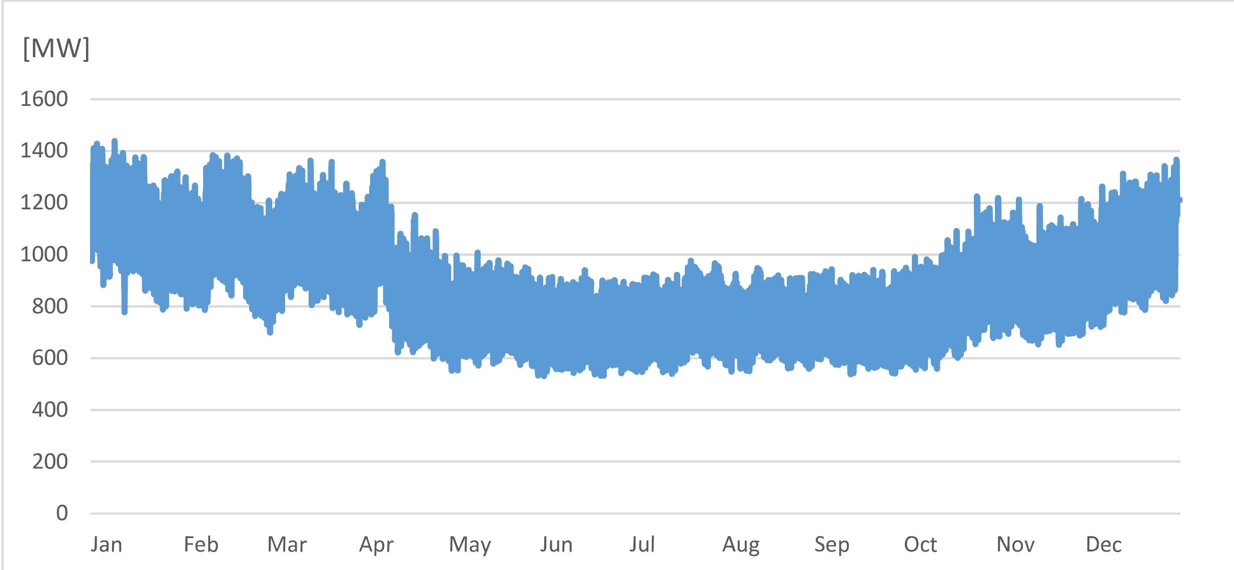

Figure 22. Power demand in North Macedonia for year 2015, source author's work

The power system of North Macedonia generated 7 753 GWh of energy. The most electricity in 2015 in North Macedonia was generated in thermal power plants that burn lignite. In total thermal power plants generated 5 746 GWh. Hydropower plants, including small hydropower plants, generated 2 007 GWh. In 2015, there are no installed capacities that use energy coming from the sun, wind and biomass for electricity generation and that is why they do not contribute to the energy mix of North Macedonia in 2015.

4.2.6. Reference scenario: Serbia

Power system of Serbia is the largest in the region. Installed capacity of the system is 7 137 MW. The main fuel used for the electricity production is coal, while water is the second. Generation capacities are shown in the figure 23. Thermal power plants that burn lignite amounts to 55.2% of the total installed capacity, i.e. 3 936 MW. Hydropower plants have share of 39.6% in the total installed capacity of the Serbian power system, i.e. 2 825 MW. In Serbia power system has units that can generated electricity using gas. They represent 4.9% of the total installed capacity, i.e. 353 MW. Generation from renewable sources is fully covered by small hydropower plants and with 23 MW they have the lowest percentage, i.e. only 0.3% of the total installed capacity of the Serbian power system.

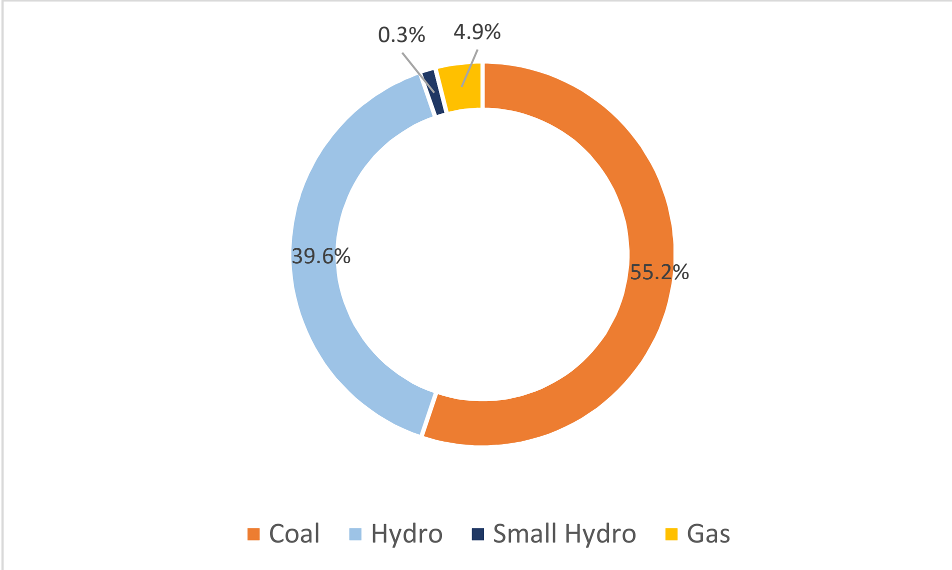

Figure 23. Generation capacities of Serbia for year 2015, source author's work

Power demand of Serbia for 2015 on an hourly basis is presented in the figure 24. The minimum demand happened on May 10 and it amounts to 2 486 MW. The maximum power demand that occurred in 2015 was 6 879 MW and it happened on December 31.

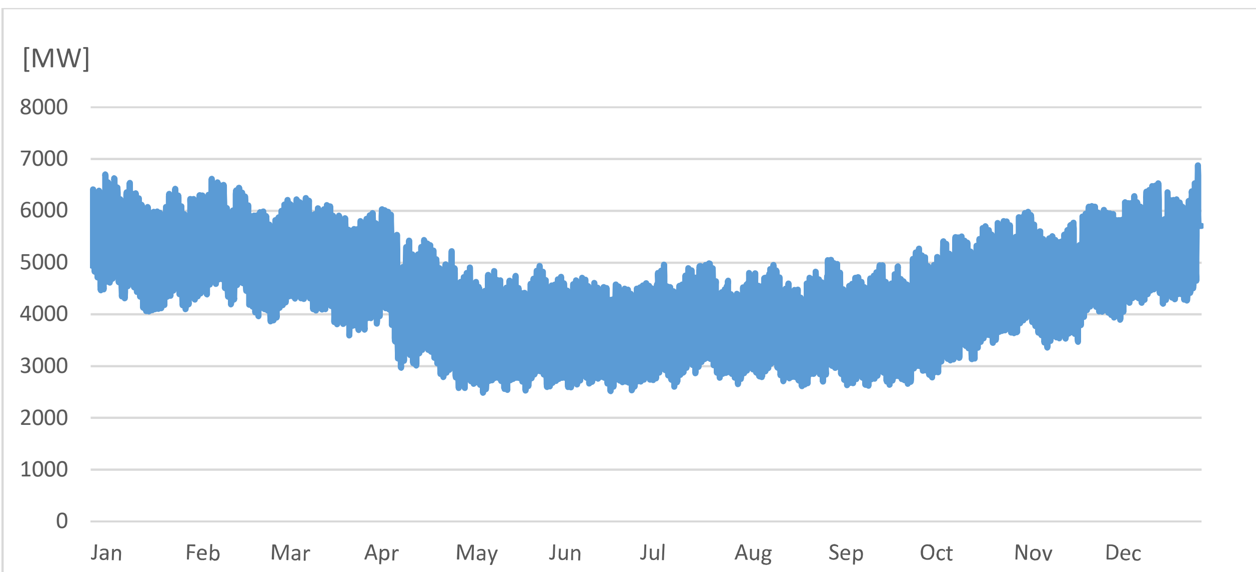

Figure 24. Power demand in Serbia for the year 2015, source author's work

The power system of Serbia generated 39 594 GWh of energy. The most electricity in 2015 in Serbia was generated in thermal power plants that burn lignite. In total thermal power plants generated 27 779 GWh. Hydropower plants, including small hydropower plants, generated 11 717 GWh. There are also 97 MW coming from thermal power plants that run on gas. In 2015, there are no installed capacities that use energy coming from the sun, wind and biomass for electricity generation and that is why they do not contribute to the energy mix of Serbia in 2015.

4.2.7. Reference scenario: Kosovo

Power system of Kosovo has installed capacity of 961 MW. Because of the existence of high calorific coal on the territory of Kosovo main fuel that has been used for electricity production is coal. In the figure 25. it is shown that installed capacity of thermal power plants that run on lignite is 915 MW and it represents 95.2% of the total installed capacity. Larger hydropower plants amount to 35 MW, which is 3.6% of the total installed capacity. Only 1.2% of the total installed capacity is cover with small hydro power plants, i.e. 11 MW, which are the only type of renewable energy sources used in the country.

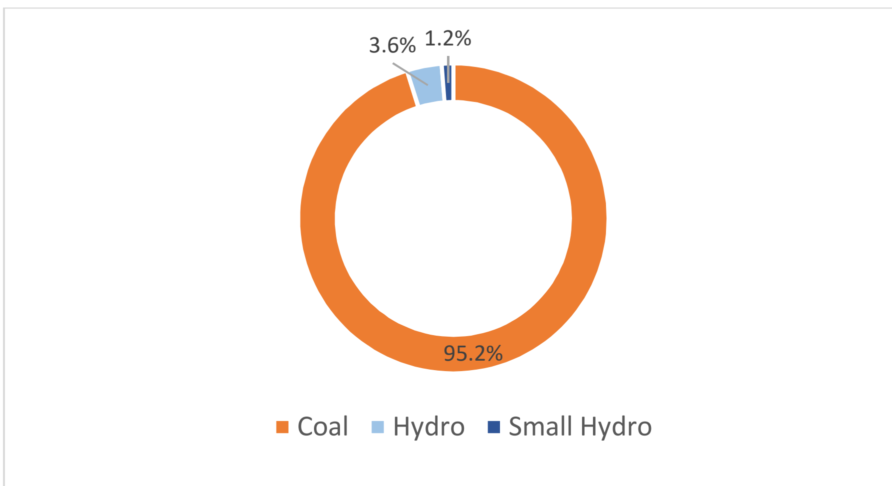

Figure 25. Generation capacities of Kosovo for year 2015, source author's work

In the figure 26. demand of power system of Kosovo in 2015 is presented. The minimum power demand happened on September 23 and it amounts to 191.1 MW. The maximum power demand in 2015 was 943.8 MW and it happened on January 4 at 20h.

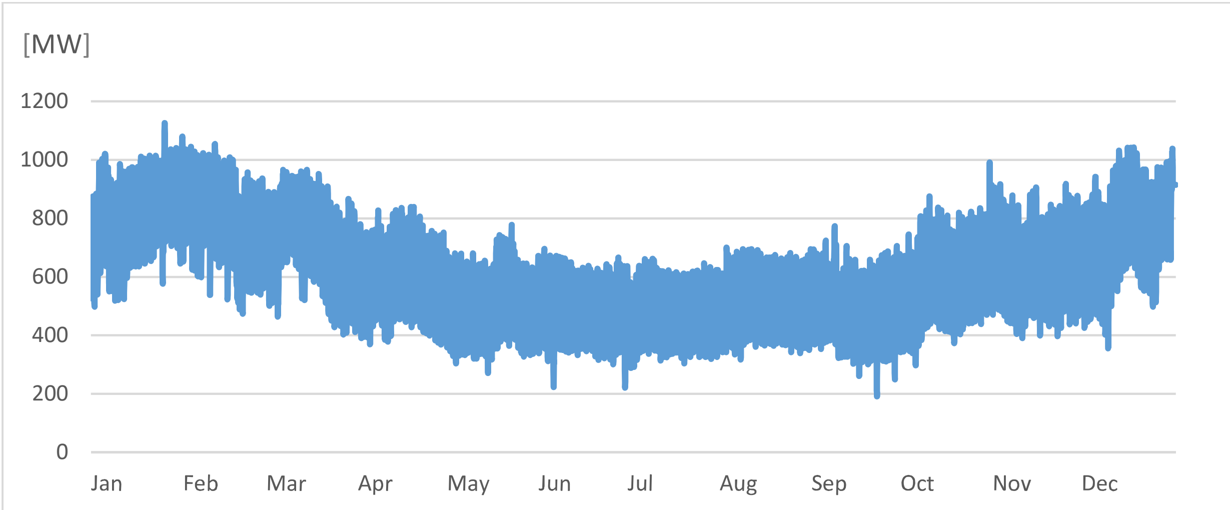

Figure 26. Power demand of Kosovo in 2015, source author's work

The power system of Kosovo generated 5 277 GWh of energy. The most electricity in 2015 in Kosovo, with no surprise, was generated in thermal power plants that burn lignite. In total thermal power plants generated 5 135 GWh. Hydropower plants, including small hydropower plants, generated 142 GWh. In 2015, there are no installed capacities that use energy coming from the sun, wind and biomass for electricity generation and that is why they do not contribute to the energy mix of Kosovo in 2015.

4.3. Scenario for 2020

For the year 2020 seven simulations were carried out. Scenario for the year 2020 was created in order for the region to be step closer to the accomplishment of the European target of 20% electricity coming from renewables. For that purpose, power systems of each one of the six countries were upgraded by adding additional power capacities coming from renewable sources so that in total all six countries would have 20% of their capacities coming from the renewables, i.e. from small hydropower plants, wind, solar and biomass power plants. First simulation is carried out for the region of Western Balkans in interconnected mode, where all six countries exchange energy between them but there is no exchange with the other neighbouring countries. The reason for this is to check if the region can cover its need on its own, i.e. without import from the neighbouring countries. The rest of simulations are carried out for each country in islanded mode, which means that there was no power exchange with any of its' neighbouring countries.

4.3.1. Scenario for 2020: the Western Balkans

In 2020 the total installed capacity of the whole region was increased by 23.33% from the 2015 level, by adding new units that produce energy coming from renewable sources. The total installed capacity in 2020 was 19 582 MW. The idea behind adding additional renewable sources in energy mix is meeting the goal of 20% of capacity coming from renewables in the Western Balkans. The percentages of new renewables added to the total installed capacities are presented in the figure 27.

Figure 27. Percentages of the additional capacities, source author's work

Out of the 3 704 MW that were added, 35.9% or 1 330 MW are coming from the wind power plants. Because of the huge potential of hydropower at the Balkans, small hydropower plants amounts to 31.1% of the total added capacities, i.e. 1 152.23 MW. Power plants on biomass are contributing with 831.6 MW to the new renewable capacities, i.e. they represent 22.5% of the total added capacities. Solar power plants amount to 10.5% of additional added capacity, i.e. 390 MW. The percentages of the renewables as well as the percentages of the other power units contributing to the generation capacities of the whole region is presented in the figure 28.

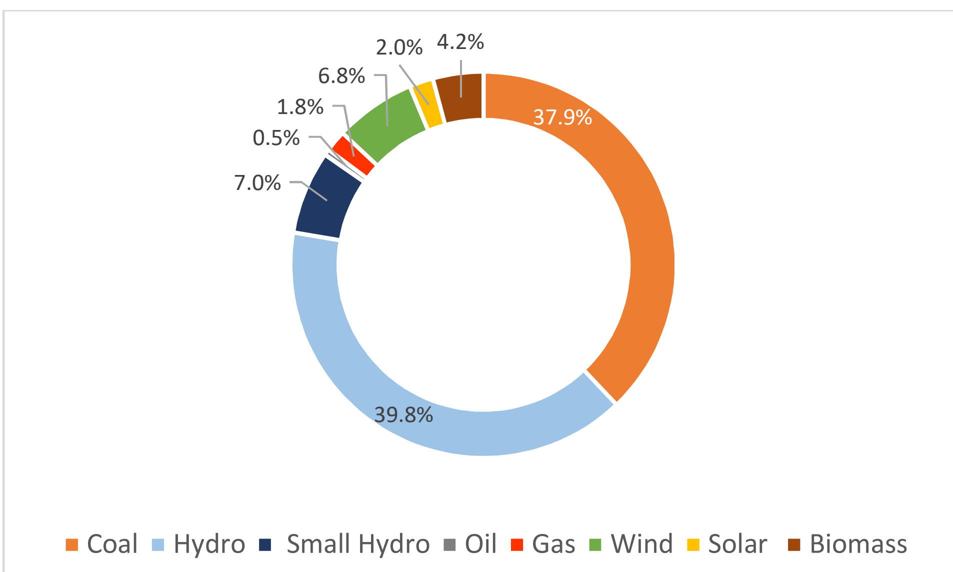

Figure 28. The Western Balkans generation capacities for the year 2020, source author's work

Power demand on an hourly basis for 2020 is presented in the figure 29. The lowest power demand of the whole region was on May 2 and it was 5 343.3 MW, while the highest demand was on December 31 and it equals 16 058.7 MW.0

The total electricity generation of the whole region for the year 2020 was 83 840 GWh. Thermal power plants generated 43 296 GWh, while hydropower units, including both large and small units, generated 36 791 GWh. Wind power plants generated 2 837 GWh of electrical energy, while solar power plants generated 526 GWh. Generation coming from the biomass power plants amounts to 390 GWh.

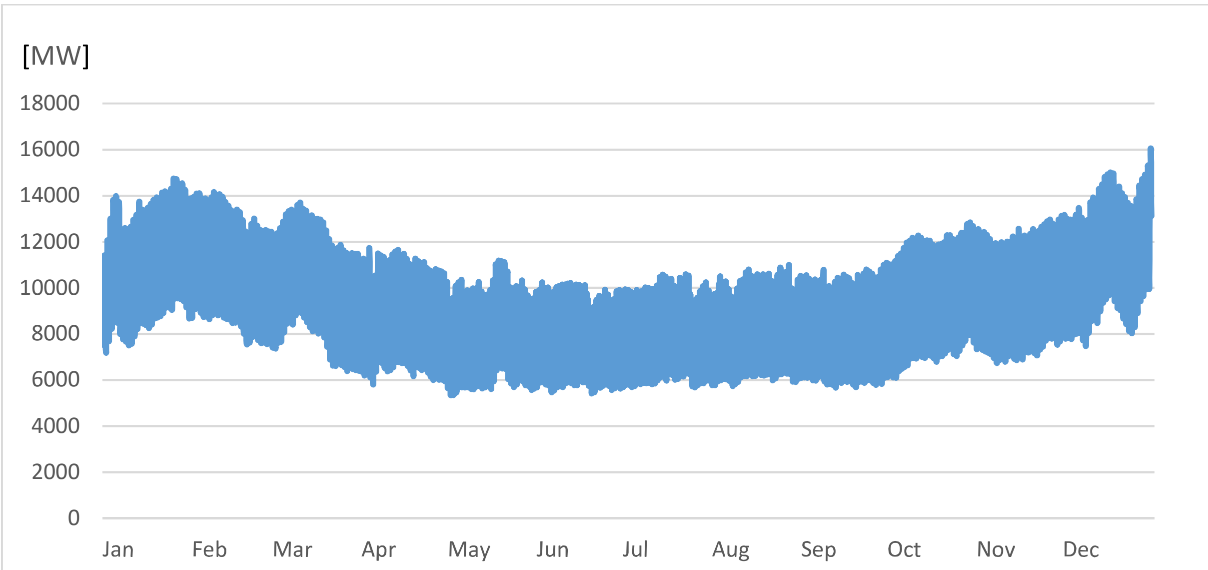

Figure 29. Power demand of the Western Balkans in 2020, source author's work

The demand was met almost during the whole period and in total there was 182 GWh of energy surplus. After the simulation for 2020 average value of total power system costs for the whole region of the Western Balkans was 159 060 EUR. Compared to 170 672 EUR of average value of the total power system costs for 2015, in 2020 the average costs dropped down by 6.8%. Values of total power system costs for 2015 and 2020 are presented in the figure 30.

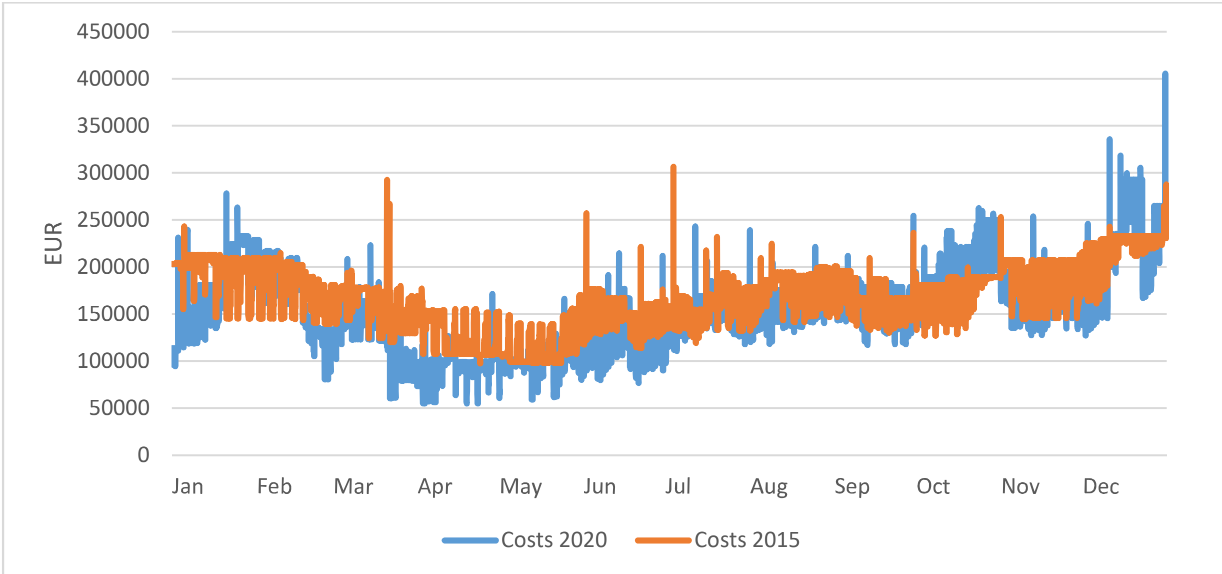

Figure 30. Total costs of the Western Balkans on an hourly basis for 2015 and 2020, source author's work

4.3.2. Scenario for 2020: Albania

In 2020 the installed capacity of Albanian power system was 2 263.2 MW. Additional renewable power plants were added to the power system from the reference scenario, i.e. Albanian power system in 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 31.

Figure 31. Percentages of the additional capacities, source author's work

Out of 368 MW that were added, 213 MW is installed in small hydropower plants, which represents 57.9% of the total additional installed capacities. The reason for such a high percentage is a huge hydro potential in Albania and suggestions coming from the national energy strategy. Wind power plants contribute with 70 MW to the additional renewable capacities, i.e. they represents 19% of the total additional capacities. Solar power plants with 13.6% are third and they contribute with 50 MW. Power system of Albania has also been enriched with 35 MW coming from biomass power plants, which represent 9.5% of the total additional capacities. The percentages of renewables as well as the percentages of the other units contributing to the generation capacities of Albania are presented in the figure 32.

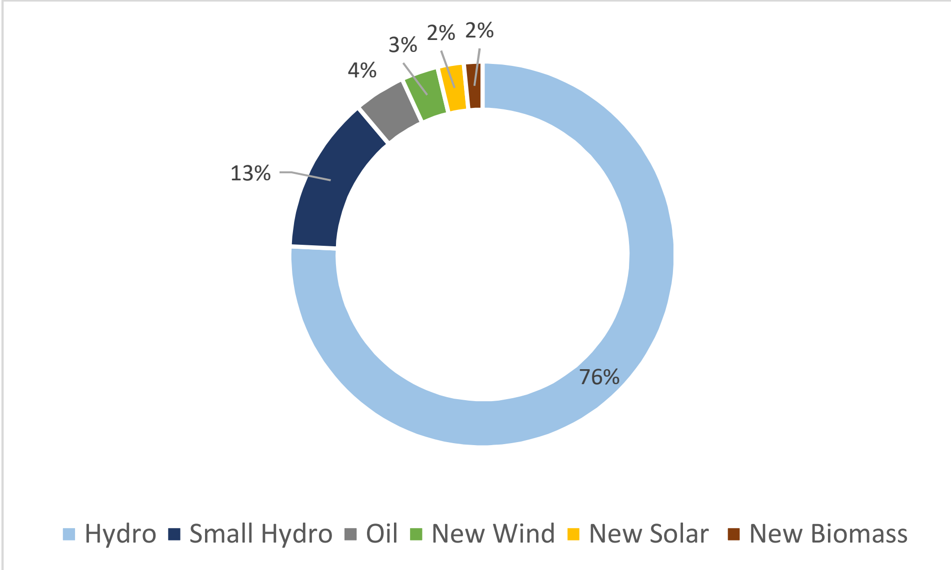

Figure 32. Generation capacities of Albania for year 2020, source author's work

The demand of the Albanian power system on an hourly basis for the year 2020 is shown in the figure 33. The minimum demand during the whole year happened on February 18 when the demand was 509 MW. The maximum demand occurred on December 30 when the demand was 2 026 MW.

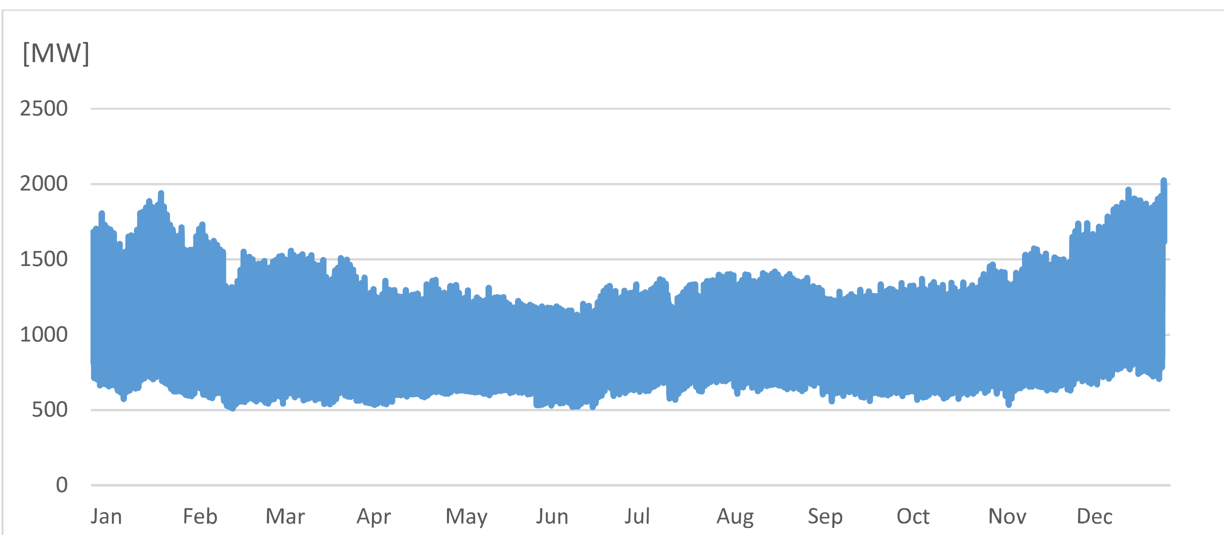

Figure 33. Demand of Albanian power system for year 2020, source author's work

The power system of Albania generated 9 011 GWh of energy. The most electricity in 2020 in Albania came from the hydropower plants, both small and large, and it sums up to 8 509 GWh. Biomass power plants generated 168 GWh, while wind power plants generated 121 GWh. Solar power plants generated extra 60 GWh. Thermal power plant that uses oil was active in 2020 and it generated 152 GWh. After analysing the demand and generation of the Albanian power system it can be concluded that in islanded mode Albanian system would face problems because the generation coming from the Albanian power plants only is not enough to meet the demand in every hour of the year. There is 271 GWh of energy that are not covered by the generation.

4.3.3. Scenario for 2020: Bosnia and Herzegovina

In 2020 installed capacity of the power system of Bosnia and Herzegovina is 4 465 MW. Additional renewable power plants were added to the power system from reference scenario. The percentages of the new renewables added to the total installed capacities are presented in the figure 34.

Figure 34. Percentages of the additional capacities, source author's work

In total 842 MW were added. Biomass represents 39.2% of the total additional capacities, i.e. 330 MW. New hydropower capacities have a share of 33.5%, which is 282 MW out of the total 842 MW. Wind power plants contribute with 150 MW to the additional renewable capacities, which is 17.8%. Solar power plants contribute with 80 MW and they represent 9.5% of the total additional capacities. The percentages of renewables and the other units contributing to the generation capacities of Bosnia and Herzegovina are presented in the figure 35.

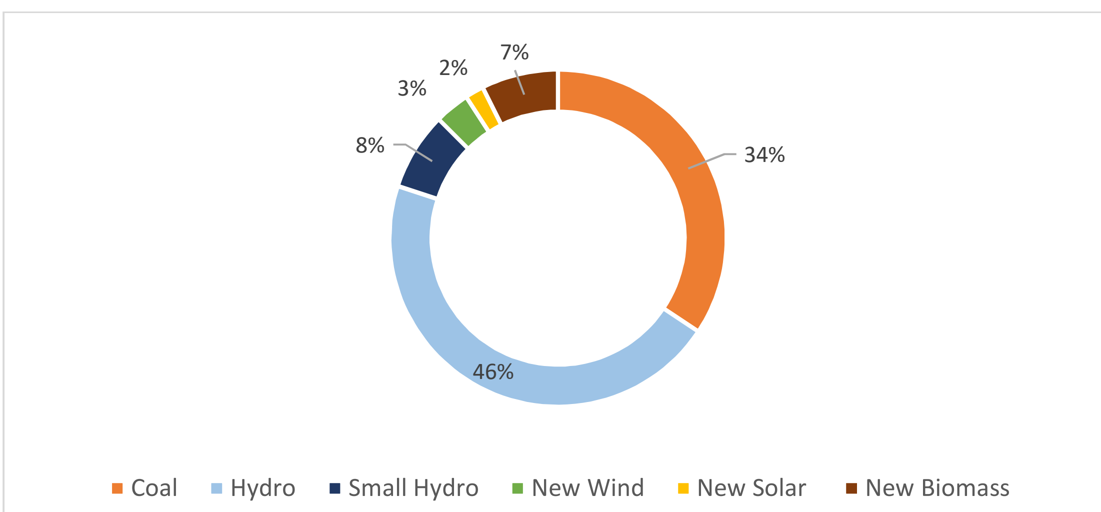

Figure 35. Generation units of Bosnia and Herzegovina for year 2020, source author's work

The hourly demand for the year 2020 of the power system of Bosnia and Herzegovina is shown in the figure 36. The minimum demand during the whole year happened on March 3 when the demand was 1088.7 MW. The maximum demand occurred on December 31 when the demand was 2 899 MW.

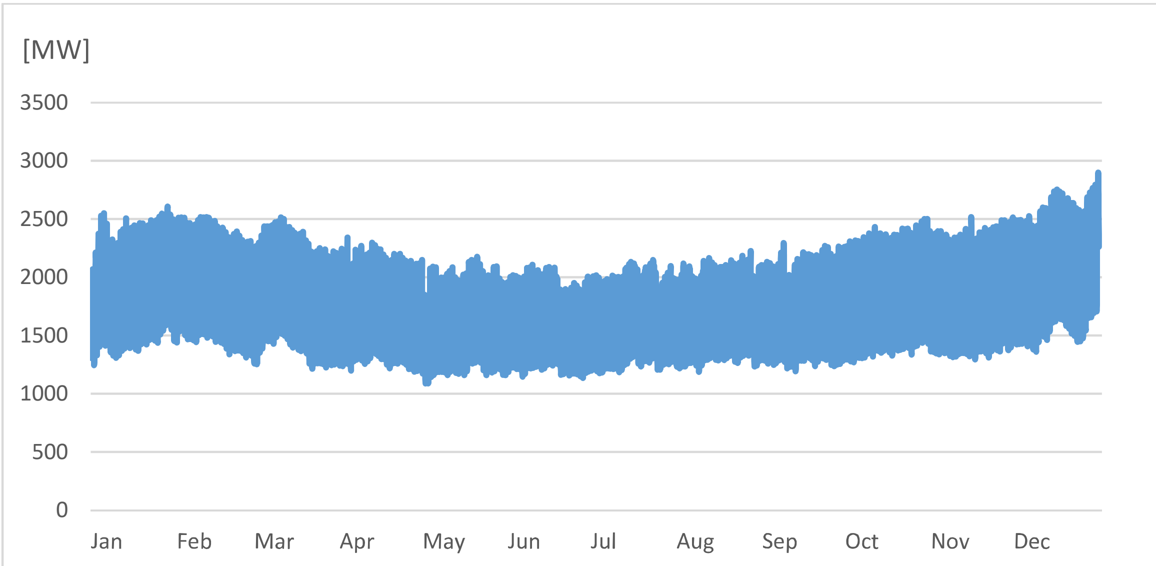

Figure 36. Power demand of Bosnia and Herzegovina in 2020, source author's work

The power system of Bosnia and Herzegovina in 2020 generated 16 111 GWh of energy. The most of it was generated in thermal power plants that burn lignite. In total thermal power plants generated 8 425 GWh. Hydropower plants, including small hydropower plants also, generated 7 271 GWh. Wind power plants generated 294 GWh. While solar power plants generated 95 GWh, biomass power plants contributed to the generation with 25 GWh. After the simulation of power system of Bosnia and Herzegovina in islanded mode it can be stated that the energy generation by the national system just, has the potential to cover the demand. Only in some hours it would happen that the generation could not meet the consumption. In total there is 1.3 GWh of an extra generated energy.

4.3.4. Scenario for 2020: Montenegro

Installed capacity of Montenegrin power system for year 2020 is 1 100 MW. Additional renewable power plants were added to the power system from the reference scenario. The percentages of the new renewables added to the total installed capacities are presented in the figure 37.

Figure 37. Percentages of the additional capacities, source author's work

Extra 208.5 MW were added to the power system from the reference case. Montenegro has a huge potential to generate electricity using wind power and that was the main motivation to have 52.8%, i.e. 110 MW, of additional capacities coming from wind power plants. Solar power plants represent 24 % of the extra added capacities, which is equal to 50 MW. Although there is a huge hydropower potential only 28 MW, i.e. 13.6% of the total added capacities, were added because of the existence of the strong movement against the small hydropower plants. Rest of the added capacities, 20 MW, are coming from the biomass power plants that represent 9.6% of the additional capacities. The percentages of renewables as well as the percentages of the other units contributing to the generation capacities of Montenegro are presented in the figure 38.

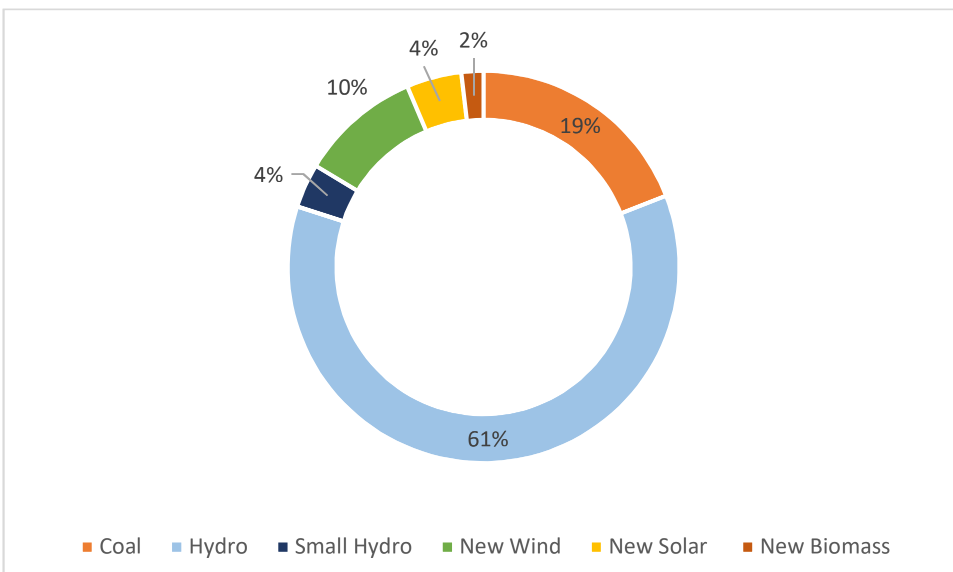

Figure 38. Generation capacities of Montenegro for year 2020, source author's work

The hourly demand for the year 2020 of the Montenegrin power system is shown in the figure 39. The minimum demand during the whole year occurred on June 24 when the demand was just 222 MW. The maximum demand happened on January 24 when the demand was 727 MW.

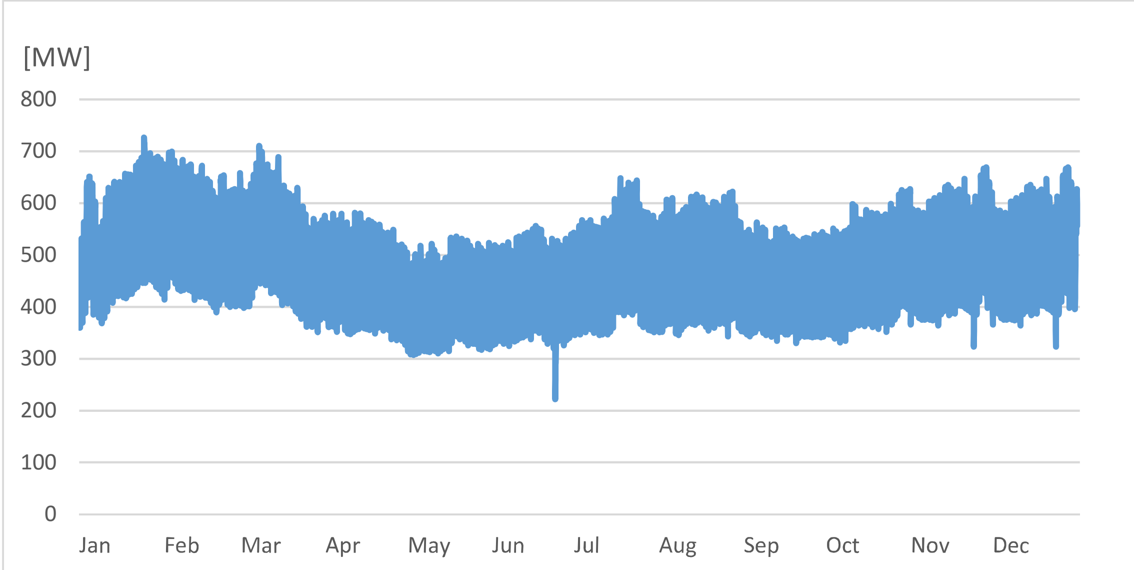

Figure 39. Demand of the Montenegrin power system for year 2020, source author's work

Montenegrin power system generated 3 948 GWh of energy. The most of it was generated in small and large hydropower plants, i.e. 1 831 GWh were generated. Thermal power plants that burn lignite contributed with 1 638 GWh. Wind power plants generated 252 GWh. Biomass power plants generated 150 GWh, while solar power plants generated 77 GWh. Results after the simulation of Montenegrin power system in islanded mode suggest that the system cannot work in islanded mode. The reason for such a conclusion can be found in the fact that during the days when the hydropower units were not operating Montenegrin generation could not meet the consumption and there are many hours when generation could not meet the demand. In total there are 342 GWh that were not covered by the national generation and in this case Montenegro is forced to buy power from its neighbours.

4.3.5. Scenario for 2020: North Macedonia

Installed capacity of the power system of North Macedonia for year 2020 was 1 675 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 40.

Figure 40. Percentages of the additional capacities, source author's work

To the power system from the reference scenario 303 MW were additionally added. Because the system has a huge potential for generating electricity that comes from wind, wind power plants sums up to 180 MW, which is 59.4% of the total additional installed capacities. New hydropower plants contribute to the total added capacities with a power of 73 MW, which represents 24.1% of the added capacities. Solar power plants sum up to 30 MW and they represent 9.9% of the additional added capacities. Rest of the added capacities, 20 MW, are coming from biomass power plants that represent 6.6% of the total capacities that were added. The percentages of renewables as well as the percentages of the other capacities contributing to the generation capacities of North Macedonia are presented in the figure 41.

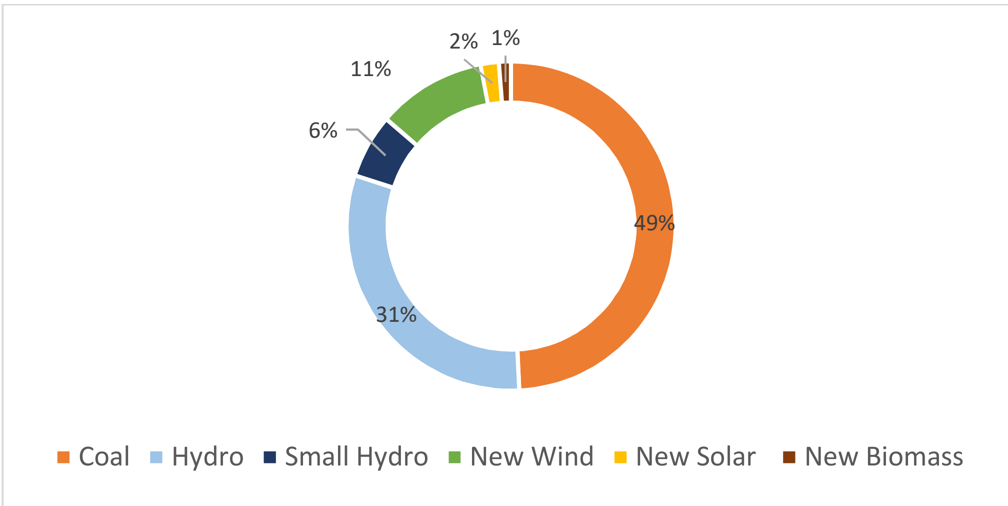

Figure 41. Generation capacities of North Macedonia for year 2020, source author's work

The hourly demand for the year 2020 of the power system of North Macedonia is shown in the figure 42. The minimum demand during the whole year happened on May 2 when the demand was 561 MW. The maximum demand occurred on December 18 when the demand was 1 909 MW.

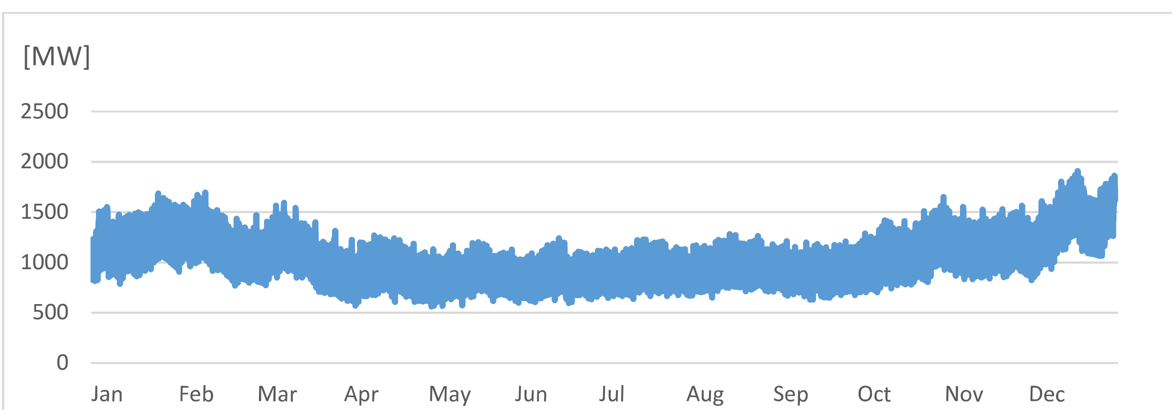

Figure 42. Power demand of North Macedonia for year 2020, source author's work

The power system of North Macedonia generated 9 054 GWh of energy. The most electricity in 2020 in North Macedonia was generated in thermal power plants that burn lignite. In total thermal power plants generated 5 652 GWh. Hydropower plants, including small hydropower plants, generated 2 867 GWh. Wind power plants generated 354 GWh. Biomass power plants generated 140 GWh, while solar power plants contributed with 41 GWh. Results after the simulation of power system of North Macedonia in islanded mode suggest that the system cannot work in islanded mode. The reason for such a conclusion is a fact that in total for 2 842 hours the demand was not met by the generation. In total there is 356 GWh of energy that could not be covered by the generation from the national resources.

4.3.6. Scenario for 2020: Serbia

Installed capacity of Serbian power system for year 2020 is 8 892 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 43.

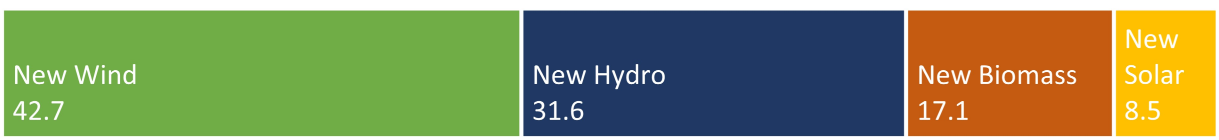

Figure 43. Percentages of the additional capacities, source author's work

Additional 1 755 MW were added to the power system from the reference case. Because the system has a huge potential in generating electricity that comes from wind and hydropower, wind power plants sums up to 750 MW, while hydropower plants sums up to 555 MW, which is 42.7% and 31.6% of the total additional installed capacities, respectively. Biomass contributes with additional 300 MW to the total added capacities, which is 17.1%. The rest is covered with solar power plants that sum up to 150 MW, which represent 8.5% of the total capacities that were added to the Serbian power system. The percentages of renewables as well as the percentages of the units contributing to the generation capacities of Serbian power system are presented in the figure 44.

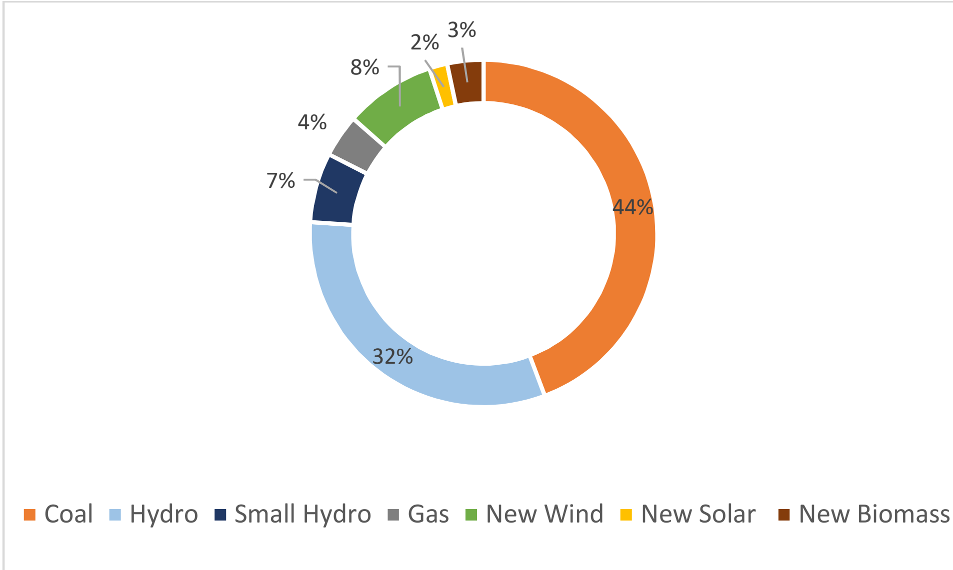

Figure 44. Generation capacities of Serbia for year 2020, source author's work

The hourly demand for the year 2020 of the power system of Serbia is shown in the figure 45. The minimum demand during the whole year happened on May 2 when the demand was 2 264 MW. The maximum demand occurred on December 31 when the demand was 7 102 MW.

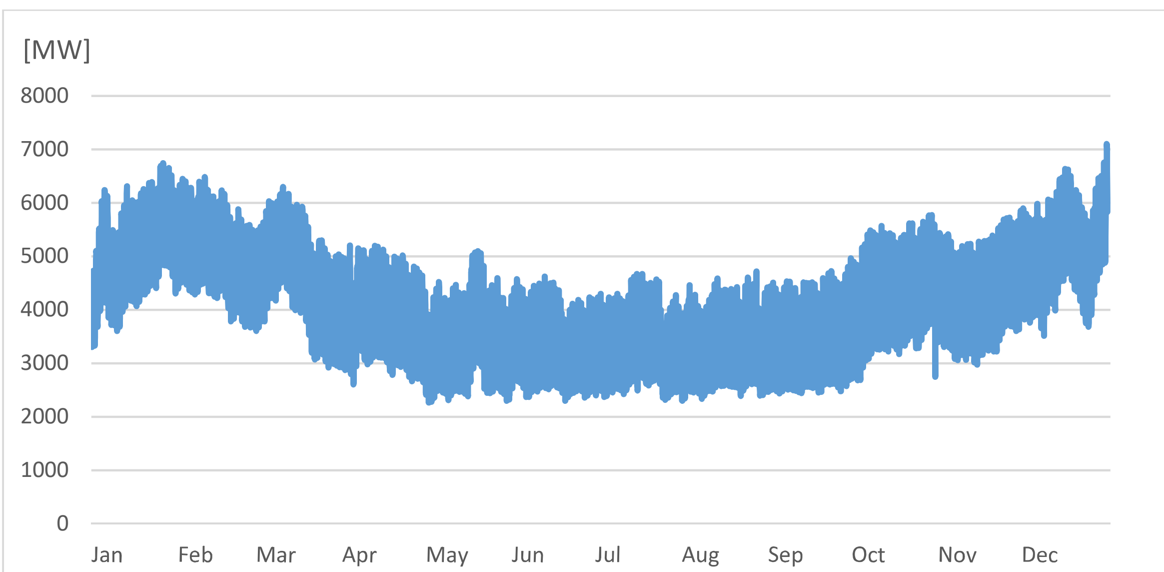

Figure 45. Demand of power system of Serbia for year 2020, source author's work

In 2020 the power system of Serbia generated 37 115 GWh of energy. The most electricity in Serbia was generated in coal-fired thermal power plants. In total thermal power plants generated 18 976 GWh. Hydropower plants, including small hydropower plants, generated 16 239 GWh. From the rest of renewables wind power plants contributed the most, since they generated 1 650 GWh. Solar power plants generated 196 GWh, while biomass power plant generated 54 MWh. Results after the simulation of power system of Serbia in islanded mode suggest that the system may work in islanded mode with small number of hours when the generation is not met by consumption. In total there is 56.3 GWh of extra energy that has been generated above the demand level.

4.3.7. Scenario for 2020: Kosovo

Installed capacity of the power system of Kosovo for year 2020 is 1 187.5 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 45.

Figure 45. Percentages of the additional capacities, source author's work

Additional 267 MW were added to the power system from the reference case. Biomass power plants sum up to 127 MW, which represents 55.9% of the total additional installed capacities. Wind power plants with capacity of 70 MW represent 30.9% of the added capacities. The rest, i.e. 13.2%, is covered with 30 MW coming from the solar power plants. The percentages of renewables as well as the percentages of the other power plants contributing to the production units of Kosovo are shown in the figure 46.

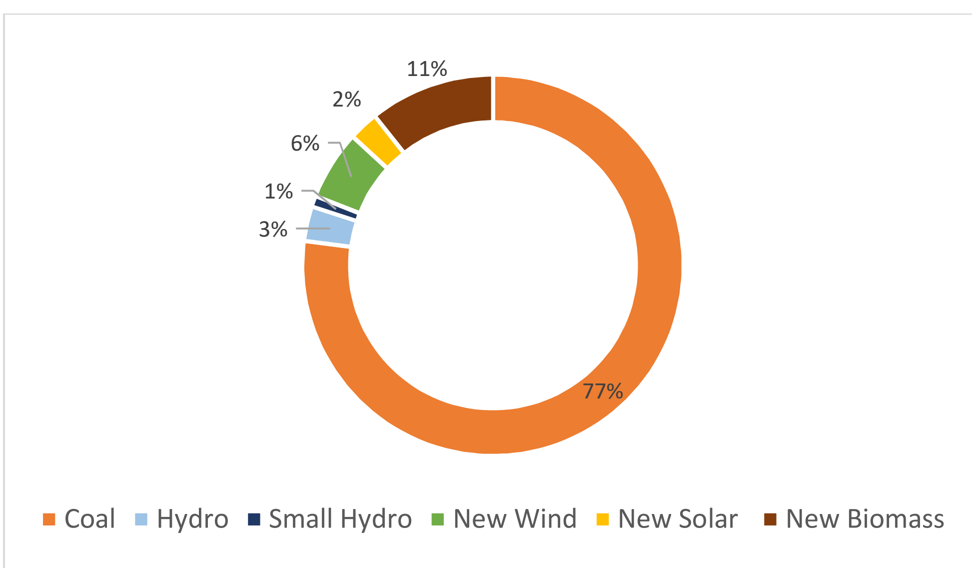

Figure 46. Generation capacities of Kosovo for year 2020, source author's work

The hourly demand for the year 2020 of the power system of Kosovo is shown in the figure 47. The minimum demand during the whole year happened on March 28 when the demand was 241.5 MW. The maximum demand occurred on January 25 when the demand was 1 510.5 MW.

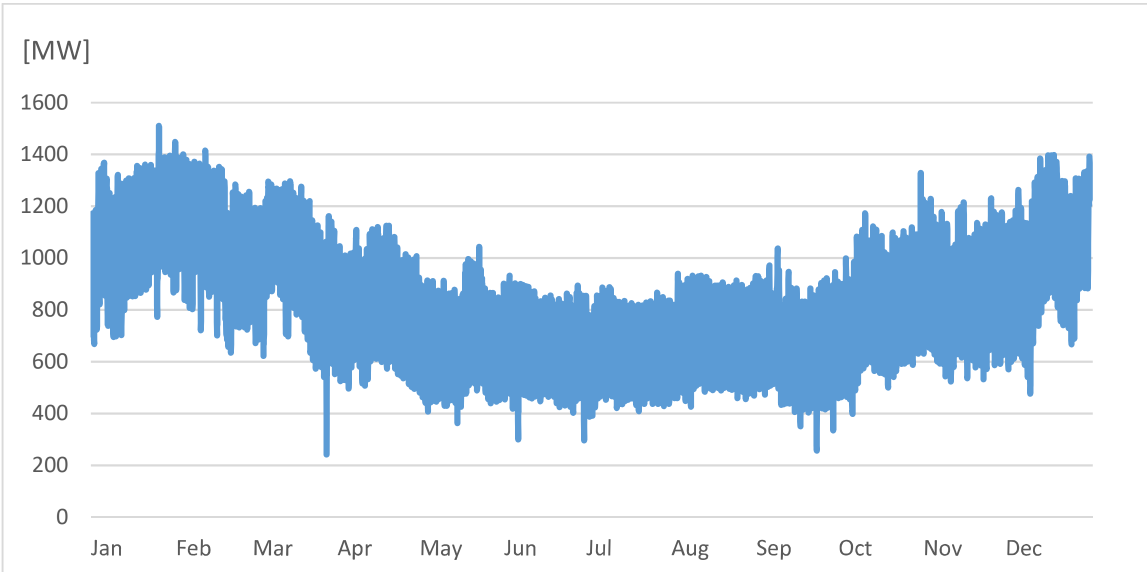

Figure 47. Power demand of Kosovo for year 2020, source author's work

The power system of Kosovo in 2020 generated 6 792 GWh of energy. The most electricity in 2020 in Kosovo was generated by coal-fired thermal power plants and in total those plants generated 5 802 GWh. Hydropower plants, including small hydropower plants, generated 142 GWh. Biomass power plant generated 685 GWh more. Wind power plants also contributed with 125 GWh, while solar contributed with 37 GWh. Results after the simulation of power system of Kosovo in islanded mode suggest that the system is not able to work in an islanded mode. There are 678 GWh of energy demanded that could not be covered by the national generation.

4.4. Scenario for 2030

For the year 2030 seven simulations were carried out. Scenario for the year 2030 was created in order for the region to be step closer to the accomplishment of the European target of 32% of electricity coming from renewables. For that purpose, power systems of each one of the six countries were upgraded by adding additional power capacities coming from renewable sources so that in total all six countries would have 32% of their generating units coming from renewables, i.e. from small hydropower plants, wind, solar and biomass power plants.

First simulation is carried out for the region of Western Balkans in interconnected mode, where all six countries exchange energy between them but there is no exchange with other neighbouring countries. The reason for this is to check if the region can cover its needs on its own, i.e. without imports from neighbouring countries. The rest of simulations are carried out for each country in islanded mode, which means that there was no power exchange with any of their neighbouring countries.

4.4.1. Scenario for 2030: the Western Balkans

In 2030 the total installed capacity of the whole region from 2015 was increased by 45%, by adding new units that produce energy coming from renewable sources. The total installed capacity in 2030 sums up to 23 038 MW. The idea behind adding additional renewable sources in energy mix is meeting the goal of 32% of energy coming from renewables in Western Balkans. The percentages of the new renewables added to the total installed capacities are presented in the figure 48.

Figure 48. Percentages of the additional capacities, source author's work

Out of the 7 160 MW that were added, 36% or 2 580 MW are coming from the wind power plants. Power plants that run on biomass are contributing with 1 746 MW to the new renewable capacities, i.e. they represent 24.4% of the total added capacities. Small hydropower plants amounts to 21.6% of the total added capacities, i.e. 1 543 MW. Solar power plants with a capacity of 1 290 MW sum up to 18% of the additionally added capacity. The percentages of renewables and other units contributing to the generation capacities of the whole region are presented in the figure 49.

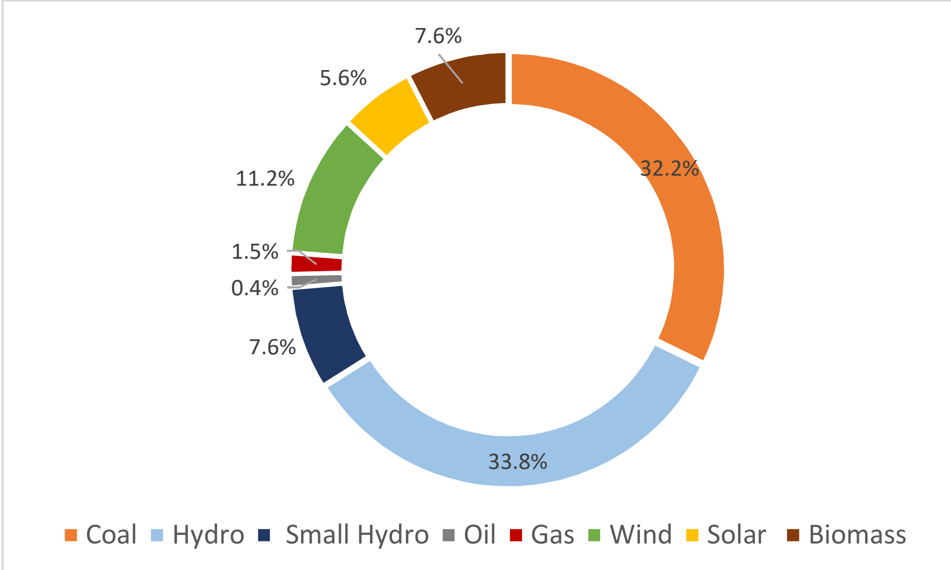

Figure 49. Generation capacities of the Western Balkans for the year 2030, source author's work

Power demand on an hourly basis for 2030 is presented in the figure 50. The lowest power demand of the whole region was at on May 2 and it was 5 464.5 MW, while the highest level was on December 31 and it sums up to 16 455 MW.

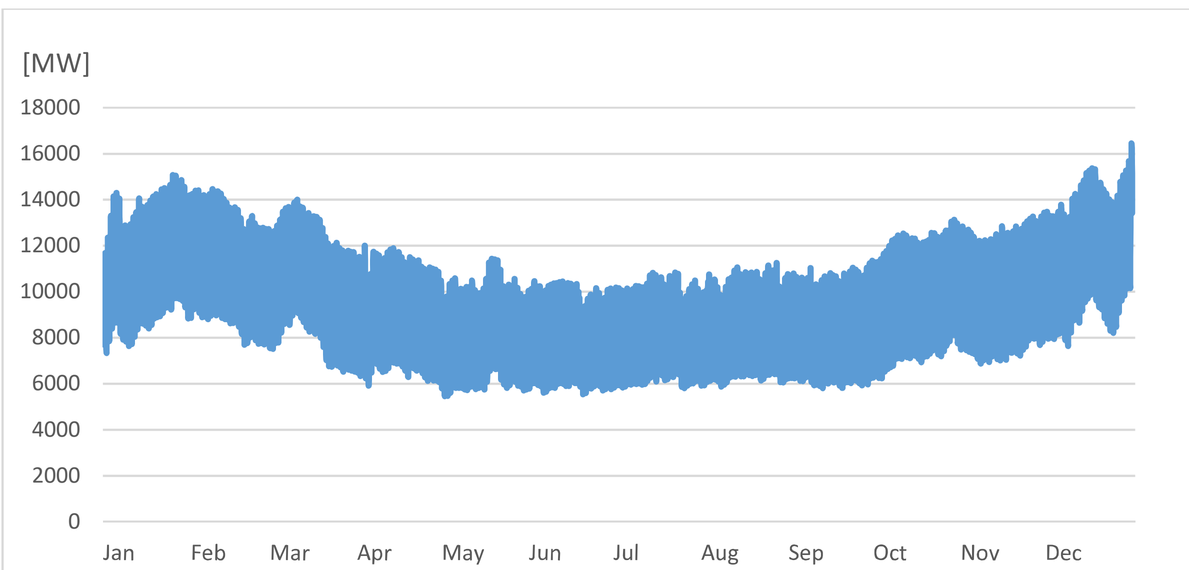

Figure 50. Power demand of the Western Balkans in 2030, source author's work

The total electricity generation of the whole region for the year 2030 was 85 607 GWh. Thermal power plants generated 39 398 GWh. Hydropower units including small hydropower plants generated 38 874 GWh. Wind power plants generated 5 450 GWh, while solar power plants generated 1 715 GWh. Biomass power plants generated the least, i.e. 169 GWh.

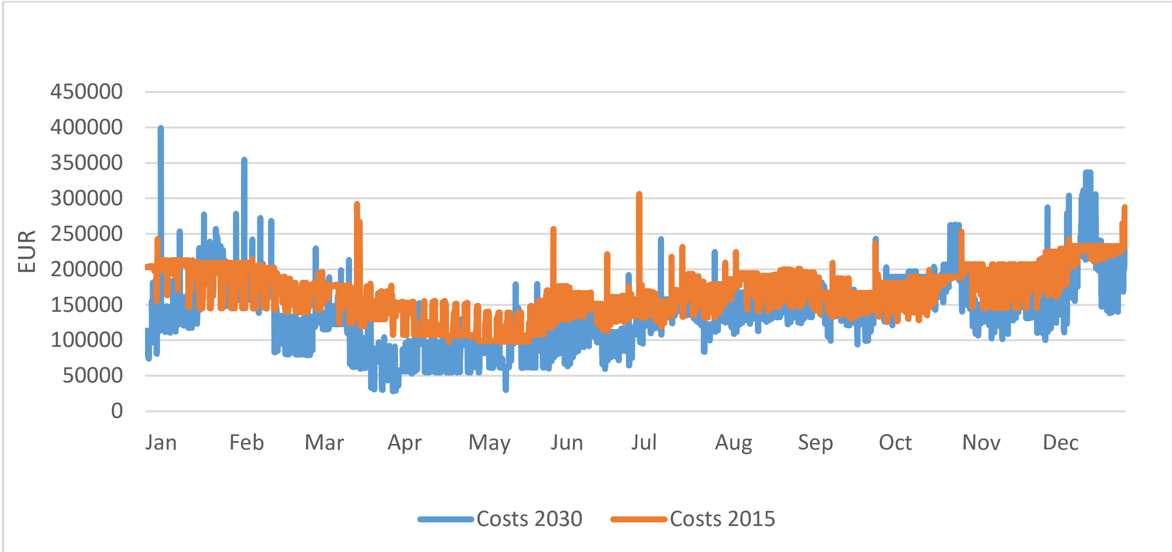

Figure 51. Total costs of the WB on an hourly basis for 2015 and 2030, source author's work

The demand was met almost during the whole period and in total there is 75.8 GWh of energy surplus. After the simulation for 2030 average value of the total power system costs for the whole region of Western Balkans was 143 070 EUR. Compared to 170 672 EUR of average total power system costs for 2015, in 2030 the average costs dropped down by 16.17%. Values of the total power system costs for 2015 and 2030 are presented in the figure 51.

4.4.2. Scenario for 2030: Albania

Installed capacity of the power system of Albania for year 2030 is 2 662 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 52.

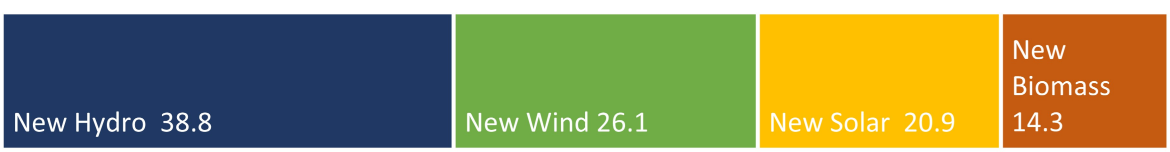

Figure 52. Percentages of the additional capacities, source author's work

Additional 767 MW were added to the power system from the reference case. Hydropower plants sum up to 297 MW, which represents 38.8% of the total additionally installed capacities. Wind power plants with capacity of 200 MW represent 26.1% of the added capacities. Solar power plant are taking part in the production of energy with installed capacity of 160 MW, which is 20.9% of the total added capacities. The rest is covered by biomass power plants that represent 14.3% of the total added capacities, i.e. 110 MW. The percentages of renewables as well as the percentages of the other units contributing to the generation capacities of Albania are shown in the figure 53.

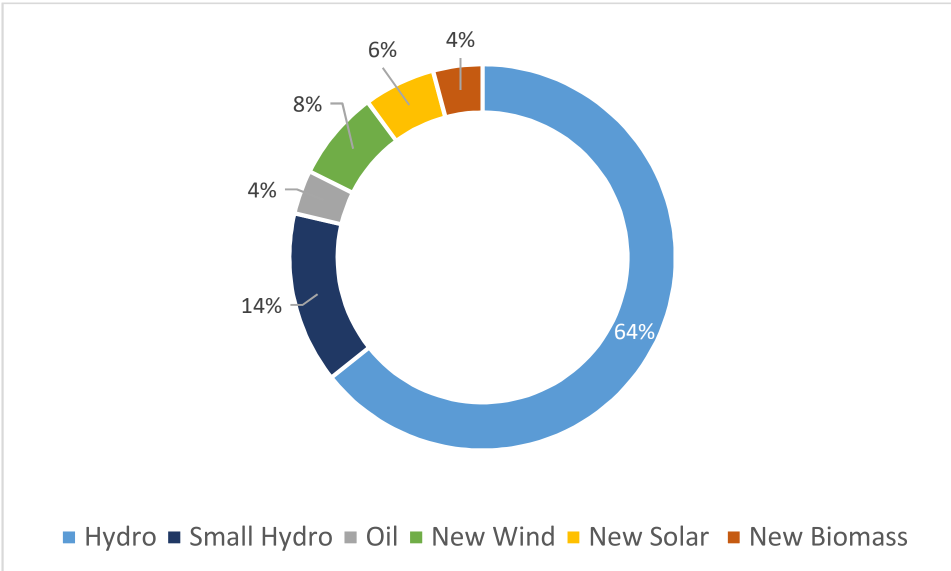

Figure 53. Generation units of Albania for the year 2030, source author's work

The demand on an hourly basis for the year 2030 of the power system of Albania is shown in the figure 54. The minimum demand during the whole year occurred on February 18 when the demand was 555.2 MW. The maximum demand occurred on December 31 when the demand was 2 401 MW.

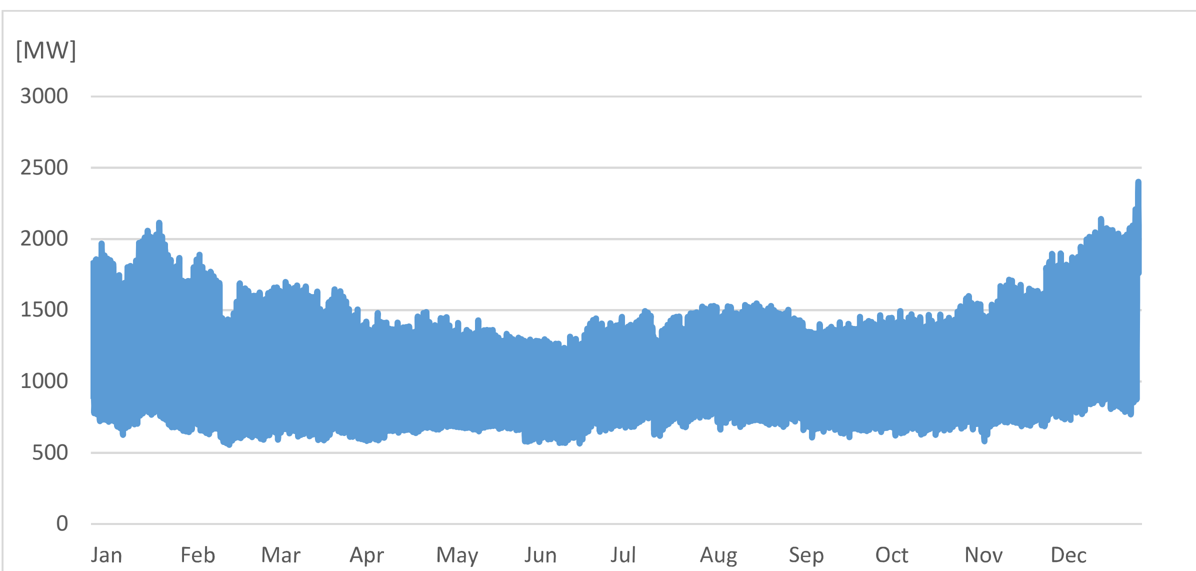

Figure 54. Power demand of Albania for year 2030, source author's work

Albanian power system in 2030 generated 10 112 GWh of energy. The most electricity in 2030 in Albania was produced in hydropower plants, including small hydropower plants. They generated 9 052 GWh. Biomass power plant generated 491 GWh. Wind power plants contributed with 356 GWh, while solar contributed with 195 GWh. Thermal power plant that runs on oil generated less than in the previous scenarios. It generated 17 GWh. Results after the simulation of power system of Albania in islanded mode suggest that the system may face problems with covering the demand during 417 hours. In total, 47.4 GWh of consumption were not covered by the generation coming from the national power plants.

4.4.3. Scenario for 2030: Bosnia and Herzegovina

Installed capacity of the power system of Bosnia and Herzegovina for year 2030 is 5 253 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 55.

Figure 55. Percentages of the additional capacities, source author’s work

Additional 1 630 MW were added to the power system from the reference case. The most of the added capacity is covered by the wind power plants that amount to 510 MW or 31.3% of the total added capacities. Biomass sums up to 420 MW, which represents 25.8% of the total additional installed capacities. Solar power plants with capacity of 360 MW represent 22.1% of the added capacities. Small hydropower plants are taking part in the production of energy with installed capacity of 340 MW, which is 20.9% of the total added capacities. The percentages of all units contributing to the generation capacities of Bosnia and Herzegovina are shown in the figure 56.

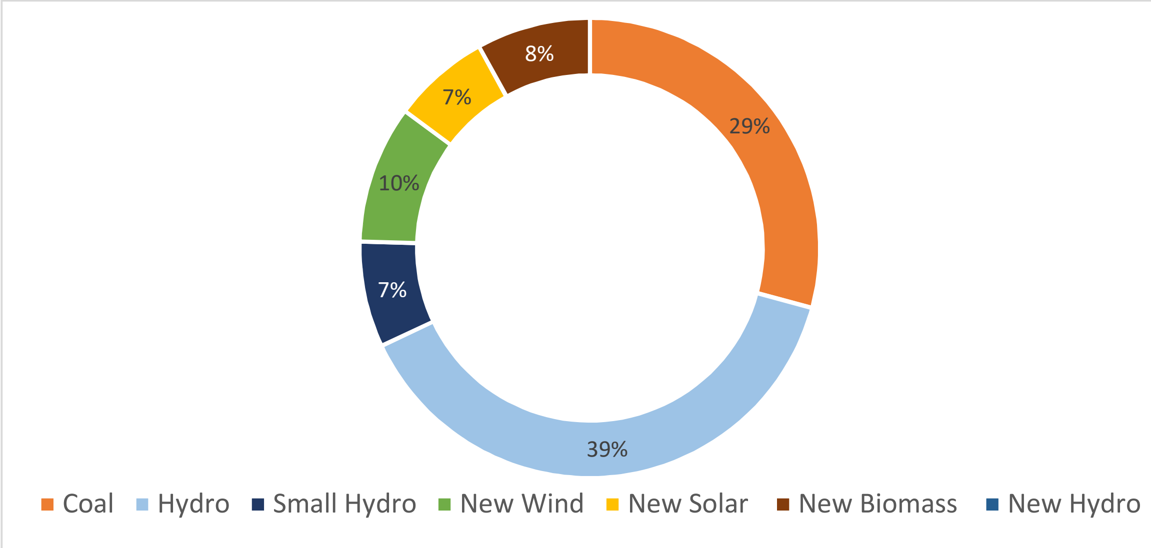

Figure 56. Generation capacities of Bosnia and Herzegovina for the year 2030, source author's work

The power demand of Bosnia and Herzegovina on an hourly basis for the year 2030 is shown in the figure 57. The minimum demand during the whole year is 1 118.4 MW and it occurred on May 3. The maximum demand occurred on December 31 when the demand was 2 978.3 MW.

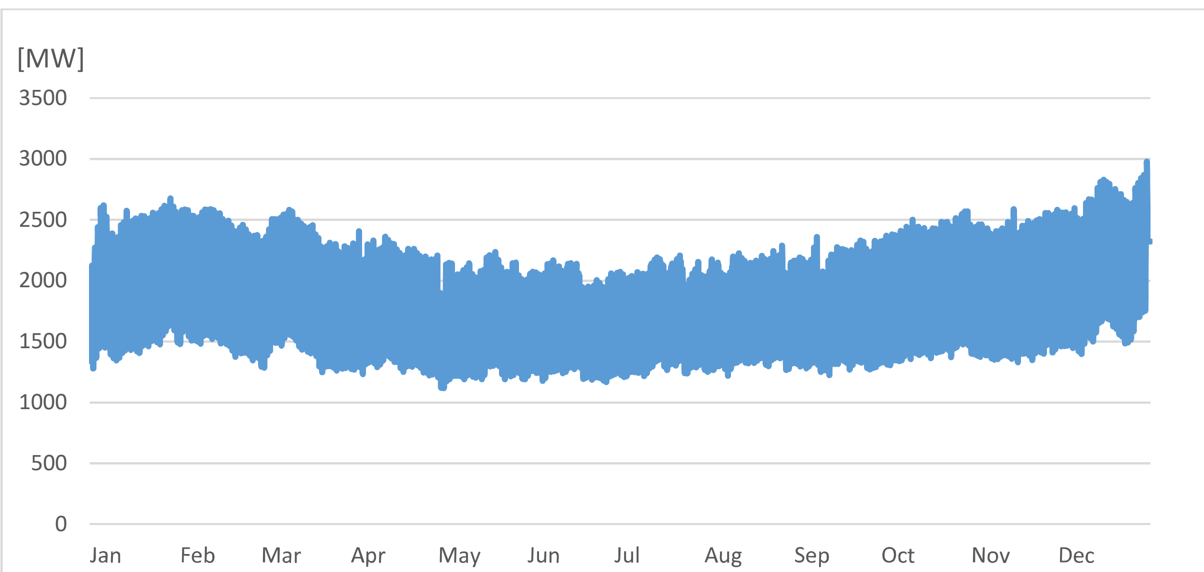

Figure 57. Demand of power system of Bosnia and Herzegovina for year 2030, source author's work

Power system of Bosnia and Herzegovina in 2030 generated 16 555 GWh of energy. The most of it was produced in thermal power plants, i.e. 7 708 GWh. On the second place are hydropower plants, including small hydropower plants, that generated 7 411 GWh. Wind power plants contributed with 1 000 GWh, while solar contributed with 428 GWh. Biomass power plants generated 7.2 GWh. Results after the simulation of power system of Bosnia and Herzegovina in an islanded mode suggest that the system potentially can be run in islanded mode. In total, 5.9 GWh of extra energy has been generated above the demand level.

4.4.4. Scenario for 2030: Montenegro

Installed capacity of Montenegrin power system for year 2030 was 1 294 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 58.

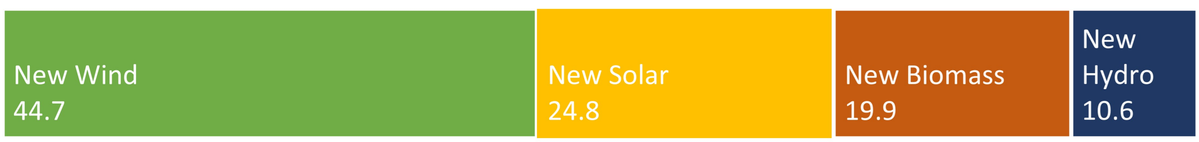

Figure 58. Percentages of the additional capacities, source author's work

Additional 402 MW were added to the power system from the reference case. Capacities coming from the wind power plants cover 44.7% of the total added capacities or 180 MW. Solar power plants with the power of 100 MW represent 24.8% of the added capacities. Biomass sums up to 80 MW, which represents 19.9% of the total additionally installed capacities. Small hydropower plants are taking part in the production of energy with installed capacity of 43 MW, which is 10.6% of the total added capacities. The percentages of generating units of the power system of Montenegro are shown in the figure 59.

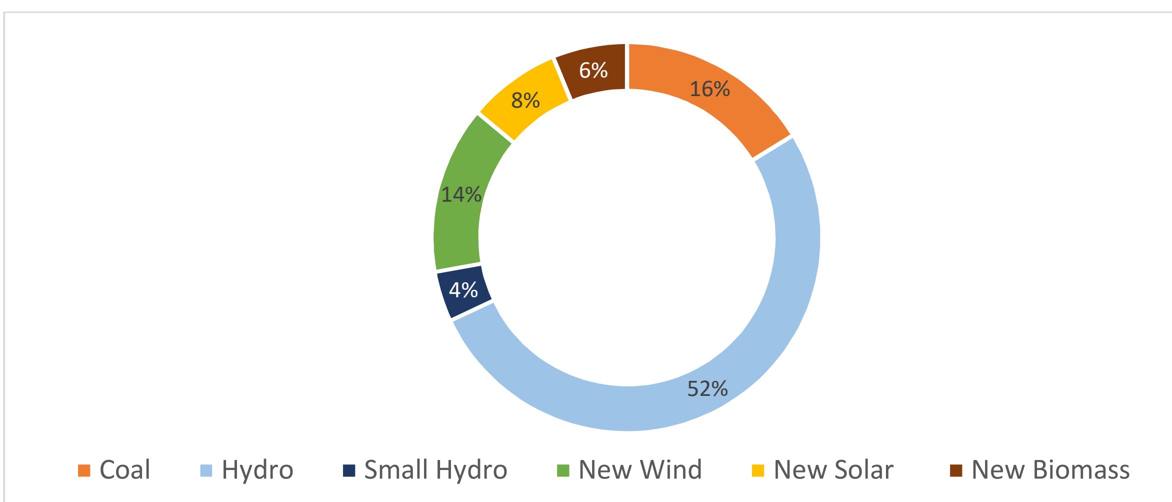

Figure 59. Generation capacities of Montenegro for the year 2030, source author's work

The demand of power system of Montenegro on an hourly basis for the year 2030 is shown in the figure 60. The minimum demand during the whole year occurred on June 26 and it was 220.8 MW. The maximum demand occurred on January 24 when the demand was 723.4 MW.

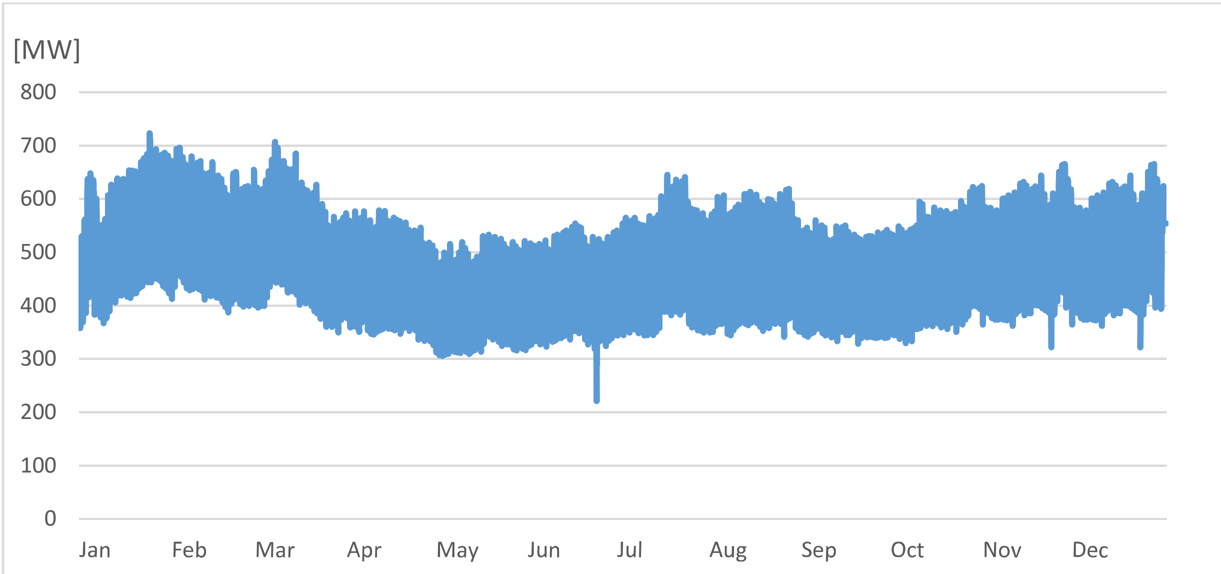

Figure 60. Power demand of Montenegro for the year 2030, source author's work

Montenegrin power system in 2030 generated 4 266 GWh of energy. Montenegrin hydropower plants, including small hydropower plants, generated the most in 2030. They generated 1 676 GWh. Coal-fired thermal power plants generated 1 552 GWh. Biomass power plant generated 472 GWh, while wind power plants contributed with 412 GWh. Solar power plants generated 154 GWh. After the simulation of the power system of Montenegro in an islanded mode results show that demand was not met by the generation for 124 hours in total. There is 3.5 GWh of consumption which Montenegrin system was not able to cover with energy coming from the national power plants.

4.4.5. Scenario for 2030: North Macedonia

Installed capacity of the power system of North Macedonia for the year 2030 was 1 970 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 61.

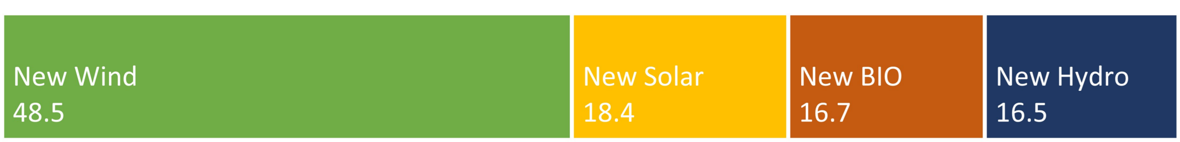

Figure 61. Percentages of the additional capacities, source author's work

Additional 598 MW were added to the power system from the reference case. Capacities coming from wind power plants cover 48.5% of the total added capacities or 290 MW. Solar power plants with capacity of 110 MW represent 18.4% of the added capacities. Biomass sums up to 100 MW, which represents 16.7% of the total additionally installed capacities. Small hydropower plants are taking part in the production of energy with installed capacity of 98 MW, which is 16.5% of the total added capacities. The percentages of units contributing to the energy mix of North Macedonia are shown in the figure 62.

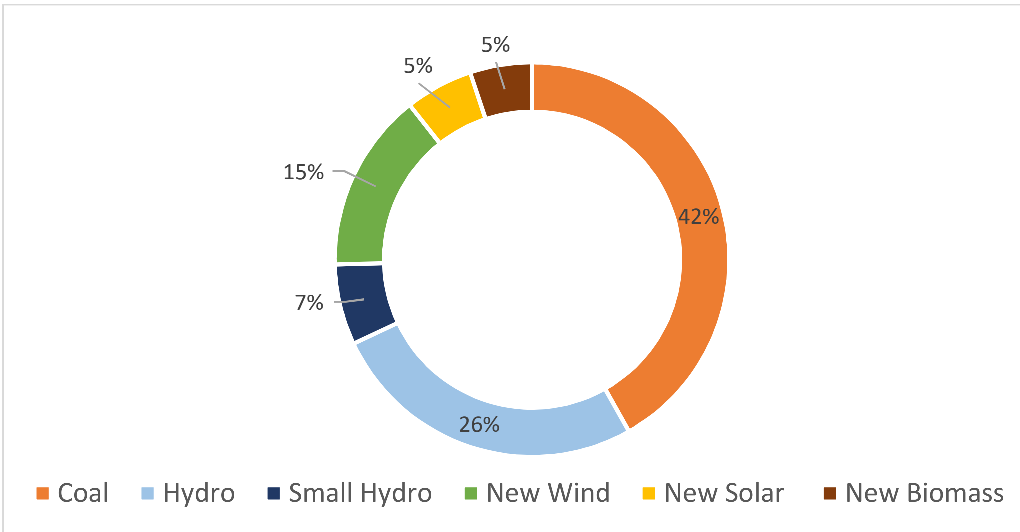

Figure 62. Generation units of North Macedonia for the year 2030, source author's work

The demand of power system of North Macedonia on an hourly basis for the year 2030 is shown in the figure 63. The minimum demand during the whole year occurred on May 2 and it was 585.6 MW. The maximum demand occurred on December 18 when the demand was 1 991.9 MW.

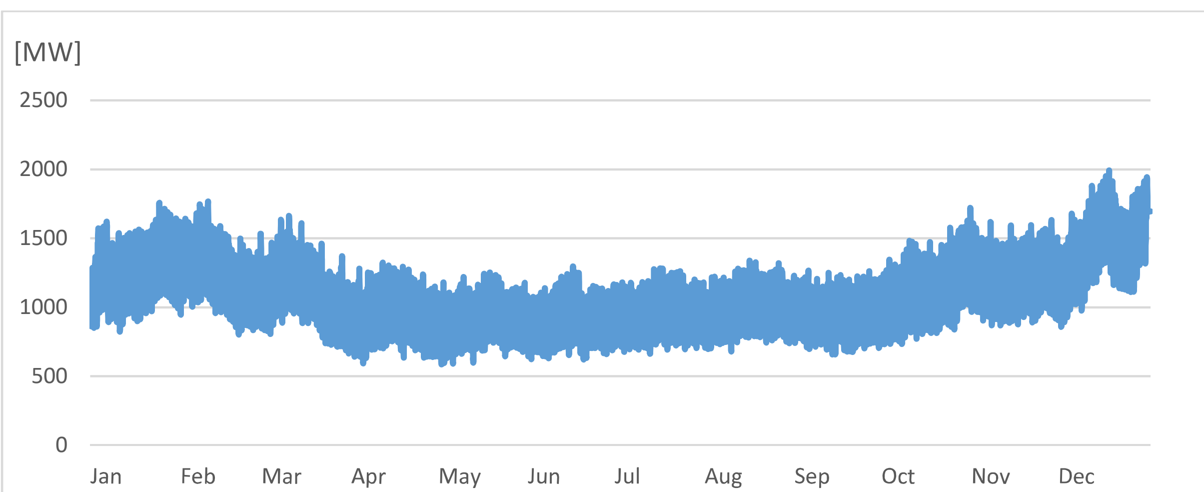

Figure 63. Power demand of North Macedonia for the year 2030, source author's work

In 2030, power system of North Macedonia generated 9 696 GWh of energy. The most electricity in 2030 in North Macedonia was produced in thermal power plants, i.e. 5 516 GWh. Hydropower plants, including small hydropower plants, generated 2 917 GWh. Biomass power plant generated 542 GWh. Wind power plants contributed with 571 GWh, while solar contributed with 150 GWh. After the simulation of the power system of North Macedonia in an islanded mode, results show that the system is not always able to meet the consumption needs. There is 123 GWh of consumption which power system of North Macedonia was not able to cover with energy coming from the national power plants.

4.4.6. Scenario for 2030: Serbia

Installed capacity of Serbian power system for year 2030 was 10 461 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 64.

Figure 64. Percentages of the additional capacities, source author's work

Additional 3 324 MW were added to the reference scenario power system. Capacities that use wind power cover 36.7% of the total added capacities or 1 220 MW. Biomass power plants has the second highest share in added capacities with 890 MW, which represents 26.8% of the total additionally installed capacities. Small hydropower plants have new installed capacity of 744 MW, which is 22.4% of the total added capacities. Solar power plants with capacity of 470 MW represent 14.1% of the added capacities. The percentages of generating units in Serbian power system are shown in the figure 65.

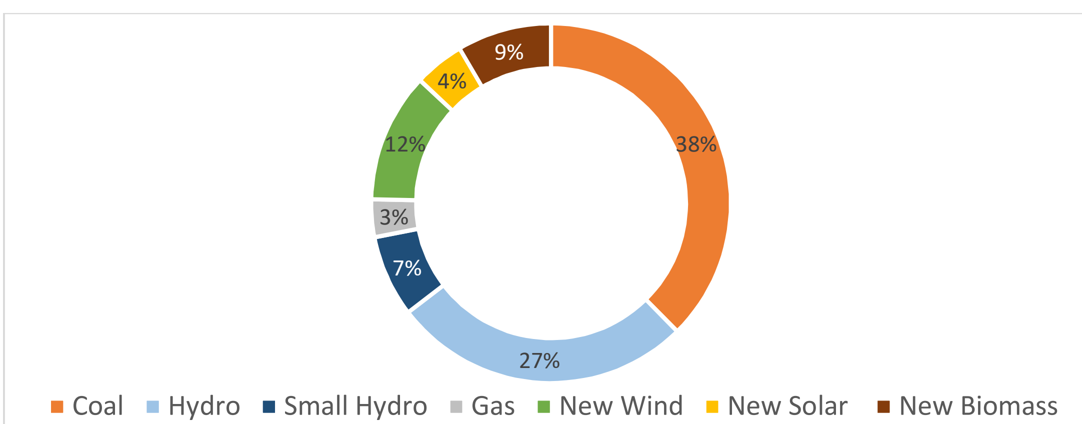

Figure 65. Generation capacities of Serbia for the year 2030, source author's work

The demand of Serbian power system on an hourly basis for the year 2030 is shown in the figure 66. The minimum demand during the whole year occurred on May 2 and it was 2 293.8 MW. The maximum demand occurred on December 31 when the demand was 7 196.3 MW.

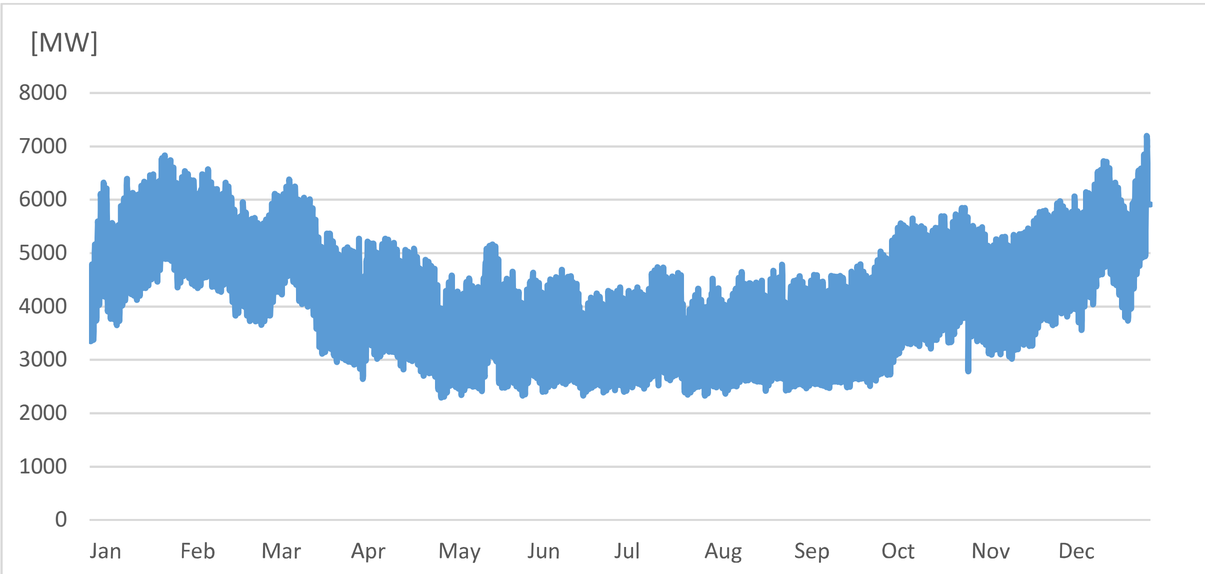

Figure 66. Power demand of Serbia for the year 2030, source author's work

In 2030, Serbian power system generated 37 579 GWh of energy. The most electricity in Serbia was produced in hydropower plants, including small hydropower plants. They generated 17 295 GWh. Thermal power plants that burn lignite produced 16 937 GWh. Wind power plants produced 2 685 GWh. Solar power plants contributed with 614 GWh, while biomass power plants produced 48 GWh. Results from the simulation of Serbian power system in islanded mode show that system was mostly always able to cover the consumption. In total, 30.7 GWh of extra energy has been generated above the demand level.

4.4.7. Scenario for 2030: Kosovo

Installed capacity of the power system of Kosovo for year 2030 is 1 397 MW. Additional renewable power plants were added to the scenario from 2015. The percentages of the new renewables added to the total installed capacities are presented in the figure 67.

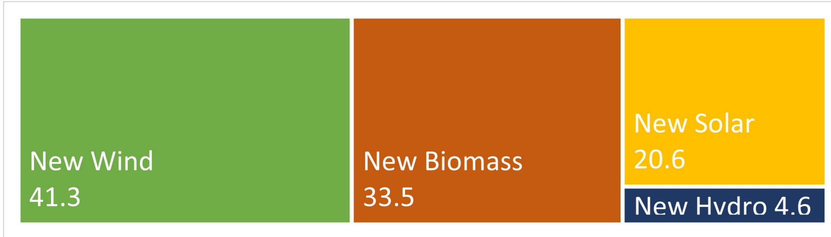

Figure 67. Percentages of the additional capacities, source author's work

Additional 436 MW were added to the power system from the reference case. Capacities coming from the wind power plants cover 41.3% of the total added capacities or 180 MW. Biomass power plants has the second highest share in added capacities with 146 MW, which represents 33.5% of the total additional installed capacities. Solar power plants have installed capacity of 90 MW, which is 20.6% of the total added capacities. In scenario for 2030 small hydropower plants with 20 MW of installed capacity were added in power system of Kosovo and they represent 4.6% of the added capacities. The percentages of renewables as well as the percentages of the other units contributing to the generation capacities of Kosovo are shown in the figure 68.

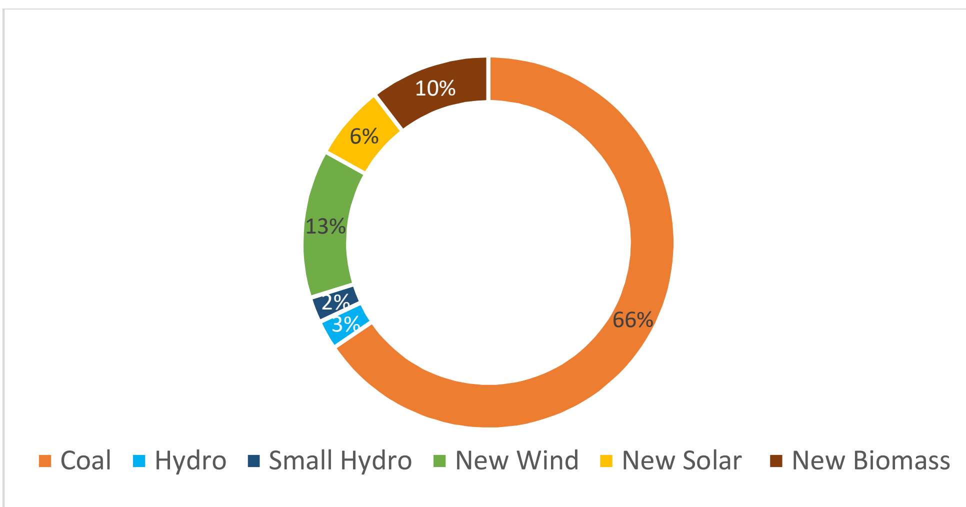

Figure 68. Generation capacities of Kosovo for the year 2030, source author's work

The demand of the power system of Kosovo on an hourly basis for the year 2030 is shown in the figure 69. The minimum demand during the whole year occurred on March 28 and it was 232 MW. The maximum demand occurred on December 31 when the demand was 1 452 MW.

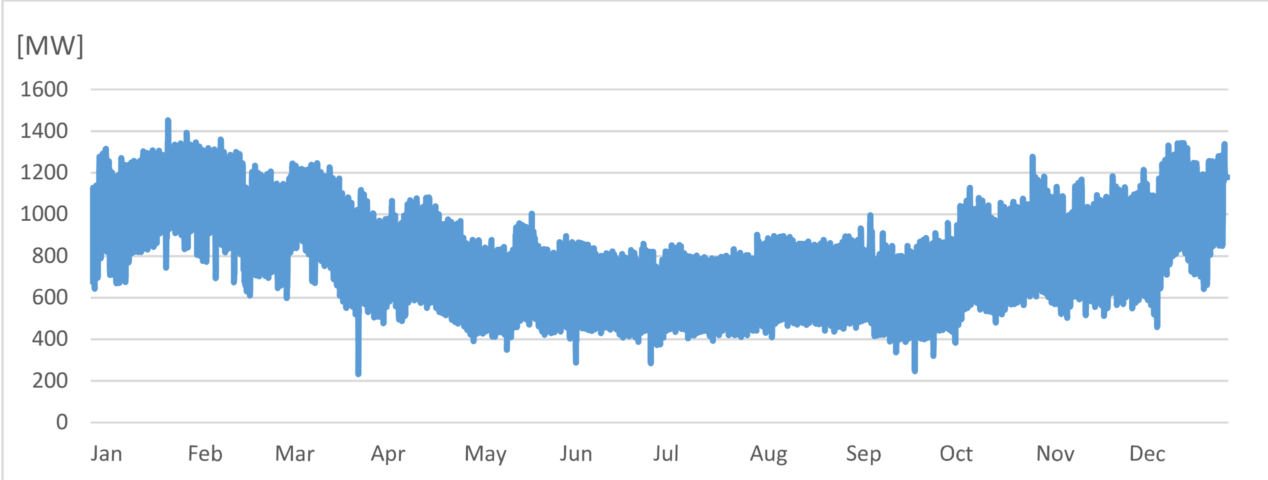

Figure 69. Demand of power system of Kosovo for the year 2030, source author's work

The power system of Kosovo in 2030 generated 6 847 GWh of energy. Coal-fired thermal power plants generated the most. They generated 5 617 GWh of energy. Biomass power plants generated 608 GWh. Wind power plants generated 321 GWh. Hydropower plants, including small hydropower plants, generated 188 GWh. Solar power plants produced 112 GWh. Results from the simulation of islanded power system of Kosovo showed that the system would not be able to cover the consumption. In total there is 332 GWh of demanded energy which power system of Kosovo was not able to cover with energy coming from the national power plants.

4.5. Comparison tables

For better understanding of the results from all three scenarios, the four tables were created. In the table 8. the basic information for all scenarios were presented. It contains following information: the installed capacity of all countries, capacity of renewable energy resources, energy generation and energy demand.

Installed capacities of the Western Balkans region and countries separately are presented for all scenarios in the table 9. The table contains information about installed capacities that run on different types of fuels, as well as their percentage in the total installed capacity.

Generation by different generation units from all scenarios are presented in the table 10. The table contains information about energy generated using different kind of fuels, i.e. water, biomass, solar, wind, oil, gas and lignite, as well as their share in total generated energy.

Electricity generation of countries in islanded mode and their generation when they are part of the integrated Western Balkans power system is presented in the table 11.

Table 8. *Comparison table*

	Scenario	Installed capacity [MW]	Renewables in MW	Percentage of renewables	Energy generated [GWh]	Energy demand [GWh]
Western Balkans	2015	15878.6	213	1.34	76127.3	75962.5
Western Balkans	2020	19582.4	3916.4875	20	83840	83657.3
Western Balkans	2030	23038.2	7372.2	32	85603.0	85527.2
Albania	2015	1895.2	84.6	4.5	6926.3	7265.4
Albania	2020	2263.2	452.6	20	9010.7	9282
Albania	2030	2662.6	852	32	10112.4	10159.8
Bosnia and Herzegovina	2015	3622	50.6	1.4	12364.6	12365.6
Bosnia and Herzegovina	2020	4465	893	20	16110.7	16109.5
Bosnia and Herzegovina	2030	5253	1680.9	32	16554.9	16549
Montenegro	2015	891.6	11.6	1.3	3236.6	3418.3
Montenegro	2020	1100	220	20	3947.8	4290
Montenegro	2030	1294.1	414.1	32	4266.4	4269.9
North Macedonia	2015	1371.8	32	2.3	7753	7838.5
North Macedonia	2020	1675	335	20	9053.8	9409.6
North Macedonia	2030	1970.3	630.5	32	9695.9	9819.6
Serbia	2015	7136.59	22.99	0.3	39593.6	39504.6
Serbia	2020	8892	1778.4	20	37114.8	37058.6
Serbia	2030	10461.2	3347.6	32	37579.3	37548.6
Kosovo	2015	960.9	10.9	1.13	5276.7	5570.3
Kosovo	2020	1187.5	237.5	20	6791.7	7469.8
Kosovo	2030	1397	447.1	32	6847.2	7179.8

Source: Author’s work

Table 9. *Installed capacities*

	Year	Small Hydro [MW]	Percent of Small Hydro in installed capacity	Biomass [MW]	Percent of Biomass in installed capacity	Solar [MW]	Percent of Solar in installed capacity	Wind [MW]	Percent of Wind in installed capacity	Large Hydro [MW]	Percent of Large Hydro in installed capacity	Lignite [MW]	Percent of Lignite in installed capacity	Oil [MW]	Percent of Oil in installed capacity	Gas [MW]	Percent of Gas in installed capacity	Installed capacity [MW]
Western Balkans	2015	212.6535	1.3%	0	0.0%	0	0.0%	0	0.0%	7795.95	49.1%	7419	46.7%	98	0.6%	353	2.2%	15878.6035
Western Balkans	2020	1364.8875	7.0%	831.6	4.2%	390	2.0%	1330	6.8%	7795.95	39.8%	7419	37.9%	98	0.5%	353	1.8%	19582.4375
Western Balkans	2030	1756.052941	7.6%	1746.16	7.6%	1290	5.6%	2580	11.2%	7795.95	33.8%	7419	32.2%	98	0.4%	353	1.5%	23038.16176
Albania	2015	84.64	4.5%	0	0.0%	0	0.0%	0	0.0%	1712.55	90.4%	0	0.0%	98	5.2%	0	0.0%	1895.19
Albania	2020	297.6375	13.2%	35	1.5%	50	2.2%	70	3.1%	1712.55	75.7%	0	0.0%	98	4.3%	0	0.0%	2263.1875
Albania	2030	382.0235294	14.3%	110	4.1%	160	6.0%	200	7.5%	1712.55	64.3%	0	0.0%	98	3.7%	0	0.0%	2662.573529
Bosnia and Herzegovina	2015	50.5575	1.4%	0	0.0%	0	0.0%	0	0.0%	2038	56.3%	1534	42.3%	0	0.0%	0	0.0%	3622.5575
Bosnia and Herzegovina	2020	333	7.5%	330	7.4%	80	1.8%	150	3.4%	2038	45.6%	1534	34.4%	0	0.0%	0	0.0%	4465
Bosnia and Herzegovina	2030	390.9411765	7.4%	420	8.0%	360	6.9%	510	9.7%	2038	38.8%	1534	29.2%	0	0.0%	0	0.0%	5252.941177
Montenegro	2015	11.566	1.3%	0	0.0%	0	0.0%	0	0.0%	670	75.1%	210	23.6%	0	0.0%	0	0.0%	891.566
Montenegro	2020	40	3.6%	20	1.8%	50	4.5%	110	10.0%	670	60.9%	210	19.1%	0	0.0%	0	0.0%	1100
Montenegro	2030	54.11764706	4.2%	80	6.2%	100	7.7%	180	13.9%	670	51.8%	210	16.2%	0	0.0%	0	0.0%	1294.117647
North Macedonia	2015	32	2.3%	0	0.0%	0	0.0%	0	0.0%	515.8	37.6%	824	60.1%	0	0.0%	0	0.0%	1371.8
North Macedonia	2020	104.95	6.3%	20	1.2%	30	1.8%	180	10.7%	515.8	30.8%	824	49.2%	0	0.0%	0	0.0%	1674.75
North Macedonia	2030	130.4941177	6.6%	100	5.1%	110	5.6%	290	14.7%	515.8	26.2%	824	41.8%	0	0.0%	0	0.0%	1970.294118
Serbia	2015	22.99	0.3%	0	0.0%	0	0.0%	0	0.0%	2824.6	39.6%	3936	55.2%	0	0.0%	353	4.9%	7136.59
Serbia	2020	578.4	6.5%	300	3.4%	150	1.7%	750	8.4%	2824.6	31.8%	3936	44.3%	0	0.0%	353	4.0%	8892
Serbia	2030	767.5764706	7.3%	890	8.5%	470	4.5%	1220	11.7%	2824.6	27.0%	3936	37.6%	0	0.0%	353	3.4%	10461.17647
Kosovo	2015	10.9	1.1%	0	0.0%	0	0.0%	0	0.0%	35	3.6%	915	95.2%	0	0.0%	0	0.0%	960.9
Kosovo	2020	10.9	0.9%	126.6	10.7%	30	2.5%	70	5.9%	35	2.9%	915	77.1%	0	0.0%	0	0.0%	1187.5
Kosovo	2030	30.9	2.2%	146.159	10.5%	90	6.4%	180	12.9%	35	2.5%	915	65.5%	0	0.0%	0	0.0%	1397.058824

Source: Author’s work

Table 10. *Energy generation*

	Year	Water [GWh]	Percent of water in total energy generated	Biomass [GWh]	Percent of biomass in total energy generated	Solar [GWh]	Percent of solar in total energy generated	Wind [GWh]	Percent of wind in total energy generated	Lignite [GWh]	Percent of lignite in total energy generated	Oil [GWh]	Percent of oil in total energy generated	Gas [GWh]	Percent of gas in total energy generated	Total Energy generated [GWh]
Western Balkans	2015	28554.0	37.5%	0.0	0.0%	0.0	0.0%	0.0	0.0%	47573.4	62.5%	0	0.0%	0	0.0%	76127.3
Western Balkans	2020	36790.6	43.9%	390.0	0.5%	526.6	0.6%	2837.2	3.4%	43295.8	51.6%	0.0	0.0%	0	0.0%	83840.1
Western Balkans	2030	38874.4	45.4%	169.5	0.2%	1714.8	2.0%	5449.9	6.4%	39398.1	46.0%	0.0	0.0%	0	0.0%	85606.7
Albania	2015	6773.9	97.8%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	152.4	2.2%	0	0.0%	6926.3
Albania	2020	8509.4	94.4%	168.0	1.9%	60.5	0.7%	120.8	1.3%	0.0	0.0%	152.0	1.7%	0	0.0%	9010.7
Albania	2030	9052.5	89.5%	491.4	4.9%	194.8	1.9%	356.5	3.5%	0.0	0.0%	17.1	0.2%		0.0%	10112.4
Bosnia and Herzegovina	2015	6597.3	53.4%	0.0	0.0%	0.0	0.0%	0.0	0.0%	5767.3	46.6%	0.0	0.0%	0	0.0%	12364.6
Bosnia and Herzegovina	2020	7271.0	45.1%	25.5	0.2%	95.2	0.6%	294.2	1.8%	8424.9	52.3%	0.0	0.0%	0	0.0%	16110.8
Bosnia and Herzegovina	2030	7410.6	44.8%	7.3	0.0%	428.4	2.6%	1000.2	6.0%	7708.5	46.6%	0.0	0.0%	0	0.0%	16554.9
Montenegro	2015	1680.1	51.9%	0.0	0.0%	0.0	0.0%	0.0	0.0%	1556.5	48.1%	0.0	0.0%	0	0.0%	3236.6
Montenegro	2020	1830.8	46.4%	150.2	3.8%	77.0	2.0%	251.8	6.4%	1638.0	41.5%	0.0	0.0%	0	0.0%	3947.9
Montenegro	2030	1676.2	39.3%	471.6	11.1%	154.1	3.6%	412.1	9.7%	1552.5	36.4%	0.0	0.0%	0	0.0%	4266.4
North Macedonia	2015	2006.9	25.9%	0.0	0.0%	0.0	0.0%	0.0	0.0%	5746.1	74.1%	0.0	0.0%	0	0.0%	7753.0
North Macedonia	2020	2866.8	31.7%	139.9	1.5%	40.9	0.5%	354.5	3.9%	5651.6	62.4%	0.0	0.0%	0	0.0%	9053.8
North Macedonia	2030	2917.1	30.1%	541.9	5.6%	149.9	1.5%	571.1	5.9%	5515.9	56.9%	0.0	0.0%	0	0.0%	9696.0
Serbia	2015	11717.3	29.6%	0.0	0.0%	0.0	0.0%	0.0	0.0%	27779.0	70.2%	0.0	0.0%	97.3	0.2%	39593.6
Serbia	2020	16238.8	43.8%	53.9	0.1%	195.9	0.5%	1650.7	4.4%	18975.6	51.1%	0.0	0.0%	0	0.0%	37114.9
Serbia	2030	17295.1	46.0%	48.3	0.1%	613.9	1.6%	2685.0	7.1%	16937.0	45.1%	0.0	0.0%	0	0.0%	37579.3
Kosovo	2015	141.9	2.7%	0.0	0.0%	0.0	0.0%	0.0	0.0%	5134.9	97.3%	0.0	0.0%	0	0.0%	5276.7
Kosovo	2020	142.0	2.1%	685.4	10.1%	37.5	0.6%	124.9	1.8%	5802.0	85.4%	0.0	0.0%	0	0.0%	6791.8
Kosovo	2030	188.5	2.8%	608.1	8.9%	112.5	1.6%	321.2	4.7%	5617.1	82.0%	0.0	0.0%	0	0.0%	6847.3

Source: Author's work

Table 11. *Electricity generation of countries in islanded mode and as part of an integrated system*

Country	Year	Water [GWh]		Difference	Biomass [GWh]		Difference	Solar [GWh]		Difference	Wind [GWh]		Difference	Lignite [GWh]		Difference	Oil [GWh]		Difference	Gas [GWh]		Difference	Total Integrated [GWh]	Total inslanded [GWh]	Difference
		Integrated	Islanded		Integrated	Islanded		Integrated	Islanded		Integrated	Islanded		Integrated	Islanded		Integrated	Islanded		Integrated	Islanded				
Albania	2015	7111.5	6773.9	337.5	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	152.4	-152.4	0	0	0.0	7111.5	6926.3	185.1
Albania	2020	8971.0	8509.4	461.6	21.6	168.0	-146.4	80.0	60.5	19.5	161.1	120.8	40.3	0	0	0.0	0	152.0	-152.0	0	0	0.0	9233.7	9010.7	223.0
Albania	2030	9711.6	9052.5	659.1	28.9	491.4	-462.5	256.0	194.8	61.2	460.2	356.5	103.7	0	0	0.0	0	17.1	-17.1	0	0	0.0	10456.7	10112.4	344.3
Bosnia and Herzegovina	2015	6653.2	6597.3	55.9	0	0	0.0	0	0	0.0	0	0	0.0	8822.5	5767.3	3055.2	0	0	0.0	0	0	0.0	15475.7	12364.6	3111.1
Bosnia and Herzegovina	2020	7278.3	7271.0	7.3	208.1	25.5	182.6	95.2	95.2	0.0	294.2	294.2	0.0	8329.9	8424.9	-95.0	0	0	0.0	0	0	0.0	16205.6	16110.8	94.8
Bosnia and Herzegovina	2030	7407.0	7410.6	-3.6	18.2	7.3	11.0	428.4	428.4	0.0	1000.2	1000.2	0.0	7881.9	7708.5	173.4	0	0	0.0	0	0	0.0	16735.7	16554.9	180.8
Montenegro	2015	1576.5	1680.1	-103.6	0	0	0.0	0	0	0.0	0	0	0.0	1526.0	1556.5	-30.5	0	0	0.0	0	0	0.0	3102.5	3236.6	-134.1
Montenegro	2020	1642.3	1830.8	-188.6	6.8	150.2	-143.4	77.0	77.0	0.0	251.8	251.8	0.0	1604.4	1638.0	-33.6	0	0	0.0	0	0	0.0	3582.3	3947.9	-365.6
Montenegro	2030	1674.4	1676.2	-1.8	0	471.6	-471.6	154.1	154.1	0.0	412.1	412.1	0.0	1572.0	1552.5	19.5	0	0	0.0	0	0	0.0	3812.5	4266.4	-453.9
North Macedonia	2015	1779.6	2006.9	-227.3	0	0	0.0	0	0	0.0	0	0	0.0	4402.8	5746.1	-1343.3	0	0	0.0	0	0	0.0	6182.4	7753.0	-1570.6
North Macedonia	2020	2457.4	2866.8	-409.5	6.7	139.9	-133.2	40.9	40.9	0.0	354.5	354.5	0.0	3118.4	5651.6	-2533.2	0	0	0.0	0	0	0.0	5977.9	9053.8	-3075.9
North Macedonia	2030	2570.7	2917.1	-346.4	0	541.9	-541.9	149.9	149.9	0.0	571.2	571.2	0.0	2403.4	5515.9	-3112.5	0	0	0.0	0	0	0.0	5695.2	9696.0	-4000.8
Serbia	2015	11385.1	11717.3	-332.2	0	0	0.0	0	0	0.0	0	0	0.0	27282.2	27779.0	-496.8	0	0	0.0	0	97.3	-97.3	38667.3	39593.6	-926.3
Serbia	2020	16299.9	16238.8	61.2	110.9	53.9	57.0	195.9	195.9	0.0	1650.7	1650.7	0.0	25434.6	18975.6	6459.0	0	0	0.0	0	0	0.0	43692.0	37114.9	6577.2
Serbia	2030	17322.0	17295.1	26.9	122.4	48.3	74.1	613.9	613.9	0.0	2685.1	2685.1	0.0	22918.4	16937.0	5981.5	0	0	0.0	0	0	0.0	43661.8	37579.4	6082.4
Kosovo	2015	141.9	141.9	0.0	0	0	0.0	0	0	0.0	0	0	0.0	5422.9	5134.9	288.0	0	0	0.0	0	0	0.0	5564.8	5276.7	288.1
Kosovo	2020	141.7	142.0	-0.3	35.9	685.4	-649.5	37.5	37.5	0.0	124.9	124.9	0.0	4808.5	5802.0	-993.5	0	0	0.0	0	0	0.0	5148.5	6791.8	-1643.2
Kosovo	2030	188.8	188.5	0.4	0	608.1	-608.1	112.5	112.5	0.0	321.2	321.2	0.0	4622.3	5617.1	-994.7	0	0	0.0	0	0	0.0	5244.8	6847.3	-1602.5

Source: Author’s work

Conclusions

Modelling of power systems is a really effective and strong tool for solving the issues in the power sector. Energy models give researchers the opportunity to test their hypothesis by creating huge amount of different scenarios. The results from these scenarios can help to understand better the functioning of the whole system and to create better energy policies in general.

Thanks to the data availability for the region of the Western Balkans and open-source nature of the model, Dispa-SET model has been used for the purpose of this Master thesis. In total 21 simulations were carried out for the three different years: 2015, which represents a reference year due to data availability, 2020 and 2030. For every year 7 simulations were created.

The Western Balkans are rich in coal and that is the reason why this type of fuel is heavily used for the electricity generation. Electricity generation coming from coal is very reliable since the generation can happen during the whole year and during the whole day. That is why it is usually used to cover the base load of the demand curve. Unfortunately, thermal power plants that burn coal are polluting air. Since the power demand in the region will increase in the future there will be need for more generating units. That was the motivation to add only generating capacities that use renewable energy. Installing renewable capacities instead of the units that use coal as their fuel would result in decrease of the air pollution.

Based on the simulation sets in all scenarios it can be noticed that the two main types of power plants that have the highest installed power in the Western Balkans are hydropower plants and coal-fired thermal power plants. Since in all scenarios there was increase of installed capacities of renewable energy power plants in the power systems, the decrease of share of the coal-fired thermal power plants in the total installed capacity of the systems was expected. In the period from 2015 to 2030 there was a drop down of coal-fired thermal power plants from 46.7% to 32.2% of the total installed capacity of the Western Balkans power system. Percentages of units that use renewable energy for electricity production, including in this case large hydro power plants, in 2020 was 59.8% and it increased by 9.4% from the level in 2015, when it was 50.4%. In 2030 there was a rise to 65.8%, which represents the increase of 15.4% from the 2015 level.

Simulations done on the national level in islanded mode showed that in 2015 percentage of units that use renewable energy for electricity generation, i.e. small hydropower plants, biomass, solar and wind power plants, had a really low share in the total installed capacities of the examined countries. Percentages vary from 0.3%, in case of Serbia, to 4.5%, in case of Albania. Adding new units that produce electricity coming from renewable energy had a positive impact on lowering the share of coal-fire thermal power plants in installed capacities of the examined countries. In Serbia and North Macedonia the share of the coal-fired thermal power plants in the total generating capacities dropped down under 50% in 2020. In all the other countries the share of these power plants in the total installed capacity was already under 50%. Kosovo is exception because, in 2015 the share was 95.2%, while in 2030 it was 65.5%. This makes Kosovo a country with a highest drop, i.e. drop of 29.7%, in share of the coal-fired power plants in the total installed capacities among the all five countries that have coal-fired power plants.

When it comes about electricity generation, results from all scenarios show that hydropower plants and coal-fired thermal power plants are also the two main types of power plants that generate the most of the electricity in the Western Balkans. Results also show that the energy mix of the region became greener by adding more units that produce electricity coming from sun, water, biomass and wind. Results after the simulation of integrated region of Western Balkans in all three scenarios, show that there is a drop in share of electricity coming from the lignite, while there is an increase of energy coming from the renewable energy sources. Compared to the level in 2015, when the lignite had a share of 62.5%, in 2020 it decreased to 51.6%, while in 2030 it dropped down to 46%. That means that in 2030 energy coming from wind, water, sun and biomass had higher share in the energy mix than lignite. Electricity generation coming from large and small hydropower plants, solar, biomass and wind power plants increased from 37.5% in 2015 to 48.4% in 2020, while in 2030 it had a share of 54% in energy mix. This situation was expected since there was no increase in installed capacities of units that burn lignite, while there was an increase of installed capacity of renewable energy power plants in all scenarios.

When the simulations were run for all six countries in islanded mode, the results show the reduction of lignite in energy mix of the countries that use lignite in energy generation. In 2015 in case of North Macedonia, Serbia and Kosovo lignite was covering more than 50% of their energy mix, while in case of Montenegro and Bosnia and Herzegovina lignite had a share slightly less than 50%. Kosovo is a specific example because its energy generation is mainly based on coal-fired power plants. In 2015, lignite had a share of 97.3% in energy mix of Kosovo. This level decreased to 85.4% in 2020 and in 2030 it was 82%, thanks to the increase of generating capacities that use renewable energy. Serbia with 25.1% is the country that had the highest drop in percentage of energy coming from lignite from the level in 2015 to the level in 2030. The percentages dropped down from 70.2% to 45.1%. The country that in

2030 had the lowest level of energy coming from the coal-fired thermal power plants is Montenegro. In 2030, lignite had a share of 36.4% in the energy mix of Montenegro.

Electricity generated from the water power plays significant role in almost all of the examined countries, with exception of Kosovo. In 2015, in Montenegro and in Bosnia and Herzegovina more than half of the energy generated was coming from the hydropower plants. In 2015, water was the only renewable energy source used in all six examined countries. Situation changed in 2020 and 2030, by adding other types of renewable energy power plants. As a result, electricity coming from the renewables increased its share in the energy mix of the countries. North Macedonia, Serbia and Kosovo are examples of the countries that had growth more than 15% in energy coming from renewables from the level in 2015 to the level in 2030. Although in 2030 Albania had a jump of only 2% from the 2015 level, the generation of electricity coming from renewables in 2030 covered 99.8% of the total energy generation.

It is also interesting to compare the energy generated in integrated region of the Western Balkans and sum of energy generated in all 6 countries of the region in islanded mode. At the very beginning it is important to remind that the region as integrated unit has a potential to cover the demand of the whole region, which is not the case when the countries have isolated power systems that have no interaction with the neighbouring systems. First huge difference is in generation coming from lignite. The difference of electricity coming from lignite between the integrated Western Balkans scenario and sum of the energy generated in all 6 countries of the region in islanded mode in 2015 was 1 589 GWh. That means that in 2015 the Western Balkans in integrated mode generated more energy coming from lignite. The same thing happened in 2020 and 2030, when the differences were 2 803 GWh and 2 067 GWh, respectively. This means that energy is greener when the simulations are done in islanded mode but at the same time the total energy generated in this scenario is not enough to cover the demand of all countries and many of them would struggle to cover their needs and would face severe problems in their power systems. The need for generating more energy in order to cover the demand resulted in higher amount of energy coming from biomass in case when the simulations are run for the countries in islanded mode. This makes sense because countries need to find energy to cover the demand curve and biomass is a good solution since it can operate until there is biomass. The bad side of biomass is that it has a price and its price is higher than the price of lignite or black-coal. As a result total power system costs are higher when the biomass power plants are used. That explains why in 2020 generation of energy coming from biomass power plants in integrated Western Balkans scenario was 833 GWh less than when the simulations were run for the countries in islanded mode. In 2030 the difference was even higher, i.e. it was 1 999 GWh. Having on mind the fact that there are more combinations for unit commitment problem when the power systems of the region are integrated and that the objective function of the model is minimisation of the total power system costs, it explains the reason why lignite is more used in case of integrated Western Balkans.

General conclusions cannot be drawn from comparison of energy generated in the examined countries when they were part of an integrated Western Balkans region and when the simulations for those countries were carried out in an islanded mode. Some countries generated more energy when they were part of integrated system, while the other generated less. Montenegro and North Macedonia are the two countries that generated less energy when they were part of integrated system in all three scenarios. In case of North Macedonia the difference is even more obvious, since the differences were 1 570 GWh in 2015, 3 076 GWh in 2020 and 4 001 GWh in 2030. Kosovo generated less as part of integrated system in 2020 and 2030, when the differences were 1 643 GWh and 1 602 GWh, respectively. On the other hand, Albania, Bosnia and Herzegovina and Serbia generated more energy in integrated system. The difference is the highest in case of Serbia in 2020 and 2030, when it was 6 577 GWh and 6 082 GWh, respectively. Checking the generation coming from the different sources it can be noted that generation coming from solar and wind power plants were the same in both cases. Only in case of Albania there were slight differences. Biomass power plant were less favoured when the countries were part of integrated Western Balkans. The biggest differences, of course, can be seen in production of energy coming from lignite. During all three years North Macedonia generated less in integrated than in islanded mode. In 2015 the difference was 1 343 GWh, in 2020 it was 2 533 GWh, while in 2030 it was 3 112 GWh. The country that increased its production of energy coming from lignite in order to fulfil the demand of the integrated Western Balkans region was Serbia. In 2020, as part of integrated region its coal-fired thermal power plants generated 6 459 GWh more than in islanded scenario, while in 2030 they generated 5 981 GWh more.

The results from the simulation scenarios suggest that the region in interconnected mode would not have huge problems in covering its need for the electricity demand even in the cases with increased percentage of renewables. In the cases when the simulations were carried out for the every country individually in an islanded mode, results were different from country to country. Some countries like Serbia and Bosnia and Herzegovina have a potential to work in the islanded mode while the rest, including Albania, Montenegro, North Macedonia and Kosovo have less potential in working in such a regime. These results confirm the need for interconnection of the power systems in the Western Balkans.

The future work should include implementation of the scenarios for 2020 and 2030 where the percentages of energy coming from small hydropower plants, wind, solar and biomass power plants in total electricity production would amount to 20% and 32%, respectively. It could be also interesting to implement scenarios for 2050, i.e. for long term planning, following the recently presented roadmap by European Commission called The European Green Deal, which will include the Western Balkans.

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