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Analysis of the water-power nexus of the Balkan Peninsula power system

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Abstract

The operation and economics of the power systems are constrained by the availability and temperature of water resources since thermal power plants need water for cooling and hydropower plants need water to generate electricity. In Europe and North America, water shortages or high river water temperatures have recurrently occurred in the last years, leading to financial losses, power curtailments, temporary shutdowns, demand restrictions, and ultimately increased wear and tear of the power plants. On the other hand, the operation of the power system may affect the quantity and quality of the water resources.

This study describes the implementation and testing of a modelling framework to analyse the interactions between water resources and the power system in the Western Balkans and the neighbouring EU Member States (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Hungary, Kosovo[1], Montenegro, North Macedonia, Romania, Serbia and Slovenia). The methodological approach consists of combining the hydrological LISFLOOD model with the Dispa-SET Medium-Term Hydrothermal Coordination (MTHC) and Unit Commitment and Dispatch (UCD) models for simulation of the regional power system. Three scenarios are used to investigate the changes in the operation of the regional power system under different hydrological conditions (dry, average and wet years).

The outcomes include economic and operational results at unit, country and regional level, plus an analysis of the thermal power plants at water-scarce locations based on their calculated water stress indices.

[1] This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.

1 Introduction

The power generation sector withdraws and consumes large amounts of water for hydropower generation and for the cooling of thermal power plants. Therefore the operation of the power generation sector is constrained by the availability of the water resources, but the water resources are also used for a variety of purposes not related to the power sector, such as irrigation, flood control, water supply, agriculture, etc. (Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2017), (Fernandez-Blanco Carramolino et al., 2016), (Magagna et al., 2019).

According to the International Commission on Large Dams, irrigation is the most common use of water reservoirs while hydropower generation represents the second largest use of single-purpose dams, followed by water supply. Multipurpose dams are mostly used for flood control and water supply.(Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2017)

In the past decade there have been several examples of issues related to the shortage of water resources or high river water temperatures needed for proper cooling of thermal power plants (Fernandez-Blanco Carramolino et al., 2016). Mostly due to the joint effects of heat waves and bad hydrological conditions of the main river channels, generation from thermal power plants may need to be curtailed, as happened with several nuclear power plants in France in 2003, with a cost of EUR 300 million. In 2006, France, Germany and Spain had to reduce their nuclear power generation due to the high river water temperatures. Poland experienced reduced coal power generation and restricted industrial demand in 2015-2016 due to the same reasons. Those events bring demand restrictions, monetary losses and increased wear of the thermal power plants. In July 2018, the heatwave across Europe forced EDF to reduce electricity generation from nuclear power reactors Bugey 2, Bugey 3, St. Alban 1 and Fessenheim 2. The power output from Bugey 3 was reduced by 665 MW, and by 300 MW in Fessenheim 2 reactor, and EDF had to prolong outages of Bugey 2 and St. Alban 1 reactors due to the high temperatures of the Rhone River. Higher temperatures of the Rhine River affected the output of nuclear, coal and gas power plants in Germany and Switzerland (Fernandez-Blanco Carramolino et al., 2016), (Magagna et al., 2019), (Röhrkasten, Schäuble, and Helgenberger, 2016), (IEA, 2012), (S&P Global Platts, 2016).

Similar episodes are expected to occur more frequently due to climate change, and that leads to questions on how to implement a better management of water and energy resources (Fernandez-Blanco Carramolino et al., 2016). This water-energy nexus is one of the matters studied by the Water-Energy-Food-Ecosystems Nexus project (WEFE) carried out by the European Commission's Joint Research Centre.

Even though the importance of the water-energy nexus is recognized as a new challenge, current power system models overlook water-related constraints as contributions to power system management. Hydropower is a mature technology that provides benefits for the total power system operation. Spinning reserve, black start capability, frequency response, flexibility and reserve with quick start and shutdown capabilities, identify hydropower as a main cost-competitive resource for integration of variable renewable sources into the European power system (Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2017), (Fernandez-Blanco Carramolino et al., 2016). Hydrological related constraints determine hydropower production, which in turn determine the operation of thermal power plants related to its water sources for proper cooling. Thus, the better understanding of the water-energy nexus is needed to enable flexible power generation for the future European power system (Fernandez-Blanco Carramolino et al., 2016).

To better represent and analyse water-power nexus, the method proposed in the WEFE project consists of combining the LISFLOOD hydrological model (Burek, van der Knijff, and de Roo, 2013) with the Dispa-SET Unit Commitment and Dispatch (Dispa-SET UCD) (Quoilin, Hidalgo Gonzalez, and Zucker, 2017) and Dispa–SET Medium-Term Hydrothermal Coordination (Dispa-SET MTHC) (Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2016) models. The latter one determines reservoir levels of the hydropower plants during a certain period, based on LISFLOOD outputs, while the first one establishes schedule operations and dispatch, as well as the economic results related to power generation.

1.1 Climate change and hydropower production

The European Union has adopted ambitious targets to help fight climate change. By 2030, the EU should achieve at least:

— 40% cuts in green gas emissions over pre-industrial level,

— 32% share for renewable energy in gross final energy consumption, and

— 32.5% improvement in energy efficiency.

The in-depth analysis in support of the communication from the European Commission, *A clean planet for all: a European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy* (European Commission, 2018) warns that:

Thermoelectric generation will be under more pressure in Southern European regions where their water cooling needs may no longer be met: they may generate up to 20% less under a 3°C scenario; 15% less in a 2°C world. Thermal electricity generation may suffer most from water stress in the near term in the Mediterranean, France, Germany and Poland.

While the magnitude of these impacts is not expected to jeopardise Europe's long-term decarbonisation path, it may entail higher costs and different regional energy mixes, unless adaptive measures are deployed, such as increased plant efficiencies, replacement of cooling systems and fuel switches. Private stakeholders in the energy system and EU and national policies should reinforce the right market framework to ensure that the climate impacts do not jeopardise the EU's stability and security of energy supply. Transitions in the electricity sector should encompass both mitigation and adaptation planning, if they are to sustain and secure a sustainable water–energy nexus in the next few decades.

A case study conducted at four hydropower plants located in the Western Balkans concludes that (WBG, 2015):

- Impacts of climate change are related to direct effects on the hydropower generation potential, that being river flow, but also indirectly through an increase in general demand for energy due to higher summer and lower winter temperatures (WBIF, 2017), (WBG, 2015).
- A decrease in river flow would affect power generation for all types of hydropower plants but the highest effect would be on run-of-river hydropower plants (WBIF, 2017), (WBG, 2015).
- With the increase in temperature, the evaporation rate of the reservoirs would affect hydropower production of the facilities with smaller reservoirs that have a high area to volume ratio. Other types of hydropower plants would experience the same effect, but in a smaller amount in total hydropower production decrease (WBIF, 2017), (WBG, 2015).
- With higher runoffs in the autumn/winter and lower in spring/summer, high impact on the overall decrease of hydropower production of run-of-river hydropower plants and hydropower plants with small storage would be experienced.(WBIF, 2017), (WBG, 2015).

The countries of the Balkan Peninsula are among some of the most water-rich countries in Europe (WBIF, 2017), with around 10 600 m^3 of water available per capita. Water resources have always been important for the Balkan Peninsula economy with its use for irrigation, industry, drinking water supply, tourism, livestock production and hydropower production. The hydropower electricity generation accounts for 49% of all electricity generated in the Western Balkan region (WBIF, 2017).

The Balkan Peninsula is getting warmer and it is expected that this trend will continue due to climate change. Even though precipitation rates change with terrain, elevation and proximity to the sea, the region is experiencing lower annual precipitation with projections for a further decrease. The projections state that if the worst case scenario happens, that being the 4°C rise, the Balkan Peninsula region could face reduced water availability with precipitations declining between 20-50% (WBG, 2014). As most countries in the Balkan region depend on hydropower sources, reduction in water availability would strongly affect the region's power system, with projections that the hydropower potential in Croatia could decrease by 35%. Also, the mean number of days during which electricity generation will be reduced by more than 90% is projected to increase due to the increased possibility of extremely low river flows in summer days (WBIF, 2017), (WBG, 2014).

Overall, we can assume that, due to the future extreme droughts in summer and floods in the autumn/winter, the adaptation of hydropower plants to climate change relies on better management of water reservoirs. The reservoirs should be managed and sized to compensate for the increase in seasonal runoffs (WBIF, 2017).

1.2 Literature review

For the past decade, the water-power nexus has been a popular research topic. The International Energy Agency brought the question on the dependence of energy on water and vice versa (IEA, 2012), (IEA, 2016). In 2014, the US Department of Energy published the report "The Water-Energy Nexus: Challenges and Opportunities" (DOE, 2014). Security of sustainable electricity supply in cooperation with the water management was discussed in (Röhrkasten, Schäuble, and Helgenberger, 2016). The cooperation between the US Department of Energy, the European Commission's Joint Research Centre and the Directorate-General for Research and Innovation organized a workshop for better integration of water and power systems (EC-JRC, 2016).

The methodology used for this study has already been applied to the Greek power system (Fernandez-Blanco Carramolino et al., 2016), the Iberian Peninsula (Fernandez Blanco Carramolino et al., 2017) and West African Power Pool (De Felice et al., 2019). The study on Iberian Peninsula included a vulnerability analysis of cooling-related constraints on maximum allowable water withdrawal for coal-fired power plants with high marginal cost and moderate installed capacity, and nuclear power plant with low marginal cost and high installed capacity. Hardy, Garrido and Juana also studied the water-energy nexus in Spain, focusing on "energy for water" and "water for energy" (Hardy, Garrido, and Juana, 2012). The "energy for water" connection is divided into water use stages for which their energy cost per water volume are calculated, with special consideration of irrigation. The "water for energy" section calculates the water needs in power plants per unit of electricity generated.

Zafirakis et al. studied the water needs in the Greek electricity sector concluding that the promotion of renewable energy sources will ensure conservation of water resources in vulnerable regions (Zafirakis et al., 2014). They collected the data on operation of representative thermal power plants and most mature RES technologies to determine the minimum water needs. They discovered that the water use of lignite-fired power plants are as expected in form of higher water withdrawal coefficient, but are lower in form of water consumption, when compared to the international available data. They concluded that higher RES penetration in water stressed regions like West Macedonia, West Peloponnesus and Crete might resolve the local water scarcity in those regions. The water-energy nexus for Greece is also studied by Ziogou and Zachariadis, who provided the calculations of water consumption for conventional thermal power plants (lignite, diesel, oil, gas fired), extraction and refining processes in the primary energy production sector, production of biodiesel (Ziogou and Zachariadis, 2015). To connect the water consumption with energy, they provided the calculation of electricity consumption for purposes of water supply and water treatment. They conclude that the most water-intensive sector is lignite and oil-fired thermal power generation with average water consumption of 1.81 m^3/MWh, followed by CCGT power generation with water consumption of 1.19 m^3/MWh. Biofuel production accounts for nearly 0.5 m^3/MWh, while the primary fuel production requires the least amount of freshwater.

When comparing the energy need for water sector, the water supply is far more energy-intensive than the water treatment. Z. Khan, P. Linares and J. García-González discuss in (Khan, Linares, and García-González, 2016) and (Khan, Linares, and García-González, 2017) the adaptation to water constraints in the Spanish energy sector and the integration of water and energy models. In (Khan, Linares, and García-González, 2016) they use two scenarios, "Unconstrained" and "Stressed", to compare the benefits of using the integrated water-energy model ("Stressed" scenario), which takes water constraints into account, and traditional non-integrated energy models ("Unconstrained"), which neglect the importance of water constrains. The main conclusion is that ignoring the water constraints in the energy sector may lead to unpredicted costs under scenarios including climate change. They estimated that the cost of not planning for the future water-restricted scenarios may range from 0.2% to 8% of the system cost, which is more than double the cost of adaptation. In (Khan, Linares, and García-González, 2017) they review the contemporary work and recommendations for future developments. The need and barriers of water and energy integration, integrated water and energy modelling and list of recommendations is represented in detail in (Khan, Linares, and García-González, 2017).

The vulnerability of electricity generation to water stress in the EU is studied in (Behrens et al., 2017), which investigates climate impacts for 1326 thermal power units and 818 water basins. They conclude that regions experiencing reduction in power availability due to the water stress increase from 47 basins to 57 between 2014 and 2030, with inclusion of water use of water demand for other sectors, besides the power sector. The energy-water-climate model integrates the power plants database, water quantity database and water temperature database. The reference year is 2014, with project scenarios for 2020 and 2030. They conclude that there are highly vulnerable regions in the Mediterranean but also in France, Germany, Poland and

Bulgaria. They also investigate the impacts of the four adaptation strategies, which include additional use of seawater for means of cooling for coastal units, usage of air cooling, early retirement of units and switching of planned power capacities to renewable generation.

For the US, the water-power nexus is discussed in (Scanlon, Duncan, and Reedy, 2013) and (DeNooyer et al., 2016). The analysis was carried out to research the water-energy nexus for states Texas and Illinois. In (Scanlon, Duncan, and Reedy, 2013) the analysis of 2011 droughts was studied to examine the power plant's vulnerability. In (DeNooyer et al., 2016) the economic implications were studied for shifting from coal to natural gas, and replacement of open-loop with the closed-loop cooling technologies. The report for the Middle East and North Africa is represented in (Siddiqi and Diaz Anadon, 2011), while the Western Africa region is discussed in (De Felice et al., 2019). In (Siddiqi and Diaz Anadon, 2011) the MENA region, composed of 20 countries spanning from Iran to Morocco, was analysed. The water consumption in energy-related sectors and the energy consumption in water-related activities were studied, with a discussion on energy and environmental implications for the included region. In (De Felice et al., 2019) the model was created to determine economic impacts, the water consumption and withdrawal, and detailed operation of the power system under different current and future assumptions. In this report, additional improvements were mentioned for the more accurate representation of water-energy nexus (Fernandez Blanco Carramolino et al., 2017).

2 Drainage Basins on Balkan Peninsula

This study considers six Western Balkan countries (Albania, Bosnia and Herzegovina, Kosovo, Montenegro, North Macedonia, Serbia) and neighbouring EU Member States (Bulgaria, Croatia, Greece, Hungary, Romania and Slovenia). The Balkan Peninsula has two main drainage basins, the Black Sea and the Mediterranean Sea (Figure 1) (WBIF, 2018). The latter can be divided into Adriatic Sea, Aegean Sea and Ionian Sea.

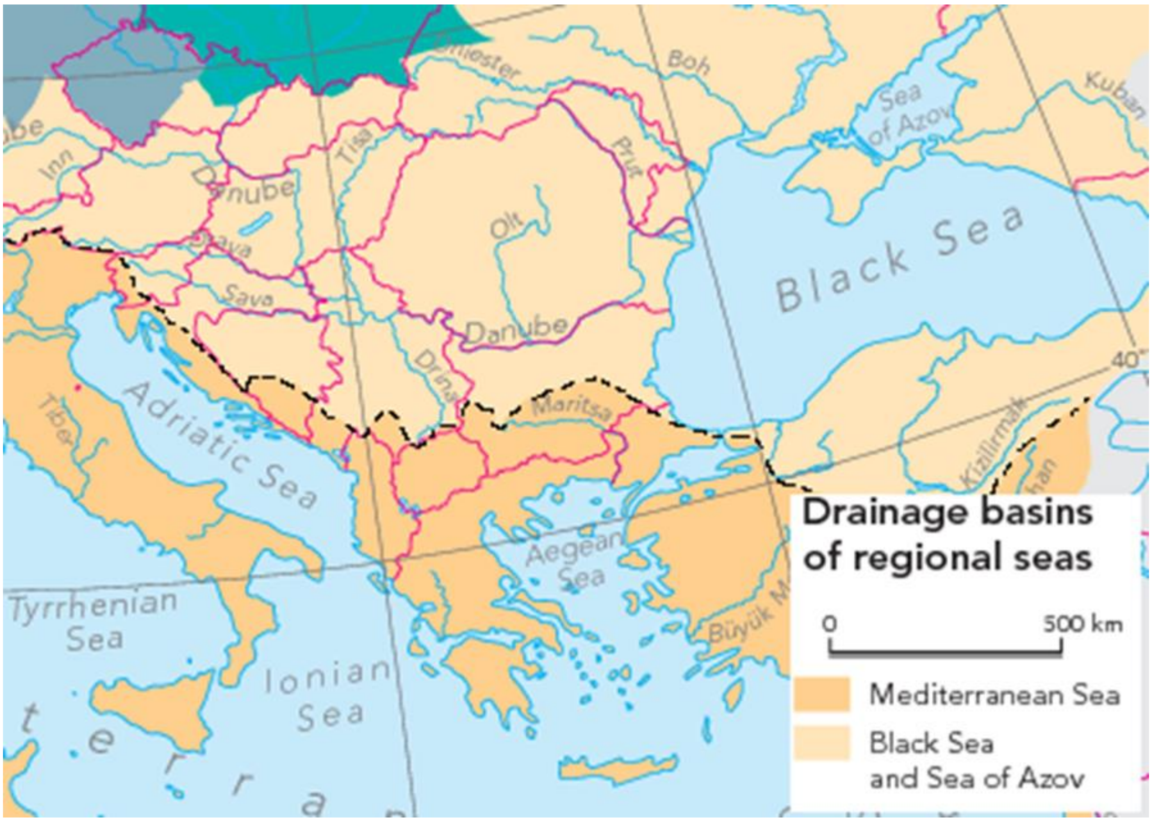
Major rivers and tributaries of the Black Sea drainage basin are Danube, Inn, Morava, Vah, Drava, Tisza, Sava, Velika Morava, Olt, Siret and Prut (Sommerwerk et al., 2009). The Danube, Sava, Drava, Krka, Una, Vrbas, Bosna, Drina and Velika Morava rivers are included in this study since they flow through mentioned countries (ICPDR, 2019). Annex 1 describes in more detail major rivers and tributaries.

The analysis of the Adriatic Sea drainage basin cover the rivers Neretva, Trebišnjica, Morača, Drin, Bune, Mat, Seman and Vjosë/Aoös, Cetina, Krka, Zrmanja and Isonzo/Soča (WBIF, 2017).

Major rivers and tributaries of the Aegean Sea drainage basin covered in this report are Evros/Maritsa, Nestos/Mesta, Strymon/Struma, Axios/Vardar, Aliakmon, Pineiós, Spercheios and Evrotas (Skoulikidis et al., 2009).

Three smaller rivers Arachthos, Acheloos and Alfeios, as part of Ionian Sea drainage basin, are covered in this report (Skoulikidis et al., 2009).

Figure 1. Two main drainage basins of the Balkan Peninsula



Source: (Ærtebjerg et al., 2001)

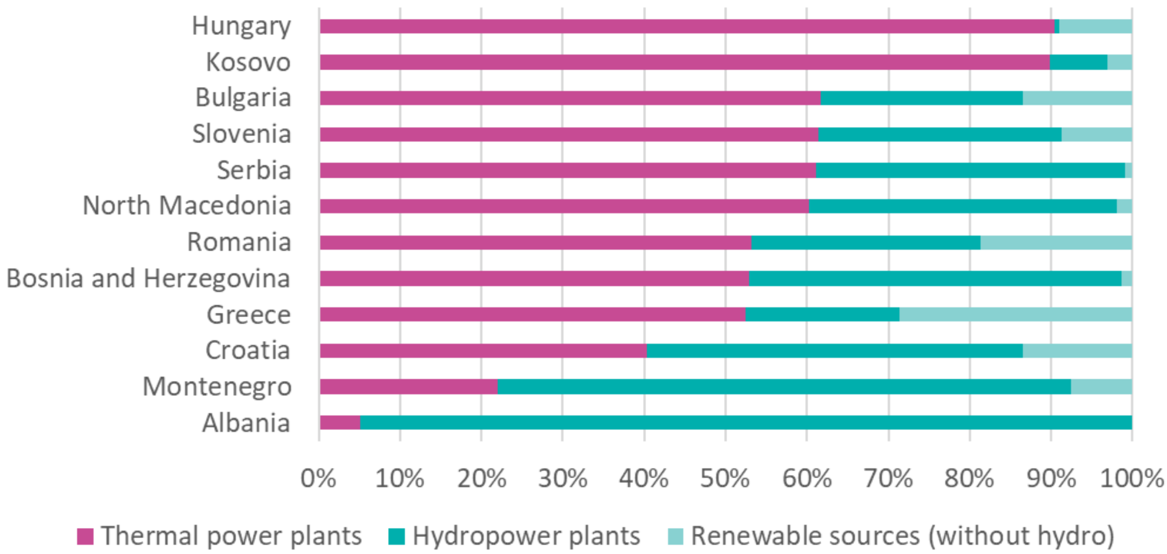
3 The power system in the Balkan Peninsula

The power sector of the Western Balkan and neighbouring countries is highly dependent on energy imports, especially oil and natural gas, with high dependence and use of coal, primarily lignite, in power generation. Besides the high carbon density due to the heavy dependence on coal, the excessive use of wood for fuel is a significant environmental concern, as it is the cause of air pollution, deforestation and land degradation (WBIF, 2017). The region has a large potential of bringing additional investments to diversify the supply sources with the addition of renewable energy sources and enhanced energy efficiency (WBIF, 2017).

Figure 2 shows regional installed capacities in form of percentages. In all countries, with exception of Albania, Croatia and Montenegro, thermal power units account for more than 50% of installed capacity. Hungary and Kosovo have significant shares of thermal capacity, 90% and 89%, respectively. In Hungary, 24% of the capacity is nuclear. All of Kosovo's thermal capacity consists of lignite-fired power plants. Romania, Greece and Bulgaria have the highest amount of installed thermal unit capacities, with 12247, 8804 and 7963 MW, closely followed by Hungary with 7579 MW. The highest percentages of fossil-fired units are in Kosovo, Hungary and Serbia (89%, 67% and 61% respectively). Countries with the highest share of hydropower generation are Albania, Croatia and Bosnia and Herzegovina (95%, 46%, and 45% respectively). Countries with the highest installed hydropower capacities are Romania, Bulgaria and Greece (6490, 3204 and 3172 MW respectively). Greece, Romania, Bulgaria and Croatia are countries with the highest shares of renewable capacity (29% (4796 MW), 18% (4314 MW), 14% (1744 MW) and 14%, respectively (JRC Hydro-power plants database, 2019), (Dispa-SET Balkans, 2019), (ENTSO-E Transparency Platform, 2018)).

Annex 2 contains a detailed description of the power system in each of countries analysed in this study.

Figure 2. Installed power capacities in Balkan Peninsula



Source: (JRC Hydro-power plants database, 2019), (Dispa-SET Balkans, 2019), (ENTSO-E Transparency Platform, 2018)

3.1 Hydropower in Balkan Peninsula

There are 1639 hydropower plants located in Balkan Peninsula (Table 1), of which 245 are large hydropower plants (installed capacity of more than 10 MW). Most of units are in Romania, Bulgaria and Slovenia. There are 1394 small hydropower plants located in the region, the majority in Slovenia, Romania, Albania and Bulgaria.

Table 1. Number of hydropower plants in the Balkan **r**egion

Country	Large HPP [> 10 MW]	Small HPP [<10 MW]	Total
Slovenia	22	535	557
Romania	99	274	373
Bulgaria	28	136	164
Albania	17	137	154
Serbia	12	85	97
North Macedonia	9	75	84
Bosnia and Herzegovina	16	66	82
Hungary	2	36	38
Croatia	18	15	33
Greece	19	9	28
Montenegro	2	16	18
Kosovo	1	10	11
Total	**245**	**1394**	**1639**
Share	15%	85%	100%

Source:(JRC Hydro-power plants database, 2019), (WBIF, 2017) (MZOE, 2017), (Guzović, 2014), (ESHA, 2012), (Argyrakis)

Large hydropower pants account for 23 594 MW, while small hydropower plants have a capacity of 1428 MW. Romanian hydropower plants account for 6576 MW of the total Balkan Peninsula region, followed by Greece with 3218 MW, Bulgaria with 3163 MW, and Serbia with 3158 MW (WBIF, 2017), (MZOE, 2017), (Guzović, 2014), (ESHA, 2012), (Argyrakis).

Even though the number of small hydropower plants represent 85.1% in the number of installed units, they account for 5.7% of the total installed capacity (WBIF, 2017), (MZOE, 2017), (Guzović, 2014), (ESHA, 2012), (Argyrakis).

Most of hydropower plants, 90% of the total installed capacity, have been constructed and commissioned before 1990 with only 866 MW added between 1990 and 2015. During the period between 2001 and 2016, 397 MW of the large hydropower plant capacities and 403 MW of small hydropower plants have been added (WBIF, 2017), (MZOE, 2017), (Guzović, 2014), (ESHA, 2012), (Argyrakis).

Table 2. Installed hydropower capacities in the WB region, in MW

Country	Large HPP [> 10 MW]	Small HPP [<10 MW]	Total
Romania	6189	387	6576
Greece	3171	46.7	3218
Bulgaria	2900	263	3163
Serbia	3092	66	3158
Bosnia and Herzegovina	2081	102	2183
Croatia	2167	33	2120
Albania	1592	252	1844
Slovenia	1105	117	1222
Montenegro	649	25	674
North Macedonia	574	97	671
Kosovo	35	25	60
Hungary	39	14	53
Total	**23 594**	**1428**	**25 022**
Share	94.3%	5.7%	100%

Source: (JRC Hydro-power plants database, 2019), (WBIF, 2017), (MZOE, 2017), (Guzović, 2014), (ESHA, 2012), (Argyrakis)

4 Modelling framework

The modelling framework used for this study consists of three parts. The LISFLOOD hydrological model, the Dispa-SET Medium-Term Hydrothermal Coordination (Dispa-SET MTHC), and the Dispa-SET Unit Commitment and Dispatch (Dispa-SET UCD) model. Results from the LISFLOOD model, in form of water inflows, are used as input data for both Dispa-SET models.

In the first step the LISFLOOD model is solved to produce water inflows that constraint the operation of power plants (De Felice et al., 2019). Then, during the second step the Dispa-SET MTHC model is run at daily time steps in order to provide the management of water resources in terms of reservoir levels and hydropower generation of run-of-river units. These outputs are then passed to the Dispa-SET UCD model (De Felice et al., 2019). In the final step the Dispa-SET UCD model is run at hourly time steps to determine the power dispatch and schedule of individual power plants, water-related results and economic results (De Felice et al., 2019).

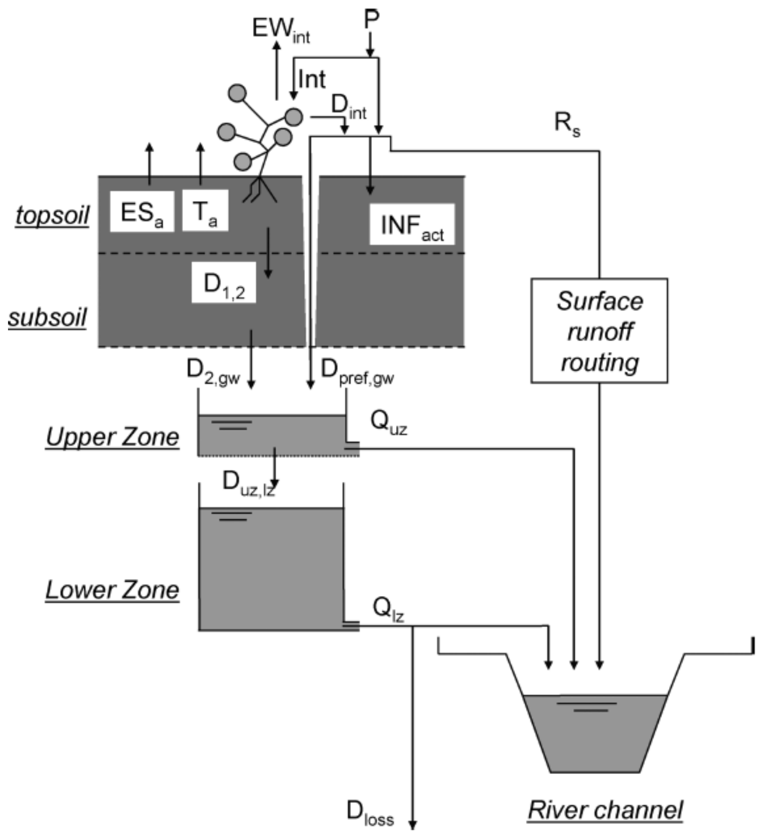
As a source of needed inflows for the Dispa-SET MTHC, and later Dispa SET UCD model, the LISFLOOD model represents important role for this study. The model will be only briefly discussed since it is not being used in the scope of this study, yet the data related to inflows are provided by JRC.

Annex 3 contains a detailed description of input data for Dispa-SET MTHC, and Dispa SET UCD models.

LISFLOOD

The LISFLOOD model has been developed by the floods group of the Natural Hazards Project of the Joint Research Centre. LISFLOOD is a hydrological rainfall-runoff model that simulates the hydrological processes in a catchment including flood forecasting, assessing the effects of river regulation measures, effects of land-use change and effects of climate change (Burek, van der Knijff, and de Roo, 2013).

Figure 3. Overview of the LISFLOOD model.



P = precipitation; Int = interception; EWint = evaporation of intercepted water; Dint = leaf drainage; ESa = evaporation from soil surface; Ta = transpiration (water uptake by plant roots); INFact = infiltration; Rs = surface runoff; D1,2 = drainage from top- to subsoil; D2,gw = drainage from subsoil to upper groundwater zone; Dpref,gw = preferential flow to upper groundwater zone; Duz,lz = drainage from upper- to lower groundwater zone; Quz = outflow from upper groundwater zone; Ql = outflow from lower groundwater zone; Dloss = loss from lower groundwater zone. Note that snowmelt is not included in the Figure (even though it is simulated by the model).

Source: (Burek, van der Knijff, and de Roo, 2013)

The model is used across a wide range of spatial and temporal scales. Since it is grid-based, the model can be used on a grid cells ranging from as little as 100 meters for the medium-sized catchments, and up to 10 km for global models. The time steps can be daily based for the simulation of the long-term water balance, while the hourly time steps are used for the simulation of the individual flood events. Also, the output of the “water balance” simulation can be used as input data for the “flood” simulations. Even though the primary output is channel discharge, all the internal rate and states variable can be written as the output with the complete user control (Burek, van der Knijff, and de Roo, 2013).

The model is made up of the two-layer soil water balance sub-models, sub-models for the simulation of groundwater and subsurface flow, sub-model for the routing of surface runoff to the nearest river channel and sub-model for the routing of channel flow. Simulated processes include infiltration, snowmelt, interception of rainfall, leaf drainage, evaporation, water uptake by vegetation, surface runoff, exchange of soil moisture between soil layers, drainage to the groundwater, bypass of the soil layer and flow through the river channel. More on the formulation of the mentioned processes can be seen in (Burek, van der Knijff, and de Roo, 2013), (Burek, van der Knijff, and de Roo, 2013), (Van der Knijff, Younis, and De Roo, 2010).

Dispa-SET Medium-Term Hydrothermal Coordination

The Dispa-SET MTHC is a model used to determine operation planning of hydropower reservoirs and thermal power plants based on minimization of system cost function composed of the system generation costs over a given planning horizon (De Felice et al., 2019). The time horizon ranges from one year to several years with daily, weekly or monthly time steps. The degree of detail of hydropower units is greater than in short-term operation at the expense of clustering the same fuel-powered thermal power plants. That means that thermal power units are aggregated by fuel and country, because the main scope of the MTHC model is to get results on hydropower generation and reservoir levels, and including each thermal unit itself would substantially increase the run time of the model. The MTHC problem can be characterized as large-scale, nonlinear and nonconvex optimization (Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2017).

The problem can be solved from two perspectives. The extensive form also knows as deterministic equivalent, which is used in this study, and the stochastic form (Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2017).

The deterministic MTHC problem assumes fixed water inflows, and based on the formulation of the hydro and thermal related technical features, the problem can be formulated as linear programming, nonlinear programming or mixed-integer linear programming (Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2017).

Related to the stochastic form, the model is based on the addition of uncertainty as hydrological scenarios for each planning stage, which consist of the amount of the water available for the electricity generation at each stage through the horizon. Scenarios are built with information from previous year. There are two ways to tackle the stochastic problem, vertical by stage/time and horizontal by scenarios (Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2016).

The deterministic form can be used to perform a scenario-based analysis for certain years, while the stochastic form is more valuable when models are used for production because the inherent uncertainty of different variables could affect the real-time operational decisions (Fernandez Blanco Carramolino, Kavvadias, and Hidalgo Gonzalez, 2017).

In this study, the deterministic approach is used and it is defined as a constrained linear programming problem in GAMS (GAMS, 2013).

Dispa-SET Unit Commitment and Dispatch

The Dispa-SET UCD model (Quoilin and Kavvadias, 2018) aims to represent the medium-term operation of large-scale power system. The problem consists of two parts:

- Scheduling start-up, shut down and operation of available generation units. The problem requires the use of binary variables to be able to represent the start-up and shut down decisions, while also considering constraints connected to the commitment status of the generation units in all time periods (Dispa-SET, 2018), (Kavvadias et al., 2018).
- Allocation of total power demand to be achieved among available generation units so that the total power system cost is minimized. This part of the problem is the economic dispatch problem, which determines the output of all generation units (Dispa-SET, 2018), (Kavvadias et al., 2018).

The problem can be formed as a mixed integer linear problem (MILP) or simplified linear program (LP) depending on the picked level of details for the input data. The implementations of both problems (MILP and LP) exists in both GAMS and PYOMO (Kavvadias et al., 2018). Continuous variables include dispatched power, the curtailed power generation and the shed load in every time step and the binary variables represent the commitment status of all units (Kavvadias et al., 2018).

The model features include: minimum and maximum power outputs for the all units, ramping limits, reserves up and down, minimum up and down times, load shedding, curtailment, pumped-hydro storage, non-dispatchable units, constraints on the targets for the renewables and/or CO_2 emissions, outages of all units, schedules for the reservoir storage level, constraints of CHP units and thermal storage, network-related constraints, different clustering methods and costs of start-up, ramping and no load (Kavvadias et al., 2018).

5 Scenario definition

This study includes scenario-based analysis for three different hydrological years. The LISFLOOD model determines the net water inflows at specific locations. The assumption is that provided water inflows are the total runoff at catchment level. Figure 4 represents the total sum of inflows for included hydropower plant locations for the period between 1990 and 2016. The yellow, green, and red highlighted lines represent respectively the runoff for the wet, average and dry years, which for the available time series are 2010, 2015 and 2007.

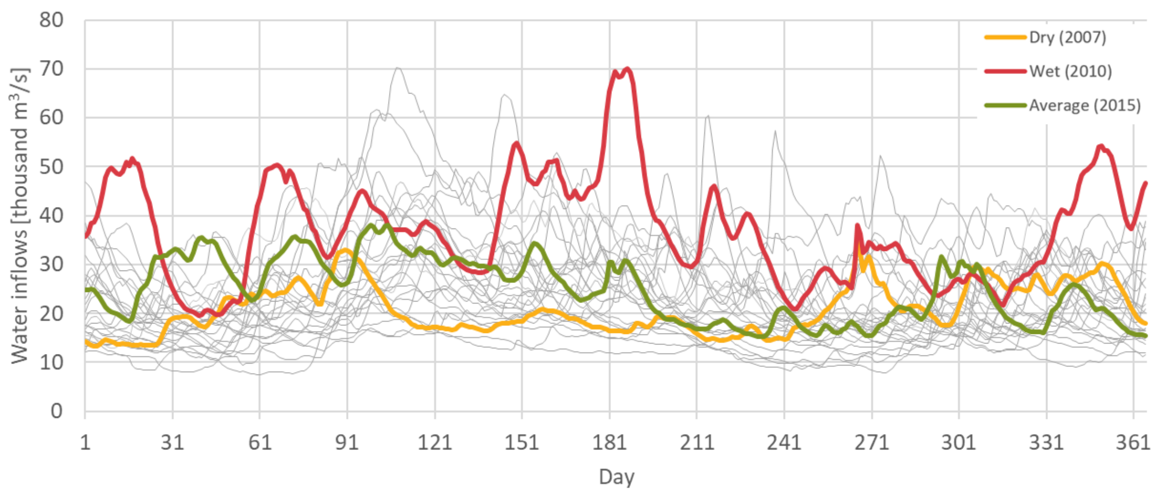
Table 3 shows the aggregated water inflows during the average year in each country. The corresponding average yearly values are 20 793, 24 847 and 37 010 m^3/s for dry, average and wet year, respectively. Water inflows peaked at 35 087, 38 119 and 70 154 m^3/s for dry, average and wet year, respectively.

Table 3. Data on net water inflows for each scenario

Scenario	Average [m^3/s]	Minimum [m^3/s]	Maximum [m^3/s]	Total [Mm^3/s]
Dry (2007)	20793	13237	35087	7.589
Average (2015)	24847	15160	38119	9.069
Wet (2010)	37010	19631	70154	13.509

Source: (Burek, van der Knijff, and de Roo, 2013)

Figure 4. The total sum of water inflows for studied region between 1990 and 2016



Source: (Burek, van der Knijff, and de Roo, 2013)

6 Model Results

6.1 Results from the Dispa-SET Medium-Term Hydrothermal Coordination model

The hydropower production for each country included in the model is used to validate the outputs of Dispa-SET MTHC. The reference year hydropower production was obtained from the ENTSO-E Transparency Platform and the International Energy Agency (IEA), and compared to model outputs (IEA, 2016), (ENTSO-E Transparency Platform, 2018). Table 4 shows model results for the year 2015, as well as statistical values.

Table 4. Comparison of hydropower production for average (2015) year

Country	**MTHC model [GWh]**	**IEA [GWh]**	**Δ/IEA [%]**	**ENTSO-E [GWh]**	**Δ/ENTSO-E [%]**
Albania	5696	5895	-3.37	/	/
Bosnia and Herzegovina	5614	5551	1.14	5650	-0.64
Bulgaria	5963	6147	-3.00	6155	-3.12
Croatia	5719	6556	-12.76	5657	1.10
Greece	6278	6150	2.07	6091	3.06
Hungary	237	234	1.39	227	4.51
Kosovo	141	140	0.45	/	/
Montenegro	1442	1491	-3.29	1415	1.90
North Macedonia	1585	1865	-14.99	1514	4.71
Romania	16849	17007	-0.93	16545	1.84
Serbia	10532	10789	-2.38	10633	-0.95
Slovenia	3997	4091	-2.30	4060	-1.56
Sum	64053	65916	-11.68	57947	0.46

After validating the model to match hydropower production to the available values for the reference year, the model was run for the additional wet and dry years with changed inputs of the water inflows in Figure 4.

The aggregated yearly hydropower production for studied region averaged at 145.91, 175.48 and 232.18 GWh/day, and peaked at 236.06, 277.96 and 331.86 GWh/day for dry, average and wet years respectively. The minimum was reached at 88.66, 89.92 and 135.02 GWh/day for the dry, average and wet years. Table 5 and Table 6 show total hydropower production of each country and historical values. The results on yearly regional aggregated hydropower generation from Dispa-SET MTHC show an increase from 53258 GWh for dry year to 64050 GWh and 84747 GWh for average and wet years, respectively. Figure 5 shows a comparison of yearly aggregated hydropower production for studied region. Figure 6 compares monthly hydropower generation for the year 2015 to model results and ENTSO-E data. The comparison shows close relation with statistical data, especially for January, March, May, June, July, September, October and November, with an error below 3%. Slightly higher differences at -422.21, -507.29 and 229.19 GWh occur in May, March and December, accounting for error of -9.88%, -7.40% and 5.97%, respectively.

Table 5. Hydropower production for wet (2010) year

Country	MTHC model [GWh]	IEA [GWh]	Δ/IEA [%]	ENTSO-E [GWh]	Δ/ENTSO-E [%]
Albania	9017	7567	19.16	/	/
Bosnia and Herzegovina	9240	8026	15.12	7870	17.41
Bulgaria	5756	5693	1.11	5431	5.98
Croatia	6824	9232	-26.09	8313	-17.92
Greece	7284	7485	-2.68	7457	-2.31
Hungary	352	188	87.45	181	94.70
Kosovo	149	156	-4.61	/	/
Montenegro	2375	2750	-13.65	2738	-13.28
North Macedonia	2103	2431	-13.49	2316	-9.20
Romania	22342	20 243	10.37	20174	10.75
Serbia	15004	12 571	19.36	12453	20.49
Slovenia	4300	4703	-8.56	4249	1.21
Sum	84746	81 045	4.57	71182	6.18

Table 6. Hydropower production for dry (2007) year

Country	MTHC model [GWh]	IEA [GWh]	Δ/IEA [%]	ENTSO-E [GWh]	Δ/ENTSO-E [%]
Albania	5224	2788	87.36	/	/
Bosnia and Herzegovina	5561	4001	38.98	4001	38.98
Bulgaria	4006	3234	23.88	2446	63.79
Croatia	5672	4864	16.62	4361	30.07
Greece	2690	3376	-20.32	3367	-20.11
Hungary	217	210	3.34	209	3.83
Kosovo	121	94	28.62	/	/
Montenegro	1336	1284	4.09	1292	3.44
North Macedonia	770	1010	-23.78	1054	-26.96
Romania	14248	15966	-10.76	15622	-8.80
Serbia	9731	10037	-3.04	9928	-1.98
Slovenia	3679	3266	12.64	2814	30.73
Sum	53255	50130	6.23	45094	6.25

Figure 5. Region aggregated hydropower generation for dry (2007), average (2015) and wet (2010) year, MTHC model

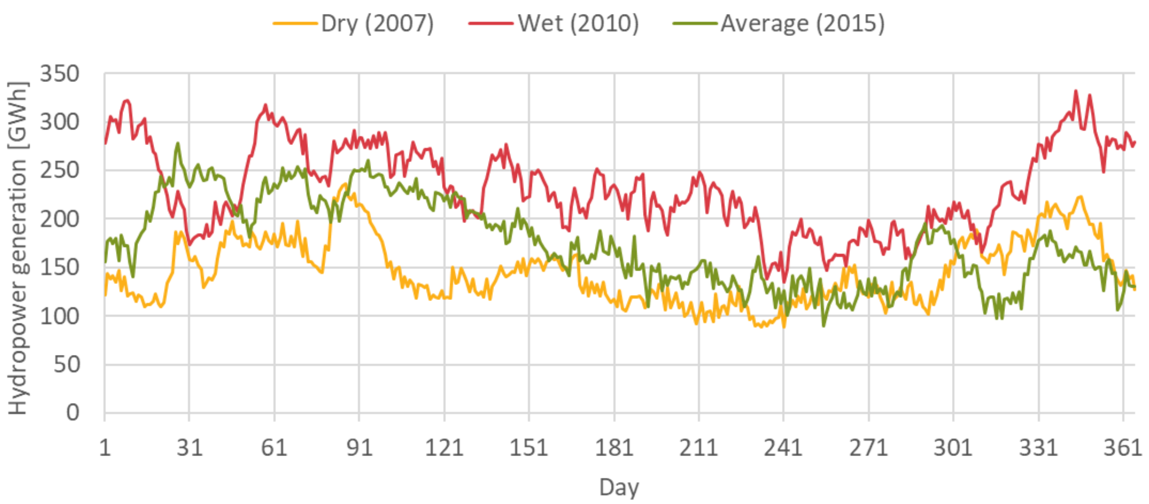
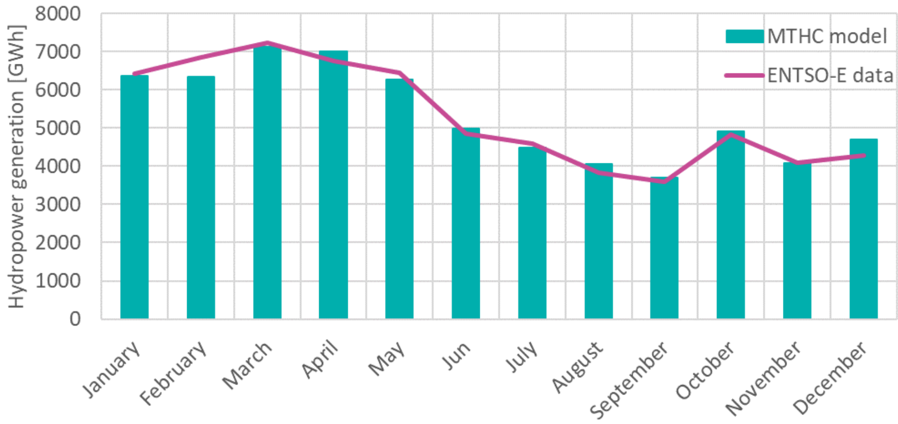


Figure 6. Comparison of region aggregated hydropower generation between MTHC model results and ENTSO-E data for the year 2015



Reservoir levels and hydropower generation of run-of-river units are key outputs of Dispa-SET MTHC model needed by Dispa-SET UTC model.

Average, region aggregated, reservoir level values are 12272, 16593 and 15492 Mm^3 for the dry, average and wet year, respectively. Maximum levels were 13226, 21238 and 18660 Mm^3, while minimum values were 10258, 12341 and 11913 Mm^3 for the dry, average and wet years, respectively. Table 7, Table 8 and Table 9 show average, minimum, and maximum, aggregated per country, reservoir level values for dry, average and wet years respectively.

Table 7. Country aggregated reservoir level values for dry (2007) year in Mm^3

Country	**Minimum [Mm^3]**	**Average [Mm^3]**	**Maximum [Mm^3]**
Albania	1794	2940	3663
Bosnia and Herzegovina	315	358	432
Bulgaria	780	945	1101
Croatia	365	491	550
Greece	2890	3457	3979
Hungary	46	68	208
Kosovo	40	40	43
Montenegro	90	198	425
North Macedonia	897	920	960
Romania	2343	2478	2791
Serbia	362	379	406
Slovenia	0.43	0.73	1.19

Table 8. Country aggregated reservoir level values for average (2015) year in Mm^3

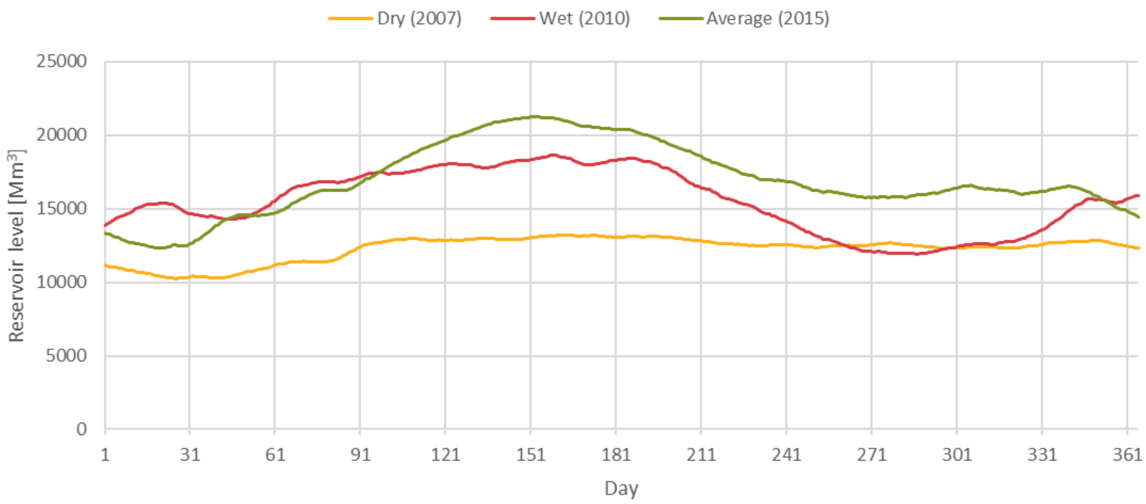
Country	**Minimum [Mm^3]**	**Average [Mm^3]**	**Maximum [Mm^3]**
Albania	893	2405	4005
Bosnia and Herzegovina	1219	1592	1717
Bulgaria	947	1333	1761
Croatia	833	940	1040
Greece	3076	4877	6444
Hungary	46	53	97
Kosovo	40	45	84
Montenegro	90	422	972
North Macedonia	1017	1098	1233
Romania	3414	3764	4006
Serbia	402	424	447
Slovenia	0.43	0.72	1.45

Table 9. Country aggregated reservoir level values for wet (2010) year in Mm³

Country	**Minimum [Mm³]**	**Average [Mm³]**	**Maximum [Mm³]**
Albania	894	2729	4006
Bosnia and Herzegovina	247	504	961
Bulgaria	910	1146	1302
Croatia	602	905	1129
Greece	3266	5046	6352
Hungary	46	75	180
Kosovo	40	41	50
Montenegro	90	385	917
North Macedonia	1108	1272	1564
Romania	1999	3061	4311
Serbia	231	327	375
Slovenia	0.43	1.04	2.17

Figure 7 shows aggregated reservoir levels for dry, average and wet years. From the end of March the reservoir level in average year is higher than in wet year. Upon checking on highest difference in reservoir levels, the biggest impact on lower reservoir level in wet year, when compared to average takes place in hydropower plants Trebinje, CHE Stejaru, Rama, Kremasta and Pasarel. They account for 72% in total difference of stored water in accumulations. All of those hydropower plants had higher water inflows for wet year, which would suggest that other variables, hard to trace and model, have a noticeable impact on the distribution of reservoir levels.

Figure 7. Annual, region aggregated, reservoir level for dry (2007), average (2015) and wet (2010) year in Mm³ as results from the MTHC model



The availability factor, defined as the ratio of available water source power and installed capacity of hydropower unit, determines generation of run-of-river units and it depends on available water inflows provided by the LISFLOOD model. The study only considers units with capacity above 10 MW, so some run-of-river units from Albania, Montenegro, North Macedonia and Kosovo are not included in this study.

The yearly aggregated average run-of-river generations are 59.17, 65.86 and 80 GWh/day, reaching the maximum of 86.19, 87.07 and 101.73 GWh/day for dry, average and wet years, respectively. Minimum values were 40.88, 43.18 and 51.52 GWh/day (Table 10, Table 11 and Table 12).

Figure 8. Annual availability factor values for dry (2007), average (2015) and wet (2010) years in GWh

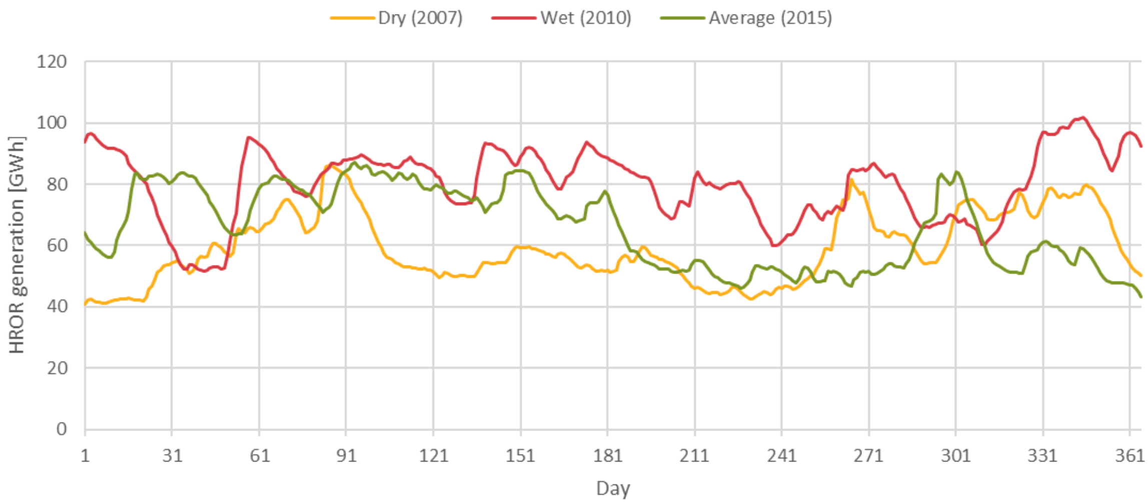


Table 10. Country aggregated HROR generation for dry (2007) year in MWh

Country	Minimum [MWh]	Average [MWh]	Maximum [MWh]
Albania	1.07	8.18	37
Bosnia and Herzegovina	113	384	911
Bulgaria	1.08	4.40	100
Croatia	4268	5659	7244
Greece	137	596	1408
Hungary	71	238	302
Romania	15576	24449	35167
Serbia	12350	20901	34636
Slovenia	3334	6932	12843

Table 11. Country aggregated HROR generation for average (2015) year in MWh

Country	Minimum [MWh]	Average [MWh]	Maximum [MWh]
Albania	1.35	11.41	110
Bosnia and Herzegovina	112	484	1878
Bulgaria	2.16	7.82	58
Croatia	3838	5882	8862
Greece	224	839	1408
Hungary	93	245	313
Romania	18500	27373	37057
Slovenia	3850	7978	14682
Serbia	12551	23035	36178

Table 12. Country aggregated HROR generation for wet (2010) year in MWh

Country	Minimum [MWh]	Average [MWh]	Maximum [MWh]
Albania	1.65	18.13	67
Bosnia and Herzegovina	138	980	2330
Bulgaria	1.89	6.08	34
Croatia	3372	5851	8107
Greece	259	944	1408
Hungary	237	303	366
Romania	20981	34115	41195
Slovenia	3692	7911	12778
Serbia	18678	29874	38128

During wet years hydropower displaces generation from gas-fired units, while during dry ones gas units cover the shortages in hydropower output. Figure 9, Figure 10 and Figure 11 show the power generation estimated by Dispa-SET MTHC, aggregated by fuel, for the average, dry and wet years, respectively.

Figure 9. Power generation aggregated by fuel for average (2015) year in GWh

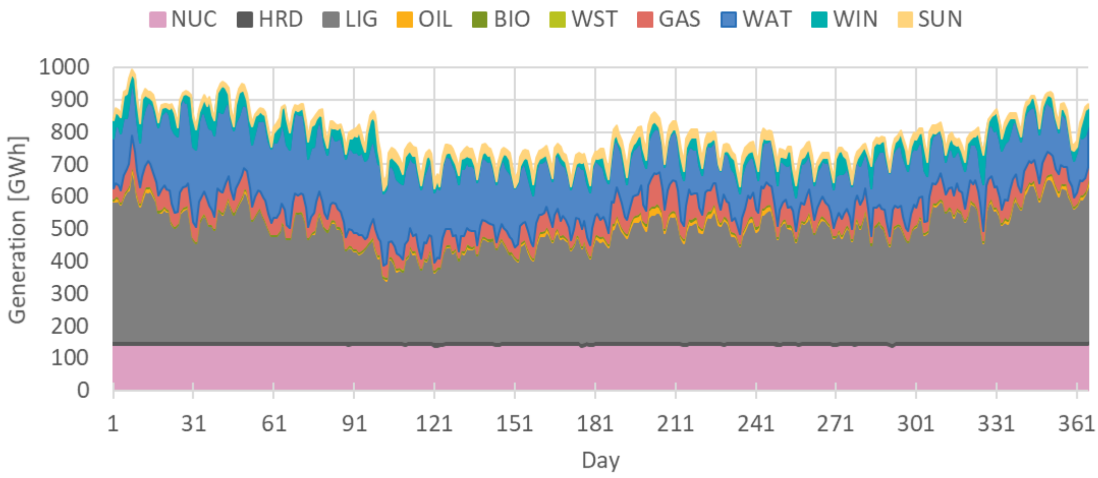


Figure 10. Power generation aggregated by fuel for dry (2007) year in GWh

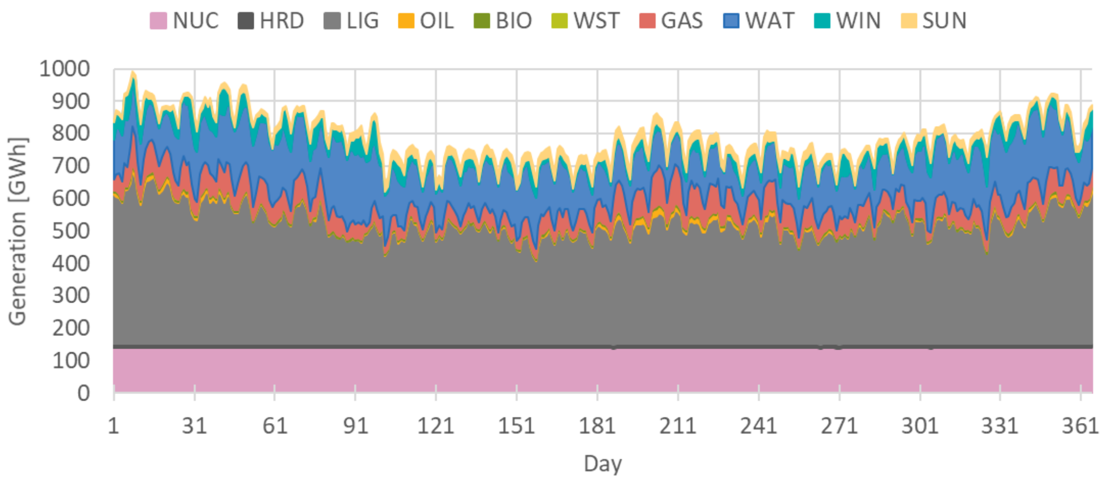
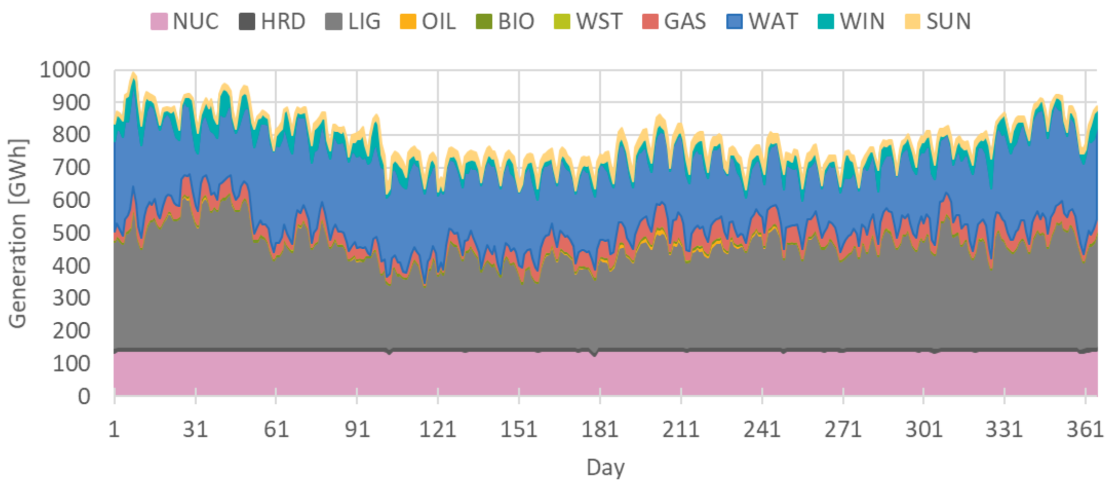


Figure 11. Power generation aggregated by fuel for wet (2010) year in GWh



6.2 Results from Dispa-SET Unit Commitment and Dispatch model

The next step of the analysis consisted of running the Dispa-SET UCD model for three different hydrological years in order to study the operation of individual power plants using the results of Dispa-SET MTHC as inputs. Table 13 shows results aggregated at regional level.

Table 13. Region aggregated results for the dry (2007), average (2015) and wet (2010) years

Region-aggregated statistics	**Unit**	**Dry**	**Average**	**Wet**
Average electricity cost	€/MWh	17.79	16.35	14.05
Total consumption	TWh	289.22	289.22	289.22
Total system cost	m EUR	4978	4573	3932
Peak load	GW	47.992	47.992	47.992
Net imports	TWh	9.452	9.452	9.452
NUC generation	TWh	48.356	48.356	48.356
LIG generation	TWh	151.33	140.15	125.12
HRD generation	TWh	3.506	3.072	2.430
GAS generation	TWh	6.244	4.682	1.462
WST generation	TWh	0.090	0.090	0.090
SUN generation	TWh	6.919	6.919	6.919
WIN generation	TWh	10.272	10.272	10.272
WAT generation	TWh	53.064	65.237	85.132
Spillage	TWh	3.088	5.174	10.648
CO_2 emissions	$MtCO_2$	164.36	152.67	133.96
Committed (All units)	No	349	353	335
Start-ups (All units)	No	27734	32361	37087
Shutdowns (All units)	No	27466	32067	36811
Committed (Thermal PP)	No	86	90	72
Start-ups (Thermal PP)	No	3356	3330	2495
Shutdowns (Thermal PP)	No	3310	3277	2460

As hydropower output grows, the average electricity cost and generation from lignite and gas fired thermal power plants fall.

The difference in average electricity cost between dry and average years is due to lower amount of energy generated by thermal units. Generation from hard coal decreases from 3.51 TWh during the dry year to 3.07 TWh in the average year, while lignite decreases from 151.33 TWh to 140.15 TWh. Power from gas-fired units also decreases from 6.24 TWh to 4.68 TWh. Thermal output is replaced by hydropower generation (which increases from 53.06 TWh to 65.24 TWh). A similar change takes place when comparing average and wet years. The drop in average electricity price from 16.35 €/MWh to 14.05 €/MWh can be explained by the decrease in electricity generation from hard coal (reduced from 3.07 TWh to 2.43 TWh), lignite (from 140.15 TWh to 125.12 TWh) and gas-fired units (from 4.68 TWh to 1.46 TWh), at the expense of increased hydropower generation (from 65.24 TWh to 85.13 TWh). Due to higher surplus of water runoff, water spillages also grow from the dry to the wet scenarios.

Thermal power units account for only 12.1, 10.3 and 6.7% of total start-ups for dry, average and wet years respectively. That suggests that hydropower plants provide most of flexibility to the system (in terms of start-ups and shutdowns). The number of start-ups of thermal power plants decrease from 3356 start-ups in dry year, to 3330 in average and 2495 in wet year. Units that cycle the most are Kelenföldi Erőmű, Gönyűi Erőmű, Maritsa Iztok 2, Maritsa Iztok 3, Maritsa Iztok 1 – AES Galabovo and CTE Rovinari. Regarding the reference year, units Kelenföldi Erőmű and Gönyűi Erőmű with 469 and 454 start-ups, more than double the number of start-ups when compared to Maritsa Iztok 2, which is an unit with the third highest start-up count. Also, Kelenföldi Erőmű and Gönyűi Erőmű increase start-ups from wet to dry year.

Even though the number of committed thermal power units in average year is higher than during dry year, the number of start-ups per committed unit still falls from 38.5 No/unit for dry year, to 36.4 and 34.2 No/unit.

Since the availability of wind and solar units remains unchanged in different scenarios, the generation from these sources also remains constant.

Table 14 compares modelled hydropower generation with data from (IEA, 2016) and (ENTSO-E Transparency Platform, 2018), for the year 2015.

Table 14. Comparison of hydropower production for average (2015) year

Country	UCD model [GWh]	IEA [GWh]	Δ/IEA [%]	ENTSO-E [GWh]	Δ/ENTSO-E [%]
Albania	5907	5895	0.20	/	/
Bosnia and Herzegovina	5664	5551	2.03	5650	0.24
Bulgaria	6392	6147	3.99	6155	3.85
Croatia	6069	6556	-7.44	5657	7.27
Greece	6288	6150	2.24	6099	3.09
Hungary	247	234	5.37	227	8.62
Kosovo	144	140	2.55	/	/
Montenegro	1515	1491	1.58	1415	7.04
North Macedonia	1855	1865	-0.51	1514	22.55
Romania	16149	17007	-5.05	16545	-2.40
Serbia	10919	10789	1.20	10633	2.69
Slovenia	4090	4091	-0.02	4060	0.75
Sum	65237	65916	-1.03	57955	2.12

Results show that modelled hydropower generation is matching available data from (ENTSO-E Transparency Platform, 2018) and (IEA, 2016). The biggest discrepancy between model results and statistics occur in Croatia, Hungary and Romania. When compared to IEA data, differences amount to -7.44, 5.37 and -5.05%, respectively. On the other hand, when compared to ENTSO-E data, differences amount to 7.27, 8.62 and -2.4%, respectively. A big difference in hydropower generation is observed in North Macedonia with respect to ENTSO-E data, although the result is close to IEA data (IEA generally reports higher values than ENTSO-E). A similar discrepancy is observed in Croatia. The percentage difference for Hungary could be explained by a total smaller amount of hydropower generation which turns out into higher percentage differences with smaller offsets from statistical data. For Romania the difference is close to 5% when compared to IEA, and -2.4% when compared to ENTSO-E data. At regional level the differences with IEA and ENTSO-E data amount to -1.03 and 2.12%.

Generation from pumped storage units amount to 6.88, 6.04 and 9.41 TWh during average, dry and wet years respectively (or 10.5, 11.4 and 11% of total hydropower generation).

Figure 12 shows hydropower generation on yearly basis, aggregated by region. Figure 13 compared modelled hydropower generation for the year 2015 with ENTSO-E data.

Figure 12. Aggregated hydropower generation for dry (2007), average (2015) and wet (2010) years, UCD model

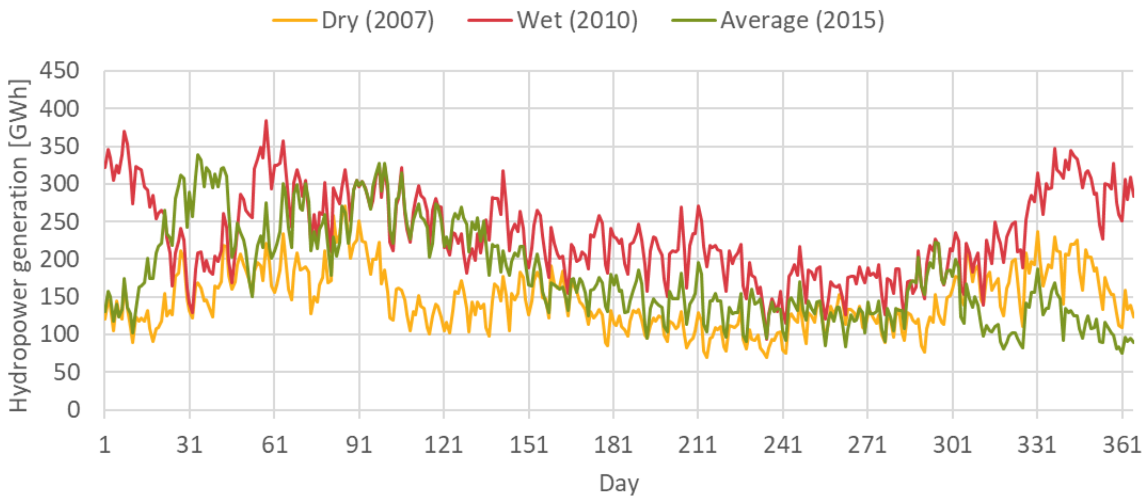
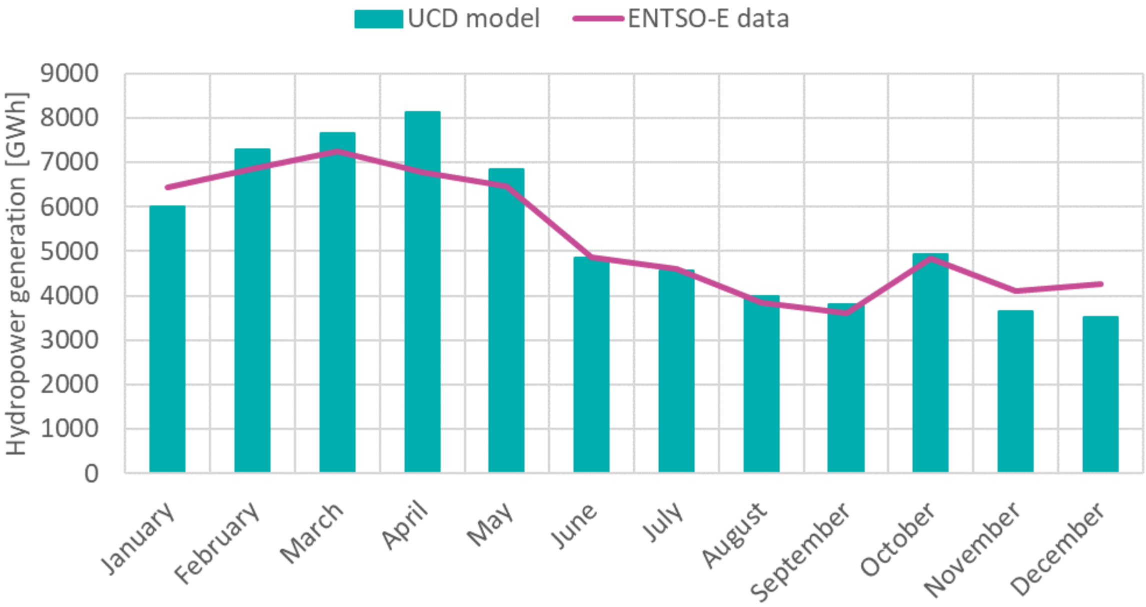


Figure 13. Comparison of modelled hydropower generation and ENTSO-E data for the year 2015



Hydropower output is higher from January and later autumn months, November and December when comparing wet and average years. During dry years, hydropower output is mostly below the wet and average years with some exceptions during part of February, and from November to December.

The comparison between model results and ENTSO-E data (Figure 13) shows a very similar trend with slightly higher differences of 1367, -771 and -453 GWh for April, December and November, respectively.

Table 15 and

Table 16 show total hydropower production of each country with respect to available data for dry and wet year. Differences on a country level are quite high in a few cases, while as a whole hydropower generation for dry and wet year differ only in percentages values around 5 to 6%.

Table 15. Hydropower generation for dry (2007) year

Country	**UCD model [GWh]**	**IEA [GWh]**	**Δ/IEA [%]**	**ENTSO-E [GWh]**	**Δ/ENTSO-E [%]**
Albania	5027	2788	80.29	/	/
Bosnia and Herzegovina	5195	4001	29.85	4001	29.85
Bulgaria	3924	3234	21.34	2446	60.43
Croatia	5821	4864	19.69	4361	33.49
Greece	2525	3376	-25.19	3367	-24.99
Hungary	223	210	6.18	209	6.69
Kosovo	128	94	36.35	/	/
Montenegro	1612	1284	25.56	1292	24.78
North Macedonia	896	1010	-11.30	1054	-15.00
Romania	13981	15966	-12.44	15622	-10.51
Serbia	10027	10037	-0.10	9928	0.99
Slovenia	3705	3266	13.43	2814	31.65
Sum	53064	50130	5.85	45094	6.24

Table 16. Hydropower generation for wet (2010) year

Country	UCD model [GWh]	IEA [GWh]	Δ/IEA [%]	ENTSO-E [GWh]	Δ/ENTSO-E [%]
Albania	9165	7567	21.11	/	/
Bosnia and Herzegovina	9744	8026	21.40	7870	23.81
Bulgaria	5682	5693	-0.20	5431	4.62
Croatia	6681	9232	-27.63	8313	-19.63
Greece	7492	7485	0.09	7457	0.46
Hungary	300	188	59.66	181	65.83
Kosovo	167	156	6.94	/	/
Montenegro	2474	2750	-10.02	2738	-9.63
North Macedonia	2525	2431	3.87	2316	9.03
Romania	22151	20243	9.42	20174	9.80
Serbia	14459	12571	15.02	12453	16.11
Slovenia	4292	4703	-8.73	4249	1.02
Sum	85132	81045	5.04	71182	6.49

Figure 14 shows total installed capacities. Figure 15 shows total power generation, aggregated by fuel for each country, for dry, average and wet years. Power dispatch and unit commitments for each country are displayed in Annex 4.

Figure 15 shows that an increase in water availability increases hydropower generation, which is an expected outcome seen in all countries, but it also increases power export capabilities, especially in Albania, Bosnia and Herzegovina, Montenegro and Serbia. As a consequence, some countries like Bulgaria and Hungary might increase their power imports. Another thing which is worth to notice is that highly efficient lignite power plants in Bosnia and Herzegovina, Greece, Montenegro, North Macedonia, Serbia and Kosovo keep the same lignite power generation level independently to the amount of hydropower on national power market, while countries with less efficient lignite power plants like Bulgaria and Hungary decrease thermal power generation and increase power import from regional market.

During dry years it is expected that less power will be available on the market and as a consequence, power will be generated from less efficient lignite power plants (Bulgaria and Hungary) or gas power plants (Greece). In these conditions, Bulgaria is becoming more competitive and able to export power from lignite power plants to other countries.

Nuclear power plants in the region always operate in base load.

Figure 14. Installed power generation capacities[2]

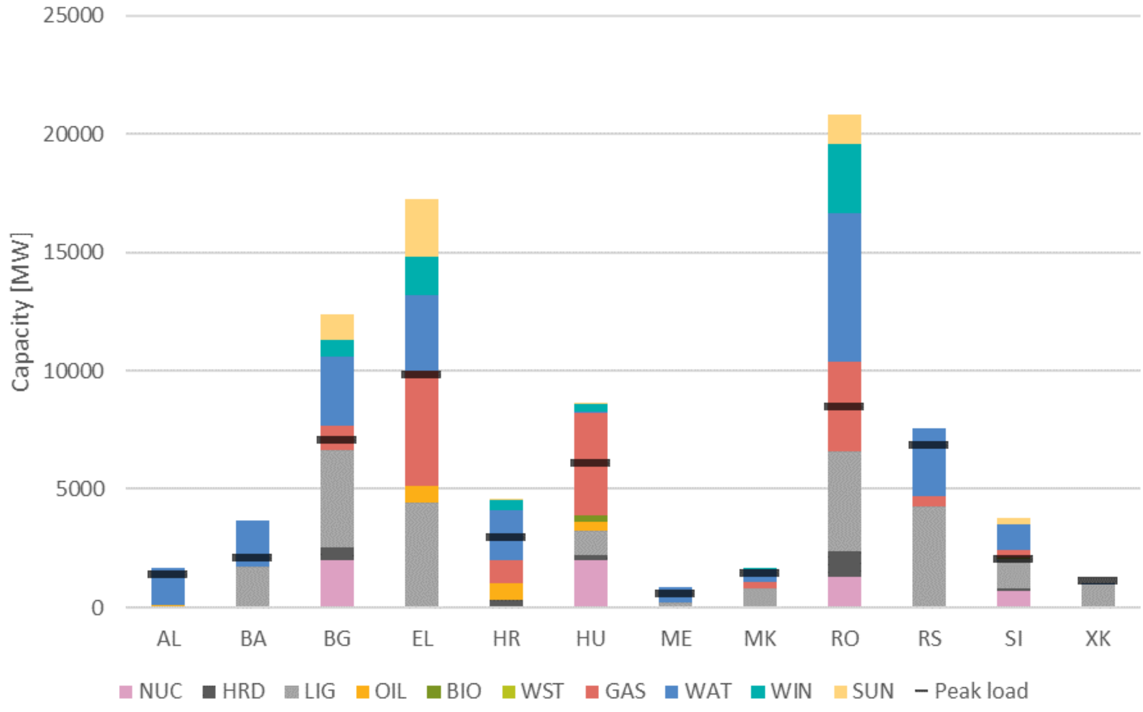
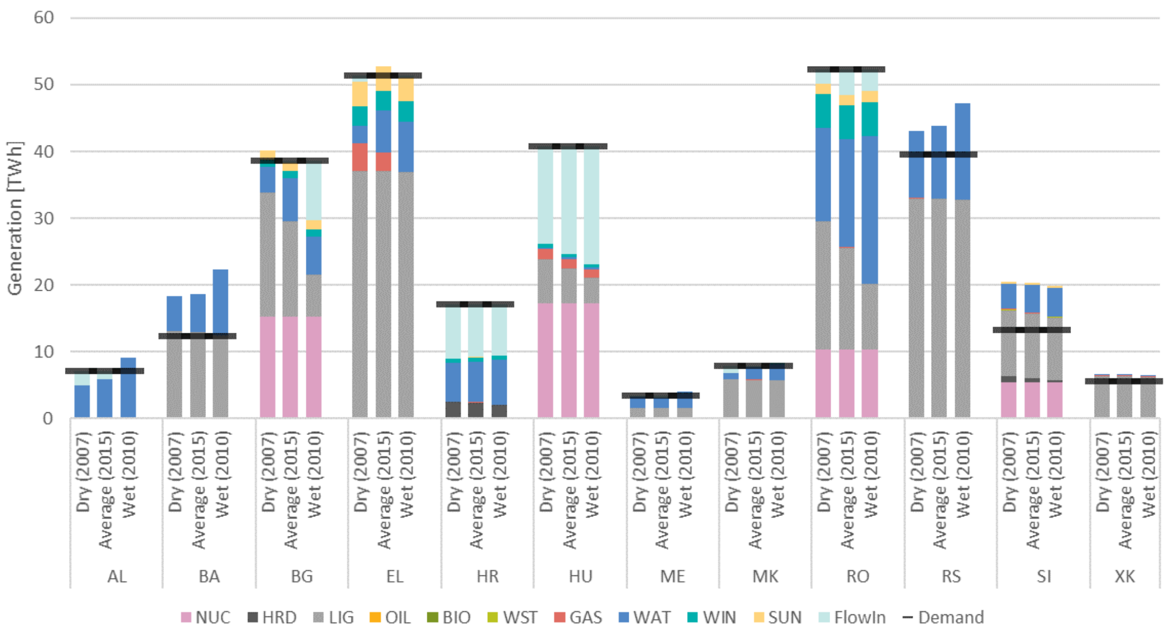


Figure 15. Power generation, aggregated by fuel for dry (2007), average (2015) and wet (2010) years



[2] Horizontal black lines indicate peak demand. Country and fuel codes are shown in the annexes

6.3 Impact of cooling of thermal power plants and hydropower operation on water resources

Hydropower generation and cooling of thermal power units have an impact on fresh water sources. As an average flexibility of most thermal power units is lower than the flexibility of hydropower plants, water scarcity would significantly affect the operation of thermal power units, especially nuclear power plants and other base-load power units. When trying to describe water availability, two terms are mostly used. Water withdrawal (WW) or gross water abstraction and water consumption (WC) or net water abstraction. WW is the amount of water removed from the ground or diverted from a water source, while WC represents water withdrawn that is not returned to the source (Medarac, Magagna, and Hidalgo González, 2018).

Table 17 shows water abstraction by sector of use for each country. The share of water withdrawal for electricity generation (cooling) in total water abstracted (TWA) is especially high in Bulgaria, Serbia and Slovenia (65, 67 and 77%, respectively).

Table 18 shows data on water withdrawal and consumption for electricity generation (cooling) (Medarac, Magagna, and Hidalgo González, 2018). In Bulgaria, Hungary and Slovenia a high share of WW is used for cooling thermal power plants (74, 68 and 73%, respectively).

Table 17. Water abstraction by sector of use for year 2015, in Mm^3

Country	TWA	WS	IR	AQ	MQ	IC	EC	CN	SC	HH
Albania	/	/	/	38	/	/	/	/	/	/
Bosnia and Herzegovina	/	321	/	/	16	/	/	/	/	/
Bulgaria	5629	869	676	/	16	58	3674	74	30	/
Croatia	683	473	/	55	2	47	/	/	/	/
Greece	9908	1418	8232	907	15	/	65	/	/	/
Hungary	4030	605	110	/	/	/	/	/	/	/
Kosovo	246	/	73	/	/	/	/	/	/	/
Montenegro	/	/	/	/	/	/	/	/	/	/
North Macedonia	/	/	/	/	/	/	/	/	/	/
Romania	6458	1019	364	/	/	/	740	/	12	/
Serbia	4689	645	88	/	8	51	3148	0.2	14	/
Slovenia	895	164	4	/	1	/	686	/	/	/

TWA - Total; WS – Water supply; IR – Irrigation; AQ – Aquaculture; MQ – Mining and quarrying; IC – Industry (cooling); EC – Electricity (cooling); CN – Construction; SC – Services; HH – Households; / - data not available

Source: (Eurostat, 2019)

Table 18. Water withdrawal and consumption for electricity production (cooling), 2015, Mm^3

Country	WW [Mm3]	Share of WW in TWA [%]	WC [Mm3]	Share of WC in WW [%]	TWA*
Bulgaria	4171	74.1	46	1.1	5629
Croatia	74	10.8	1	1.2	684
Greece	62	0.6	50	80.6	9908
Hungary	2729	67.7	32	1.2	4030
Romania	2419	37.5	64	2.6	6458
Slovenia	654	73.1	15	2.3	895

(*) – data from (Eurostat, 2019)

WW – water withdrawal; TWA – total water abstraction; WC – water consumption

Source: (Medarac, Magagna, and Hidalgo González, 2018)

6.3.1 Water withdrawal and consumption

Table 19 shows water withdrawn for hydropower generation. Generally, water withdrawal for hydropower generation follows a hydrological trend of runoffs obtained fom the LISFLOOD model for the corresponding scenario. Higher water withdrawal, thereby higher hydropower generation, takes place during a wet year. As the scenarios were selected based on regional water runoffs, it is observed that the average scenario water withdrawal does not follow the same trend of the "average" statistical year on a country level. Water withdrawals during average and wet years are very close in Greece, Kosovo, North Macedonia and Slovenia. On the contrary, withdrawals during average and dry years are closer in Albania, Bosnia and Herzegovina, Hungary, Montenegro, Romania and Serbia. In Bulgaria withdrawals are higher during the average, according to LISFLOOD outputs. Even though hydropower generation in Croatia is higher than during wet year, regarding the average hydrological year, it is interesting to note that water withdrawal for an average year is higher than for wet year. This unexpected behaviour is explained by a higher hydropower generation (and thus higher water withdrawal) of run-of-river units HE Varaždin, HE Dubrava and HE Čakovec during an average year. Those units have higher water withdrawals per produced MWh of electricity, and account for 3.62 Bm^3 of water withdrawn for hydropower generation.

Table 19. National water withdrawals for hydropower for dry (2007), average (2015) and wet (2010) years, in Bm^3

Country	WW 2007 [Bm3]	WW 2015 [Bm3]	WW 2010 [Bm3]
Albania	22.83	25.91	42.65
Bosnia and Herzegovina	30.12	33.04	59.42
Bulgaria	14.04	23.46	20.36
Croatia	54.58	60.57	56.96
Greece	10.96	27.15	33.54
Hungary	17.50	19.14	22.89
Kosovo	0.42	0.49	0.52
Montenegro	1.91	1.82	3.21
North Macedonia	4.28	9.00	12.12
Romania	291.53	345.33	452.37
Serbia	187.12	208.75	257.30
Slovenia	77.23	88.15	89.08
Total	712.51	842.82	1050.43

Total fresh water withdrawal for cooling thermal power plants is equal to 10425, 10235 and 9865 Mm^3 for dry, average and wet year, respectively. Total freshwater consumption for cooling thermal power units reaches 257, 241 and 216 Mm^3.

Table 20 shows modelled water withdrawal for three different hydrological years as well as data from statistical sources (Eurostat, 2019).

Table 20. Comparison of modelled water withdrawal for thermal power units and statistical values for dry (2007), average (2015) and wet (2010) years, in Mm^3

Countries	WW 2007	WW 2007 Eurostat	WW 2015	WW 2015 Eurostat	WW 2010	WW 2010 Eurostat
Albania	0	/	0	/	0	/
Bosnia and Herzegovina	30	/	30	/	29	/
Bulgaria	3129	3493	2995	3674	2701	3491
Croatia	0	/	4	/	0	94
Greece	74	100	73	65	73	88
Hungary	2983	4176	2970	/	2956	4000
Kosovo	14	/	14	/	14	/
Montenegro	4	/	4	/	4	/
North Macedonia	13	12	13	/	13	14
Romania	1774	3497	1766	740	1756	905
Serbia	1374	2974	1367	3148	1358	2986
Slovenia	1030	706	999	686	962	707

WW – water withdrawal; WW Eurostat - (Eurostat, 2019)

Table 21 and Figure 16 show modelled results of water withdrawal and consumption. Bulgaria, Hungary, Romania, Serbia and Slovenia have significant WW values, when compared to WC. All those countries, except Serbia, have nuclear power plants in their energy portfolios (Paksi Atomerőmű, Cernavoda, Krško and Kozloduy) cooled with once-through systems. Serbian power plants TE Nikola Tesla A, TE Nikola Tesla B, TE Morava, TE Kostolac and TETO Novi Sad are also cooled by once-through systems. Once-through cooling systems withdraw 102.5 m^3 of water per produced MWh of electricity, and consume only 0.43 m^3 of water per generated MWh of electricity (Medarac, Magagna, and Hidalgo González, 2018). Hence the big gap between WW and WC data.

WW and WC change in different hydrological years. The biggest difference in WW is present in Bulgaria, while other countries vary slightly. Water withdrawal for Bulgaria is 16% higher in dry with respect to wet year. In Slovenia WW in dry year is 7% higher than in the wet year. For the rest of the countries the differences range between 1 and 5%. In Hungary the difference is only 0.9% increase, since there is enough water for cooling. Although the amount of water available for cooling is crucial, river temperatures need also to be within appropriate ranges. This study does not consider these effects.

Water consumption reaches its highest values in Bulgaria, Romania and Hungary with 65, 56 and 21% increase in water consumption from wet to dry hydrological year.

Table 21. Water withdrawal and consumption as model results for dry (2007), average (2015) and wet (2010) year, in Mm^3

Country	**WW 2007**	**WC 2007**	**WW 2015**	**WC 2015**	**WW 2010**	**WC 2010**
Albania	0	0	0	0	0	0
Bosnia and Herzegovina	30	24	30	24	29	23
Bulgaria	3129	42	2995	36	2701	25
Croatia	0	0	4	0	0	0
Greece	74	60	73	59	73	59
Hungary	2983	30	2970	27	2956	25
Kosovo	14	12	14	11	14	11
Montenegro	4	3	4	3	4	3
North Macedonia	13	11	13	11	13	10
Romania	1774	43	1766	36	1756	27
Serbia	1374	9	1367	9	1358	9
Slovenia	1030	24	999	24	962	23

WW – water withdrawal; WC – water consumption

Figure 16. Water withdrawal and consumption for thermal power units for dry, average and wet years

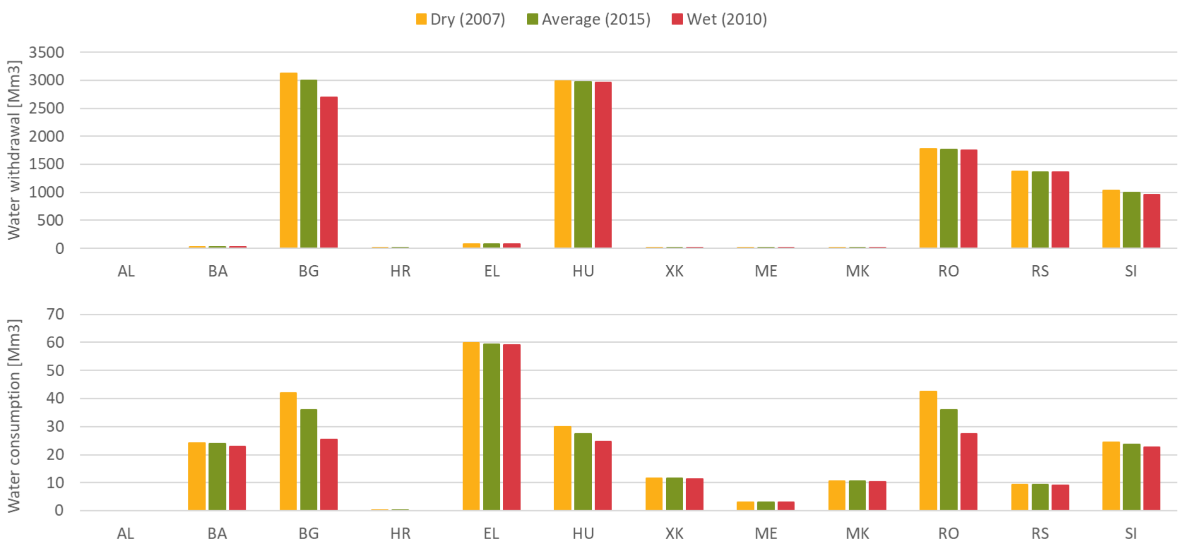
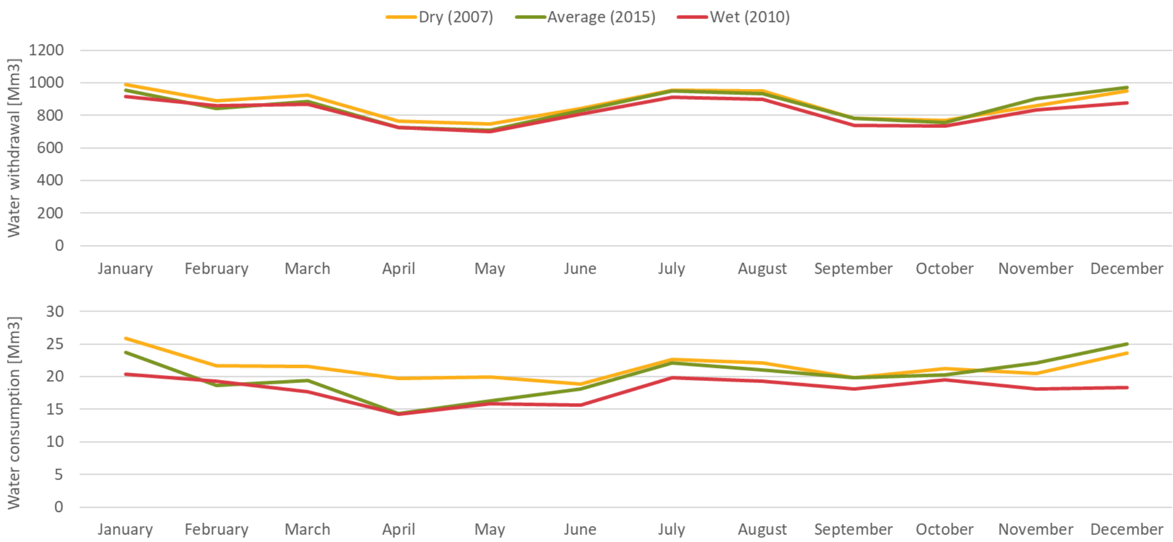


Figure 17 shows water withdrawal and water consumption on a monthly basis. Maximum WW and WC are observed at the beginning and at the end of a year in all simulations. WW decrease in April and May and also in September and October. The minimum WW are 748, 707 and 700 Mm^3/Month for dry, average and wet years, respectively, which are close the values of 707 and 700 Mm^3/Month for average and wet scenarios. The minimum values for WC are 18.8, 14.4 and 14.2 Mm^3/Month in dry, average and wet years, respectively. The minimum WW for all three hydrological years are observed in May, while on the other hand, the minimum WC during a dry year is experienced in June, and in April in the case of average and wet years.

Note that real consumption and withdrawal may differ from modelled values since its calculation is based on constant values of water withdrawal and consumption factors obtained from available literature, depending on type of technology and fuel (Medarac, Magagna, and Hidalgo González, 2018).

Figure 17. Water withdrawal and consumption for thermal power units on a monthly basis for dry (2007), average (2015) and wet years (2010), in Mm3



6.3.2 Water stress index

The water stress index (WSI) of a power plant is estimated as the water withdrawn divided by the water runoff at the location for each time step. This index varies between values 0 and 1, the first meaning that the unit is not producing and there is no withdrawal, and the latter meaning that all the available water runoff is used for cooling purposes.

Table 22 divides thermal power units that use freshwater for cooling into three categories, based on their WSI values throughout simulated year period.

The first category consists of units with WSI values in the range 0.1-1.

The second category represents units that have significantly high WSI values, even higher than 1. High WSI values can be due to several reasons:

— Those power plants could have other water sources not considered by LISFLOOD, like underground water sources or a public water supply system.

— The water source used for cooling may also be located in another cell (the LISFLOOD model divides the region by 5x5 km cells). This could explain why the nuclear power plants Paksi Atomerőmű, Kozloduy and Cernavoda have extremely high WSI values even though they use the Danube River for cooling.

The third category represents units that have small WSI values, on average below 0.1, due to high water runoffs on their locations and/or small water withdrawal and consumption due to the specific cooling type. Those units are not affected by dry hydrological scenarios and are able to generate electricity without affecting local water availability.

Table 22. Water stress index categories of committed thermal power units using fresh water for cooling

Power plant	Cooling Type	0.1<WSI<1	1<WSI	WSI<0.1
TE Tuzla	NDT		●	
TE Ugljevik	NDT		●	
TE Gacko	NDT			●
TE Kakanj	MDT	●		
Bobov Dol	NDT		●	
Kozloduy	OTF		●	
Maritsa Iztok-3	NDT	●		
Maritsa Iztok-2	OTF/NDT		●	
CHP Republika	NDT			●
Maritsa 3	NDT			●
Maritsa Iztok-1 - AES Galabovo	NDT			●
KTE Jertovec	NDT			●
TE-TO Sisak	OTF			●
Amyntaio	NDT			●
Agios Dimitrios	NDT		●	
Thiva Heron	AIR			●*
Thisvi Elpedison	AIR			●*
Korinthos Power	AIR			●*
Kardia	NDT	●		
Megalopolis	NDT	●		
Thesasaloniki	MDT		●	
Komotini	NDT			●
Florina	NDT	●		
Literi	AIR			●*
Nyíregyházi	NDT			●
Dunamenti Erőmű	OTF		●	
Gönyűi Erőmű	OTF			●
Bakonyi Gázturbinás Erőmű/ Ajkai Hőerőmű	NDT/MDT			●
Paksi Atomerőmű	OTF		●	
Mátrai Erőmű	NDT		●	
Tisza Erőmű	OTF			●
Lőrinci Gázturbinás Erőmű	CP			●
Újpesti Erőmű&GREENERGY	AIR			●*
Kelenföldi Erőmű&PLOOP	OTF			●
TE Pljevlja	NDT		●	
TE TO AD Skopje	MDT/DHC			●
TE Oslomej	NDT	●		
TE Bitola	NDT	●		
CTE Rovinari	NDT			●
CCCC Brazi	NDT		●	
CTE Isalnita	NDT			●
CNE Cernavoda	OTF		●	
CTE Turceni	NDT		●	
CET Drobeta	NDT			●
CET Craiova II	NDT			●
CET Oradea I	MDT	●		
TE Nikola Tesla B	OTF			●
TETO Zrenjanin	MDT		●	
TE Kolubara	MDT	●		
TE Morava	OTF			●
TE Kostolac A	OTF			●
TETO Novi Sad	OTF			●
TE Kosovo A&TE Kosovo B	MDT/NDT	●		
TPP Brestanica	NDT			●

Power plant	Cooling Type	0.1<WSI<1	1<WSI	WSI<0.1
TE Šoštanj	NDT	●		
TE TO Ljubljana	OTF	●		
NE Krško	OTF	●		

(*) – AIR cooling, which is the main reason for small WW and WC

NDT – natural draft cooling tower; MDT – mechanical draft cooling tower (induced draft cooling tower); OTF – once through cooling using fresh water; AIR – Air (dry) main condenser cooling; DHC – District heating cooling; CP – cooling pond

Table 23 to Table 28 provide detailed results on water withdrawal, consumption and runoff, as well as the water stress index values for thermal power plant within the first category. Those units were selected due to representative WSI values. Table 23, Table 25, and Table 27 show water withdrawal, consumption and runoff for power plants Florina, Kakanj, Kardia, Kosovo A and B, Maritsa Iztok 3, Megalopolis, NE Krško, Oslomej, Oradea I, TETO Ljubljana, TE Bitola and TE Šoštanj. Table 24, Table 26 and Table 28 show additional data on water stress index for each power plant from the first category.

Table 23. Water runoff, withdrawal and consumption of thermal power units from first category, for average (2015) year

EIC code	Name	Cooling type	River	WW	WC	WR
29WAISMELITII--H	Florina	NDT	Geropotamos	5.0	3.9	27.9
36W-TE-KAKANJ--S	Kakanj	MDT	Bosna	7.3	6.0	1494.0
29WAISKARDIAIV-X	Kardia	NDT	/	21.1	17.2	215.0
34WETL-KOLUA---P	Kolubara	MDT	Beljanica	4.3	3.5	599.1
34WETL-KOSOA---C/34WRTL-KOSOB---7	Kosovo A and B	MDT/NDT	Sitnice	14.1	11.5	382.2
32W001100100063E	Maritsa Iztok 3	NDT	Maritsa	12.1	9.9	92.3
29WAISMEGAL-IV-C	Megalopolis	NDT	Alfeios	9.8	8.0	224.2
28W-G-000000119L	NE Krško	OTF	Sava	903.0	5.5	5989.0
33W-TECOSLOMEJ-7	Oslomej	NDT	Treska	2.1	1.7	33.7
30W-CET-ORAD---W	Oradea I	MDT	Crisul Repede	1.7	1.4	6.9
28W-G-000000082I	TETO Ljubljana	OTF	Ljubljanica	74.3	0.3	2742.0
33W-TEC-BITOLA-F	TE Bitola	NDT	Crna Reka	10.8	8.8	30.0
28W-G-000000080M	TE Šoštanj	NDT	Paka	21.3	17.4	93.8

WC – water consumption in Mm^3; WW – water withdrawal in Mm^3: WR – water runoff in Mm^3 (LISFLOOD); NDT – natural draft cooling tower; MDT – mechanical draft cooling tower (induced draft cooling tower); OTF – once through cooling using fresh water

Table 24. Water stress index values for thermal power units from first category, for average (2015) year

Name	Average WSI	Hours WSI<0.1	Hours 0.1<WSI<0.2	Hours 0.2<WSI<0.5	Hours WSI>0.5
Florina	0.52	1874	479	2471	3936
Kakanj	0.07	6816	816	1128	0
Kardia	0.18	2551	2543	3666	0
Kolubara	0.05	6792	1392	576	0
Kosovo A and B	0.15	4236	2892	1008	624
Maritsa Iztok 3	0.32	2791	1364	2806	1799
Megalopolis	0.10	4636	3263	861	0
NE Krško	0.24	1465	4321	2518	456
Oslomej	0.12	5189	1848	1723	0
Oradea I	0.52	2644	695	2410	3011
TETO Ljubljana	0.09	6915	1576	269	0
TE Bitola	0.66	520	1239	1458	5543
TE Šoštanj	0.47	924	1275	2902	3659

WSI – water stress index

Table 25. Water runoff, withdrawal and consumption of thermal power units from first category, for wet (2010) year

EIC code	Name	Cooling type	River	WW	WC	WR
29WAISMELITII--H	Florina	NDT	Geropotamos	5.0	3.9	46.3
36W-TE-KAKANJ--S	Kakanj	MDT	Bosna	7.1	5.7	3242.0
29WAISKARDIAIV-X	Kardia	NDT	/	21.0	17.1	211.1
34WETL-KOLUA---P	Kolubara	MDT	Beljanica	4.2	3.4	838.7
34WETL-KOSOA---C/34WRTL-KOSOB---7	Kosovo A and B	MDT/NDT	Sitnice	13.9	11.3	359.5
32W001100100063E	Maritsa Iztok 3	NDT	Maritsa	9.2	7.5	95.7
29WAISMEGAL-IV-C	Megalopolis	NDT	Alfeios	9.8	8.0	188.9
28W-G-000000119L	NE Krško	OTF	Sava	903.0	5.5	8780.0
33W-TECOSLOMEJ-7	Oslomej	NDT	Treska	2.0	1.7	50.3
30W-CET-ORAD---W	Oradea I	MDT	Crisul Repede	0.9	0.7	12.0
28W-G-000000082I	TETO Ljubljana	OTF	Ljubljanica	38.6	0.2	3365.0
33W-TEC-BITOLA-F	TE Bitola	NDT	Crna Reka	10.7	8.7	41.7
28W-G-000000080M	TE Šoštanj	NDT	Paka	20.9	17.0	112.2

WC – water consumption in Mm^3; WW – water withdrawal in Mm^3: WR – water runoff in Mm^3 (LISFLOOD); NDT – natural draft cooling tower; MDT – mechanical draft cooling tower (induced draft cooling tower); OTF – once through cooling using fresh water

Table 26. Water stress index values for thermal power units from first category, for wet (2010) year

Name	Average WSI	Hours WSI<0.1	Hours 0.1<WSI<0.2	Hours 0.2<WSI<0.5	Hours WSI>0.5
Florina	0.28	3316	1292	2792	1360
Kakanj	0.03	8257	144	359	0
Kardia	0.18	2962	2827	2971	0
Kolubara	0.01	8736	24	0	0
Kosovo A and B	0.08	6113	1937	710	0
Maritsa Iztok 3	0.31	4289	1346	1752	1373
Megalopolis	0.12	4408	2644	1708	0
NE Krško	0.19	2760	4082	1558	360
Oslomej	0.08	6338	1781	641	0
Oradea I	0.33	5772	755	1601	632
TETO Ljubljana	0.10	7664	881	215	0
TE Bitola	0.49	767	2016	2091	3886
TE Šoštanj	0.44	1566	1314	2691	2919

WSI – water stress index

Table 27. Water runoff, withdrawal and consumption of thermal power units from first category, for dry (2007) year

EIC code	Name	Cooling type	River	WW	WC	WR
29WAISMELITII--H	Florina	NDT	Geropotamos	5.0	3.9	20.3
36W-TE-KAKANJ--S	Kakanj	MDT	Bosna	7.4	6.0	1343.0
29WAISKARDIAIV-X	Kardia	NDT	/	21.2	17.3	121.5
34WETL-KOLUA---P	Kolubara	MDT	Beljanica	4.3	3.5	434.1
34WETL-KOSOA---C/34WRTL-KOSOB---7	Kosovo A and B	MDT/NDT	Sitnice	14.2	11.6	147.4
32W001100100063E	Maritsa Iztok 3	NDT	Maritsa	14.6	11.9	52.0
29WAISMEGAL-IV-C	Megalopolis	NDT	Alfeios	9.8	8.0	107.0
28W-G-000000119L	NE Krško	OTF	Sava	903.0	5.5	5764.0
33W-TECOSLOMEJ-7	Oslomej	NDT	Treska	2.1	1.7	15.2
30W-CET-ORAD---W	Oradea I	MDT	Crisul Repede	2.2	1.8	5.9
28W-G-000000082I	TETO Ljubljana	OTF	Ljubljanica	104.0	0.4	2359.0
33W-TEC-BITOLA-F	TE Bitola	NDT	Crna Reka	10.9	8.9	18.2
28W-G-000000080M	TE Šoštanj	NDT	Paka	21.9	17.8	127.5

WC – water consumption in Mm^3; WW – water withdrawal in Mm^3: WR – water runoff in Mm^3 (LISFLOOD); NDT – natural draft cooling tower; MDT – mechanical draft cooling tower (induced draft cooling tower); OTF – once through cooling using fresh water

Table 28. Water stress index values for thermal power units from first category, for dry (2007) year

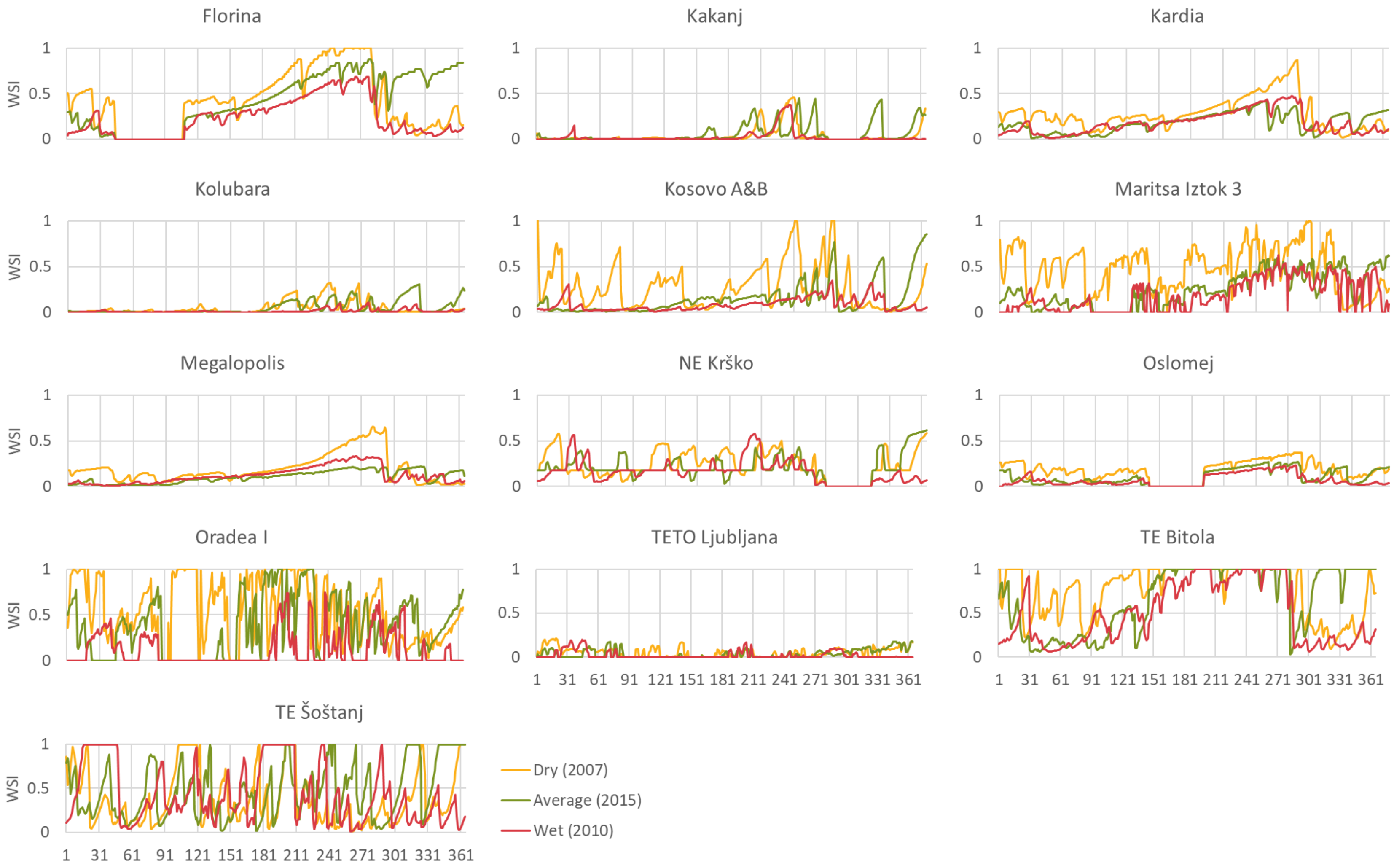
Name	Average WSI	Hours WSI<0.1	Hours 0.1<WSI<0.2	Hours 0.2<WSI<0.5	Hours WSI>0.5
Florina	0.51	1754	1153	2974	2879
Kakanj	0.04	7873	288	599	0
Kardia	0.28	1296	1516	4801	1147
Kolubara	0.05	7536	577	647	0
Kosovo A and B	0.28	2881	1227	3261	1391
Maritsa Iztok 3	0.52	1105	769	2585	4301
Megalopolis	0.19	2425	3627	1873	835
NE Krško	0.27	1513	3239	3696	312
Oslomej	0.20	1947	3415	3398	0
Oradea I	0.60	1019	708	2479	4554
TETO Ljubljana	0.10	6032	2247	481	0
TE Bitola	0.75	29	167	2161	6403
TE Šoštanj	0.38	1440	1825	3141	2354

WSI – water stress index

Figure 18 displays data shown in Table 24, Table 26 and Table 28. Water stress indexes of the first category of thermal power units are displayed on a daily basis. Changes between a different hydrological year can be observed. In general, as expected, higher WSI values occur during dry year due to higher electricity generation from thermal power units and lower water runoff values. For some days, when higher power generation and lower runoff is experienced, unexpected behaviour may happen, with WSI values during an average year higher than in a dry year.

When taking in account that total water runoff used to estimate WSI is shared between several sectors, the WSI values obtained for Florina, Kosovo A and B, Maritsa Iztok 3, Oradea I, TE Bitola and TE Šoštanj suggest that those locations could have significant water scarcity problems when experiencing dry hydrological conditions. The average WSI value in TE Šoštanj is the lowest for dry scenario since water runoff provided by LISFLOOD is higher than in average and wet year. The average water runoff for dry year is 4.04 m^3/s, while for average and wet scenarios it is 2.98 and 3.56 m^3/s, respectively.

Figure 18. Daily water stress index values of first category thermal power units for dry (2007), average (2015) and wet (2010) year.



7 Conclusions

This study describes an implementation of a modelling framework, already tested in other JRC studies (Fernandez-Blanco Carramolino et al., 2016), (Fernandez Blanco Carramolino et al., 2017) and (De Felice et al., 2019), for a detailed analysis of impacts of different hydrological conditions on the power system in the Balkan Peninsula. This method is able to simulate the water-power nexus in the region with a very high level of detail, since it is able to quantify economic impacts, emissions, water withdrawn and consumed, and detailed operation of the power system (scheduling and use of interconnectors) under different conditions. The study also relies on an extensive review of data.

Dispa-SET models behave soundly, despite data-related limitations, replicating available statistics up to a great extent. Outcomes of the simulation are robust since they are based on long time-series of climate data. Therefore the data and the model presented in this study can be used to support design and monitoring of energy- and water-related policies.

Besides power generation, results from the Dispa-SET UCD model include economical, commitment and power dispatch values for each unit. Results show an increase in hydropower generation from 53.1 TWh in dry year to 65.2 TWh and 85.1 TWh in average and wet years. The rise is mostly at the expense of generation from lignite and gas-fired power plants. Inversely proportional to increase of hydropower generation, an average electricity cost decreased from 17.79 €/MWh in dry year to 16.35 and 14.05 €/MWh in average and wet year, respectively.

In years with higher water availability, in countries with lower efficiency of lignite power plants it is more affordable to import electricity than to generate it in their own plants. In countries with higher efficiency of lignite power plants, these plants operate in base load and surplus of hydropower is sold to the market. In years with lower water availability it is possible also for countries with low efficiency of lignite power plants to export electricity.

This modelling framework allows for the identification of the weakest points of a power system from the point of view of water resources. To that purpose the water stress index (WSI) is used to determine thermal power plants which are the most vulnerable to water scarcity: Florina, Kosovo A and B, Maritsa Iztok 3, Oradea I, TE Bitola and TE Šoštanj. Policies aimed to limiting the withdrawal of the most water-stressed units would have consequences in overall system costs, marginal price of electricity, water values, generation mix and emissions. All these impacts can be quantified with this approach, and that is crucial for a region such as the Western Balkans and the neighbouring EU Member States that still relies almost completely on thermal and hydro power plants.

For future studies, water-related constrains in form of water availability and river temperature should be added to the Dispa-SET model to allow a better representation of power dispatch when there is not enough water for cooling, or river temperature is too high. Joint optimization of power system and other sectors utilizing fresh water sources should be carried out for a comprenhensive analysis. Other possible improvements could consist of an addition of constraints representing the river network to model cascades, or stochastic modelling.

The approach shown in this study is complex and data-intensive. It requires gathering and merging of multiple data sets. Improvements in data collection and transparency would significantly help future energy modelling and validation.

Future work should cover scenarios that include projections of future power systems, with rising share of renewable energy sources and expected effects on water resources due to climate change.

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Annexes

Annex 1: Overview of the drainage basins in the Balkan Peninsula

Black Sea drainage basin

The major rivers and tributaries to Black Sea are Danube, Inn, Morava, Vah, Drava, Tisza, Sava, Velika Morava, Olt, Siret and Prut (Sommerwerk et al., 2009). Danube, Sava, Drava, Krka, Una, Vrbas, Bosna, Drina and Velika Morava Rivers are included in this study (ICPDR, 2019).

Figure 19. Danube river basin district overview

Source: (ICPDR, 2019)

Danube river basin

The Danube represents the second largest river in Europe with its flow distance of 2826 km. It flows through 19 countries and drains an area of around 800 000 km^2 and its average altitude is 458 m. The main Danube tributaries are Leitha, Raab, Drava, Sava and Velika Morava rivers (WBIF, 2017).

Because of its size, west to east flow orientation, and diverse relief, there are big differences in climate between Lower and Upper Danube. Atlantic climate has an influence on the Upper Danube where winters are mild and precipitations are higher, while the Lower Danube exhibits lower precipitations, dry and cold winters due to the influence of eastern continental regions. Parts of rivers Drava and Sava are affected by Mediterranean climate. The highest precipitations are in higher parts of Alps (~3200 mm) while the lowest precipitations are in Black Sea and delta regions (~350 mm). Average peak precipitation for western part of the basin happens in July, for southeast parts it peaks in February/March, while it peaks at autumn months for areas influenced by Mediterranean climate. Middle and Lower Danube have the highest average annual temperatures of around 11-12°C, while seasonal differences increase from west to east. For example, the seasonal temperature difference in Hungary can be as high as 74°C (Sommerwerk et al., 2009).

Due to spatial differences in precipitation, there is a strong effect on surface run-off and most of the flow comes from Austrian and Romanian mountains (around 40%). The average annual specific discharge decreases from 25-35 L/s/km^2 in Alpine mountains to 19 L/s/km^2 for the Sava, 6.3 L/s/km^2 for the Tisza and to 2.8 L/s/km^2 for the rivers of eastern Carpathian region. Iron Gate dams and larger water management schemes along the Prut, Siret, Argeș and Olt Rivers modified the flow regime of the Lower Danube.(Sommerwerk et al., 2009) The list of the hydropower plants in the Danube River Basin can be seen in documents (WBIF, 2017) and (Euronatur, 2012).

Table 29. Flow regime of the Danube river and its tributaries

River	Station	Catchment area [km^2]	Mean annual discharge [m^3/s]
Danube	Berg	4047	38.5
Danube	Vienna	101731	1920
Danube	Ceatal Izmail	807000	6486
Inn	Passau-Ingling	26084	732
Morava	Moravsky Jan	24129	110
Vah	Sala	10620	138
Drava	Donji Miholjac	37142	541
Tisza	Senta	141715	792
Sava	Sremska Mitrovica	87996	1527
Velika Morava	Ljubičevski most	37320	277
Olt	Stoenești	22683	172
Siret	Lungoci	36036	210
Prut	Cernicvi	6890	67

Source: (Sommerwerk et al., 2009)

Sava river basin

The River Sava, with its flow length of 945 km represents the largest Danube tributary by volume and the second largest by catchment area (95 793 km^2). Sava basin is international basin covering six countries, 40% in Bosnia and Herzegovina, 26% in Croatia, 15.4% in Serbia, 11% in Slovenia, 7.5% in Montenegro and 0.1% in Albania.(WBIF, 2017) Sava's watershed covers 45 to 70% of the surface area of Slovenia, Bosnia and Herzegovina, Croatia and Montenegro and its water resources represent almost 80% of freshwater resources of mentioned four countries (WBIF, 2017). Around 8.8 million people live in Sava River basin with cities like Belgrade, Zagreb, Sarajevo, Ljubljana and Banja Luka being the largest cities on the River Sava or its tributaries (WBIF, 2017).

Sava River is formed out of headwaters of Dolinka Sava and Bohinjka Sava from Lake Bohinj. Its river bed passes through Slovenia and Croatia where it continues along the border of Croatia and Bosnia and Herzegovina, from the confluence of the River Una and almost to the confluence of the River Drina. In Serbia, it remains a lowland river with wide channel and it enters the River Danube in Belgrade (Sommerwerk et al., 2009).

Sava is under influence of Alpine and Mediterranean climates with an average annual air temperature of 9.2°C and average annual precipitation of 1000 mm. In the upper Kupa region and in Julian Alps, maximum precipitation reaches around 3800 mm, while minimum precipitation of around 600 mm is reached in Pannonian Plain. Average annual discharge is 1572 m^3/s, while its largest tributary, the River Drina, has a discharge of 370 m^3/s. Sava contributes for 25% of the total Danube discharge (Sommerwerk et al., 2009).

Major Sava tributaries are rivers Kupa, Una, Vrbas, Bosna and Drina (Sommerwerk et al., 2009).

Kupa partly forms a natural border between Croatia and Slovenia. It originates in Croatia in mountain region of Gorski Kotar. Before it reaches Slovenian border, it receives inflow from small Čabranka River. It receives inflow from the River Lahinja before eventually detaching from Slovenian border. The river then reaches the city of Karlovac where it receives inflow from Dobra and Korana Rivers. Before it reaches the city of Sisak and enters the River Sava, it merges with Glina and Odra Rivers (Wikipedia, 2019).

The Una sub-river basin has an area of 10 816 km^2. The length of the river is 214 km and it forms part of the border between Croatia and Bosnia and Herzegovina. The climate is continental with annual precipitation of around 900 mm. The spring is in Croatia and after 12 km of flow, it enters mountains in north western Bosnia and Herzegovina, while proceeding to the Una-Sana Canton. The confluence is in Croatia near Jasenovac.(WBIF, 2017).

The Vrbas sub-river basin has an area of 6386 km^2 and it is the smallest Sava River tributary in Bosnia and Herzegovina. The spring of the river Vrbas is in the mountain Vranica (WBIF, 2017).

The Bosna sub-river basin has a catchment area of 10 457 km and it is the second largest tributary of the River Sava in Bosnia and Herzegovina. The spring is located in Sarajevsko polje, in the Igman Mountain (WBIF, 2017).

The Drina sub-river basin is the largest tributary of the River Sava. It is 346 km long and the catchment area is 19 570 km^2. The catchment is shared between Bosnia and Herzegovina, Serbia, Albania and Montenegro. The river is composed of Piva and Tara Rivers which flow from Montenegro.

The list of hydropower plants in Sava River Basin can be seen in document (WBIF, 2017) and (Euronatur, 2012).

Figure 20. The Sava river basin with tributaries

Source: (WBIF, 2017)

Velika Morava river basin

Velika Morava is a large right-bank tributary of the lower Danube, upstream of the Iron Gate dams. It drains around 40% of Serbian territory with a catchment area of around 38 000 km^2. The catchment is located partly on Bulgarian territory (~3%) as well as on parts of North Macedonia and Montenegro. Its average channel width is 140 m and the average water depth of 1-4 m (Sommerwerk et al., 2009).

Main tributaries are Crnica, Jovanovačka Reka, Ravanica, Resava and Resavica on the right side, and Jasenica, Rača, Lepenica, Belica River, Lugomir and Kalenićka Reka on the left side. Before it reaches Danube, Velika Morava River splits, while creating 47 km long arm called Jezava. From the left side, it is joined by Ralja River and it flows into Danube (WBIF, 2017).

With its length of 185 km, Velika Morava starts at the confluence of the South and the West Morava near the small town of Stolać. The West Morava branch is the longest tributary with the length of 493 km and its longest water source of the River Ibar. Ibar is the longest tributary of the West Morava which gives the Ibar-West Morava-Velika Morava river system a length of 550 km, being the longest waterway in the Balkan Peninsula. (Sommerwerk et al., 2009),(WBIF, 2017).

South Morava drains southeast Serbian territory with the catchment area of 15 446 km^2. The river's two biggest headwaters originate from the Rilo-Rhodope and North Macedonian-Serbian Mountains. Its largest tributary is the River Nišava with the length of 218 km and catchment area of 4068 km^2. The source of Nišava is located in southern slopes of Stara Planina Mountains in Bulgaria. It merges with South Morava near the city of Niš (Sommerwerk et al., 2009).

West Morava drains southwest Serbian territory with the catchment area of 15 567 km^2. Its headwater sources are located in Golija, Mučanj and Tara Mountains in the Dinaric Alps. The headwaters merge near the village Leposavić. The biggest West Morava's tributary is the River Ibar with its source in eastern Montenegro. It merges with West Morava near the city of Kraljevo (Sommerwerk et al., 2009).

The climate of the Velika Morava River is mostly continental with average annual temperatures of 11-12 °C. Precipitation is the highest in May and June while being the lowest in February and October. Average discharge is 277 m^3/s and it peaks during the snowmelt period in springtime (Sommerwerk et al., 2009).

The first major hydro water activities started between 1960 and 1995 on the whole Velika Morava River Basin. The river directions were shortened, meander has been cut off and swamp areas have been transformed into fish ponds. Extensive drainage system has been carried out to increase the proportion of arable land. Multiple dams and water reservoirs have been built to be used for hydropower generation, municipal water supply, irrigation and flood protection (Sommerwerk et al., 2009).

The list of hydropower plants in Velika Morava River Basin can be seen in documents (WBIF, 2017) and (Euronatur, 2012).

Drava river basin

The River Drava is the 4th largest and the 4th longest Danube tributary with its catchment area of 40 087 km^2 and the length of 719 km. It is shared by Italy, Austria, Slovenia, Hungary and Croatia. The main tributaries are Austrian rivers Isel, Möll, Lieser and Gurk and the River Mura that reaches Drava at Croatian-Hungarian border. Drava merges with the Danube near the city of Osijek and basin is inhabited by approximately 3.6 million people. The largest cities on the River Drava are Graz, Maribor and Osijek (Sommerwerk et al., 2009).

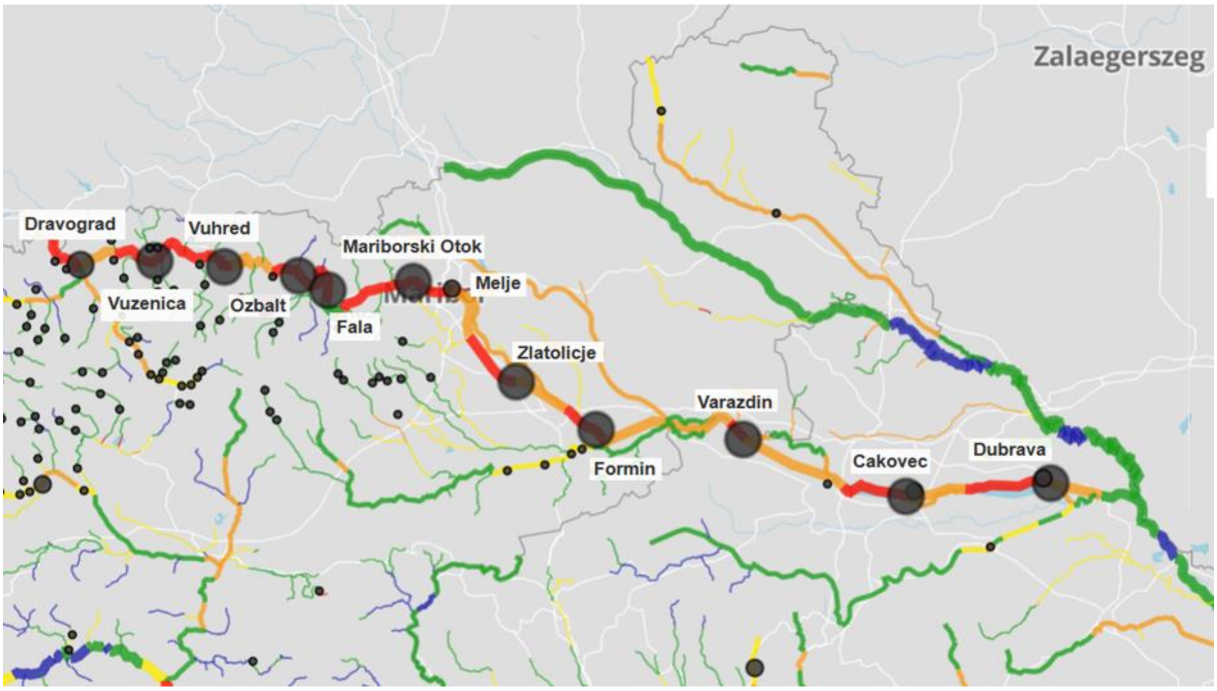
The source of Drava River is located in Southern Alps in Italy near Dobbiaco. For its first few kilometers of flow, it drops 400 m in altitude, while entering Austria. It flows through Eastern Tyrol and Carinthia, while separating central Alps from limestone Alps. Drava then continues through northeast Slovenia and enters Croatia (Sommerwerk et al., 2009).

There are 23 installed hydropower plants in the upper region, upstream of Mura confluence, numbering 12 power stations in Austria, 8 in Slovenia and 3 in Croatia. (Figure 21) Also, there are 26 hydropower plants along the River Mura. Downstream of Mura confluence the river is not suitable for effective hydropower generation and river continues forming Croatian-Hungarian border for 145 km. The confluence of the River Drava forms The Nature Park Kopački Rit (Sommerwerk et al., 2009).

The climate is mild continental and partly humid with an average temperature of 10.9 °C. The average rainfall is between 600-750 mm. The highest flow occurs in May and June because of the Alpine snowmelt period. There is a second peak of flow in late autumn due to high precipitation in Southeast Alps. The lowest flow regime is experienced in January and February. Due to high precipitation in the upper basin, the River Drava has high flood risk in the upper part of the river but the flood is prevented with the construction of dams and reservoirs. Average discharge of the River Drava is 541 m^3/s (Sommerwerk et al., 2009).

Human activities resulted in significant changes on the hydrological regime. The River Drava is regulated since the past century, but there are some semi-natural parts of the basin in lower parts. The upper part hydropower regime causes major water level changes, which impact flora and fauna (Sommerwerk et al., 2009).

Figure 21. Part of the Drava river and the hydropower plants located in Slovenia and Croatia



Source: (Euronatur, 2012)

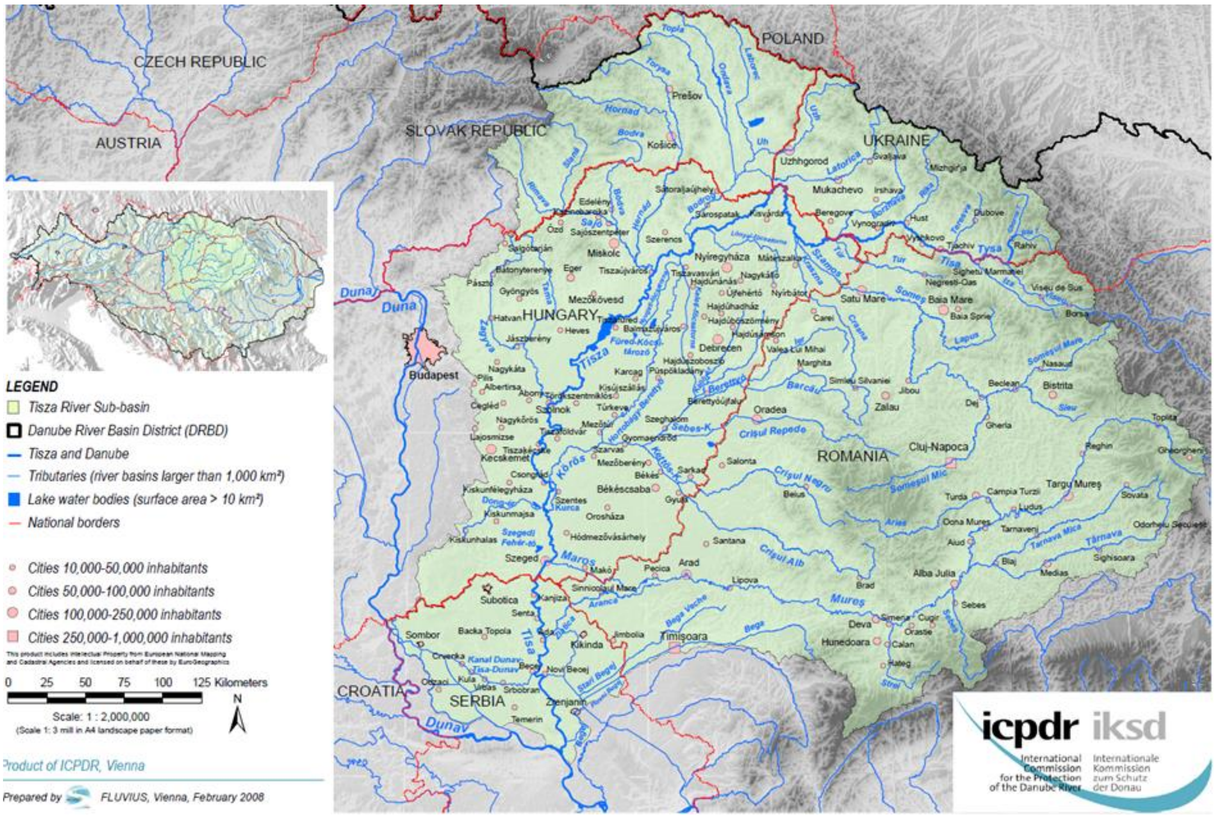
Tisza river basin

Tisza River Basin is the longest tributary of the Danube River with the second largest discharge after Sava. Its catchment area is 157 186 km^2 which represents 19.5% of the Danube River Basin. The basin drains the largest catchment area in the Carpathian Mountains before flowing through Great Hungarian Plain and joining the River Danube. Original length of the River Tisza was 1400 km, but due to the extensive measures of flood control the river is shortened to 966 km (ICPDR, 2008).

The Tisza River Basin can be divided into mountainous Upper Tisza Basin with tributaries in Ukraine, Romania and eastern part of Slovak Republic and lowland part in Hungary and Serbia that is surrounded by East-Slovak Plain, the Transcarpathian lowland in Ukraine and the plain on the western fringes of Romania. The River Tisza flow can be divided into three parts. The Upper Tisza River from its source to the confluence of Someș River, the Middle Tisza where the largest tributaries, Bodrog and Someș rivers, reach the main river channel, and the Lower Tisza on the downstream of mouth of the River Mures (ICPDR, 2008).

Due to the river's particular geomorphology in form of short, steep fall from Carpathian Mountains which suddenly turns into the flat lowland of Great Hungarian Plain, the river experiences extreme dynamics. Extreme dynamics results in severe floods with the most damaging being the 2010 flood where the costs of rehabilitation in a single county, Bosod- Abaúj-Zemplén, exceeded 6.45 million euros (Borsos and Sendzimir, 2018).

Figure 22. The Tisza river basin



Source: (ICPDR, 2008)

Five countries share territories in the Tisza River Basin percentages of catchment area being 46.2, 29.4, 9.7, 8.1 and 6.6% for Romania, Hungary, Slovak Republic, Ukraine and Serbia, respectively. The biggest cities in the Tisza River Basin are Uzhhorod and Mukachevo in Ukraine, Kosice in Slovak Republic, Debrecen and Miskolc in Hungary, Cluj-Napoca, Timișoara and Oradea in Romania and Subotica in Serbia (ICPDR, 2008).

Mean air temperatures vary from 3 °C in the Apuseni Mountains to more than 11 °C in lower and middle parts of Tisza River. The maximum temperatures are reached in July, while the minimum is observed in January. The mean values of annual precipitation vary from 500 to 1600 mm/a. The highest values are experienced in northwest parts Carpathians and in the Apuseni Mountains, while the minimum are observed in southwestern parts of basin, along with the Tisza River channel (ICPDR, 2008).

The largest tributaries are rivers Mures, Körös, Someș and Bodrog with catchment areas of 30 332, 27 537, 18 146 and 13 579 km^2, respectively (ICPDR, 2008).

There are more than 60 reservoirs used for purposes of hydropower, flood protection, irrigation, fish farming, water supply and recreation. The total estimated volume of Tisza's river reservoirs is 2.7 billion m^3 (ICPDR, 2008).

There are 33 hydropower plants (> 10 MW) located in Tisza river basin. Most of them are located in Romania (27), while three are located in Slovak Republic, two in Hungary and one in Ukraine (ICPDR, 2008).

Adriatic Sea drainage basin

The analysis of the Adriatic Sea Drainage Basin will cover rivers Neretva, Trebišnjica, Morača, Drin, Bune, Mat, Seman and Vjosë/Aoös, Cetina, Krka, Zrmanja and Isonzo/Soča (WBIF, 2017).

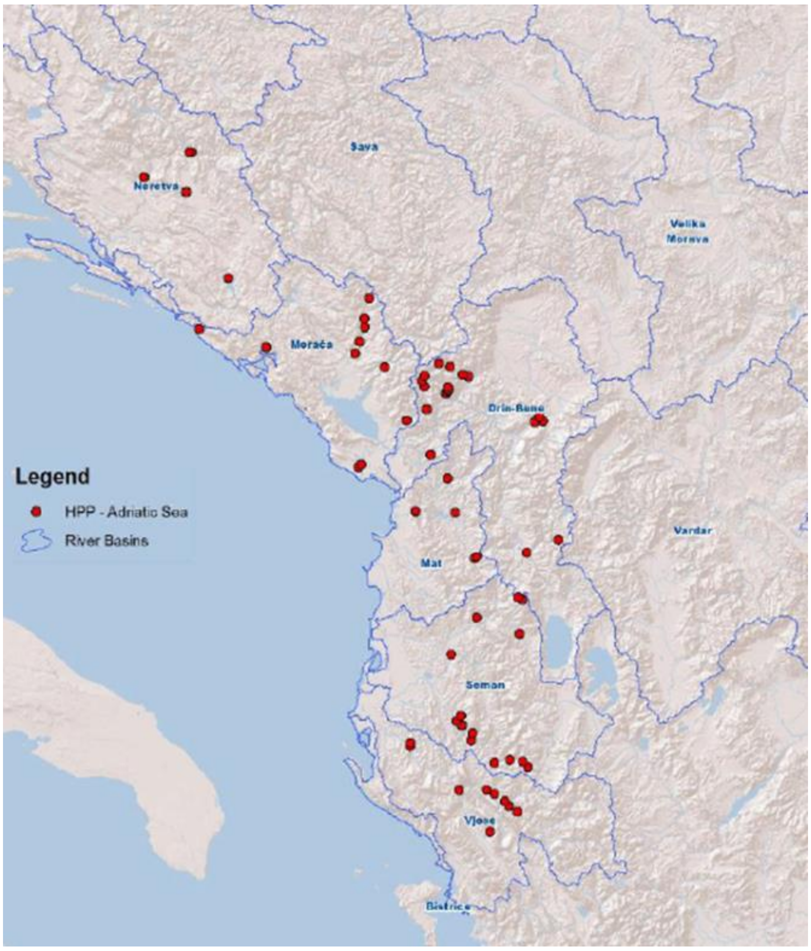
Neretva-Trebišnjica river basin

The catchment area of the Neretva-Trebišnjica River Basin is 10 380 km^2 and it is shared between Croatia and Bosnia and Herzegovina. The total length of the River Neretva is 230 km, of which 208 km are in Bosnia and Herzegovina territory and 22 km in Croatian territory. The rivers source is in Bosnia and Herzegovina at the base of the Zelengora Mountain and it enters southern Croatia forming delta with an area of 200 km^2. The Neretva River is the largest karstic river in the Dinaric Mountains and it is also hydrologically connected with Trebišnjica River (WBIF, 2017),(Skoulikidis et al., 2009).

The River Neretva experiences high annual precipitation, but its flow is lost in the underground and the karstic springs that have substantial contribution to the surface flow. The maximum runoff occurs in December and the minimum in July/August. Jablanica, Rama, Grabovica, Salakovac and Mostar are five hydropower plants located in Bosnia and Herzegovina that utilize the flow of the River Neretva (Skoulikidis et al., 2009).

The Neretva-Trebišnjica River Basin has a crucial socio-economic role in energy generation, drinking water supply and agricultural use (WBIF, 2017).

Figure 23. River basins of the Adriatic Sea drainage basin with locations of HPP



Source: (WBIF, 2017)

Morača river basin

Morača River springs in northern Montenegro under the Rzača Mountain. The main tributaries are the Koštanica, Sjevernica, Javorski Potok, Trnovačka Rijeka, Slatina, Ibrištica, Ratnja and Požanjski Potok. It generally flows southwards for 113 km before entering the Skadar Lake. On its northern part, the River Morača is fast mountain river. Its biggest tributary is the River Zeta, which merges with Morača north of the city of Podgorica (WBIF, 2017).

Drin-Buna river basin

Drin River is the largest Albanian river and it is the third greatest river discharge in the European Mediterranean. The Drin River catchment area is 14 173 m^2 with a length of 285 km. The river is composed of the two main river branches, the White Drin and the Black Drin. The White Drin drains Serbia and Montenegro and the Black Drin originates from the Lake Pespa and the Lake Ohrid. The River Buna merges with Drin before they enter the Adriatic Sea. The River Buna drains the Shkodra Lake (WBIF, 2017),(Skoulikidis et al., 2009).

The Black Drin river is transboundary river since it flows from its source in North Macedonia to Albania and merges with the White Drin near the city of Kukës. The total length of the river is 149 km. With the main purpose of hydropower production, there are two dams with their associated reservoirs with a total installed power of 126 MW. The Black Drin River has a catchment area of a 3350 km^2 with average annual precipitation of 993 mm. Its average annual discharge is 52 m^3/s (WBIF, 2017).

The main tributary of the Black Drin River is the River Radika which is formed by a number of small springs in the area of Shara and Korab mountains. The catchment area of the River Radika is around 880 km^2 while its average annual flow is approximately 30 m^3/s. Its main tributaries are Mavrovksa, Ribnica and Mala Reka Rivers (WBIF, 2017).

Mat river basin

The catchment area of the River Mat is 2441 km^2 and the total length is 115 km. It springs in Diber County near Martanesh. It passes cities Klos and Burrel and after 10 km flows into a large Ulëz Lake. Downstream of the Ulëz Lake it enters the smaller Shkopet Lake and forms gorge through the mountain. It enters the Adriatic Sea near Fushë-Krujë, close to the cities of Lezhë and Lac (WBIF, 2017).

Seman river basin

The Seman River is the second longest river in Albania with the catchment area of 5649 km^2 and the length of 281 km. It is composed of two rivers in Berat County, near the village of Kozare. Osum and Devoll Rivers, after merging, pass along Fier County where Gjanica River joins in and they enter the Adriatic Sea, south of the lagoon of Karavasta. Precipitation is scarce with annually averaging to 1084 mm. Its average annual flow is 95.7 m^3/s. The average temperature of the water ranges from 6.8 °C in January up to 25.5°C in August (WBIF, 2017).

Vjosë/Aoös river basin

The Vjosë/Aoös River flows through the northwest part of Greece before it enters Albania. Its largest tributary is Drino River with a catchment area of 1320 km^2 (WBIF, 2017).

The Vjosë/Aoös flow length is 272 km with 86 km of flow being in Greece. The catchment of the entire Vjosë/Aoös River Basin is around 6700 km^2. Its highest discharge is in winter months, up to 400 m^3/s, while the lowest river flow occurs during the month from July to October. The most of its catchment area is in its natural form with restricted agriculture, forestry, cattle breeding and aquaculture (WBIF, 2017),(Skoulikidis et al., 2009).

Cetina river basin

The River Cetina is a 101 km long river in southern Croatia with the catchment area of 1463 km^2. It springs in northwestern slopes of Dinara Mountain from multiple springs near the village Cetina, 7 km north of a small town Vrlika. A large Peruća Lake created by the Peruća Dam is located near Vrlika. Cetina River then passes to the lower Sinj karst field, passing through the city of Sinj. Passing Sinj, the river continues eastwards through the city of Trilj, before it continues westward around the Mountain Mosor. Then it flows into the Adriatic Sea in the city of Omiš. The main tributaries of the Cetina River Basin are rivers Rumin, Kosinac, Ruda, Dragović, Dabar, Vojskova and Karakašica (Wikipedia, 2019).

The flow of the River Cetina is regulated by means of the hydropower plants operation. The hydropower plants located on the Cetina River are HE Peruća, HE Orlovac, HE Đale, HE Kraljevac and HE Zakučac (Euronatur, 2012), (Wikipedia, 2019).

The Krka river basin

The River Krka is 73 km long, located in Croatia's Dalmatia County with its catchment area of 2088 km^2. The river springs at the foot of Dinara Mountain, near the border between Croatia and Bosnia and Herzegovina. The river flows through Krčić Canyon before it enters the karst valley of Knin, where its tributaries Kosovčica, Orašnica and Butižnica merge with the river. The river then passed to Brljansko Lake, while further downstream, river forms Visovačko Lake. A 7 km long Visovačko Lake ends at the confluence of the River Krka and its largest tributary, the River Čikola. Downstream of the mentioned confluence, the river flows past the town of Skradin, before it forms Prokljasko Lake together with its tributary, the River Gudača. At the last, the river enters Adriatic Sea at Šibenik Bay (Wikipedia, 2019).

Hydropower plants located on the River Krka are HE Jaruga, HE Miljacka and three small hydropower plants HE Golubić, mHE Roški Slap and mHE Krčić (Euronatur, 2012), (Wikipedia, 2019).

The Zrmanja river basin

The River Zrmanja is a 69 km long Croatian river in southern Lika and northern Dalmatia County and its catchment area is a 907 km^2. The river spring is located under the southern peak of the Pljesevica Mountain called Postak. It flows southward through the narrow and long valley before it turns westwards reaching the town of Obrovac. Few kilometers downstream, the river enters the Adriatic Sea at Novigradsko More Bay. Its main tributary is the River Krupa (Wikipedia, 2019).

The Soča/Isonzo river basin

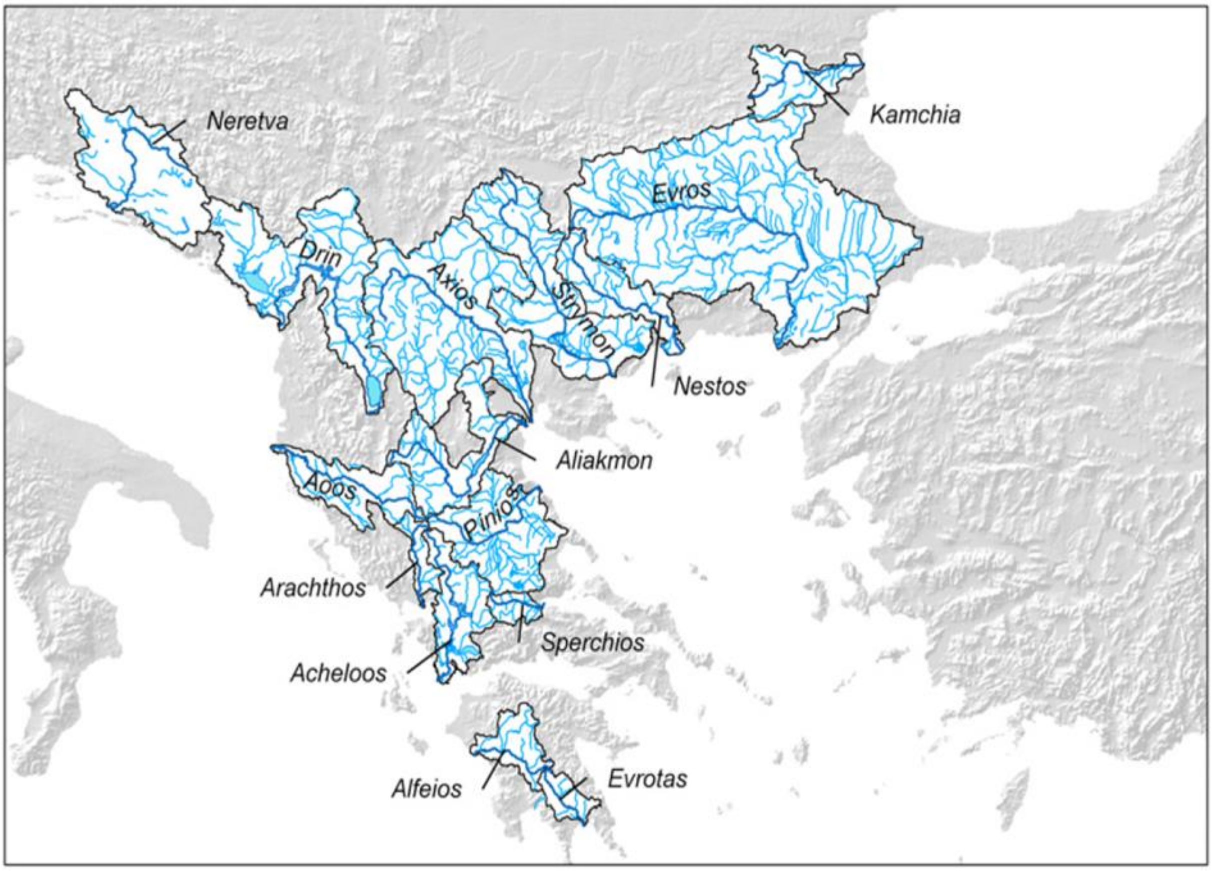
The River Soča is a 138 km long river that flows through northeastern Italy and western Slovenia. Its catchment area is 3400 km^2 and it springs in the Julian Alps, in the Trenta Valley at an elevation of 876 m. The river flow passes the towns of Bovec, Kobarid, Tolmin, Kanal ob Soči, Nova Gorica and Gorizia, before it enters the Adriatic Sea near the town of Manfalcone (Wikipedia, 2019).

The course of the Soča River can be divided into Upper and Medium Soča Valley and Lower Soča. The Upper Soča Valley flow is natural and it is located between the river's source and the village of Most na Soči. In the Medium Soča Valley river flow is regulated by means of three dams and accumulating lakes for the purpose of the hydropower generation in HE Plave, RHE Avče, HE Doblar and HE Solkan hydropower plants. Lower Soča in its span from Italian-Slovenian border to its mouth is a free flowing river (Euronatur, 2012), (SEE-River, 2019).

Aegean Sea drainage basin

The analysis of the Aegean Sea Drainage Basin will cover rivers Evros/Maritsa, Nestos/Mesta, Strymon/Struma, Axios/Vardar, Aliakmon, Pineiós, Spercheios and Evrotas (Skoulikidis et al., 2009).

Figure 24. Rivers of the South Balkan region



Source: (Skoulikidis et al., 2009)

Evros/Maritsa river basin

The Evros/Maritsa River Basin is a large river basin shared between Greece, Turkey and Bulgaria, with 66.4% territory in Bulgaria, 27.2% in Turkey and 6.4% in Greece. It springs in Bulgaria, forms border between Greece and Turkey and at last, forms large delta in the Aegean Sea. The main tributaries are Tundzha, Arda and Ergene Rivers (Skoulikidis et al., 2009).

The Evros/Maritsa River Basin numbers around 100 tributaries with a mean annual discharge of its main tributaries, Arda, Tundzha and Ergene of 2.2 km^3, 1.08 km^3 and 0.87 km^3, respectively. Its maximum flow occurs in spring, between March and May, while the minimum is reached between July and September. Rainfall contributes to the whole discharge for around 60% depending on the region. There are 21 large scale reservoirs with a total storage of 3440 Mm^3. Even though there is a large number of reservoirs on the river, the runoff is highly variable with frequent floods (Skoulikidis et al., 2009).

Nestos/Mesta river basin

The Nestos/Mesta River is a highland river that springs at eastern slope of Rila Mountain in Bulgaria. It flows through Bulgaria and Greece entering Aegean Sea while forming a large delta. The main tributary is Dospatis River, which sinks in Bulgaria and joins Nestos/Mesta River in Greece (Skoulikidis et al., 2009).

Most of the runoff occurs from snow melting in mountains and the rain in lower regions. Maximum flow occurs between April and August while its minimum occurs in September. There are 6 large reservoirs on its tributaries in Bulgaria with the largest one being Dospatis reservoir with a total storage capacity of 430 Mm^3. In Greece, there are three large reservoirs for hydropower generation, Thysavros, Temenos, Platanovrisi and a small irrigation dam Texotes.(Skoulikidis et al., 2009).

Strymon/Struma river basin

The catchment area of the Strymon/Struma River Basin is located in Bulgaria, Greece, North Macedonia and Serbia, but Bulgarian and Greek part represent 88% of the whole catchment area. The main tributaries are rivers Strumeshnitsa, Treklyanska in Bulgaria and Aggitis River in Greece (Skoulikidis et al., 2009).

There are 56 multi-purpose reservoirs in Bulgaria with the total storage capacity of 141 Mm^3. The largest ones are reservoirs Djakovo, Studena and Pchelina (Skoulikidis et al., 2009).

Axios/Vardar river basin

The Axios/Vardar River Basin is the second largest basin in the Aegean Sea Drainage. It drains 83% of North Macedonia and small parts of Greek, Serbian and Bulgarian territory. The main tributaries are Crna and Brejalinica Rivers. The river springs at western slopes of the Mountain Crna Gora before it reaches Skopje-Veles plain where it merges with the Treska River. Tributaries Pčinja, Crna and Bregalnica join the river before it enters Greece. Together with rivers Aliakmon, Gallikos and Loudias it forms wide delta in Thermaikos Gulf (Skoulikidis et al., 2009).

The highest flow occurs in April and minimum in August. The mean annual runoff of its main tributaries is 2.78 km^3. In North Macedonia, 17 large dams have been built to control floods with its total storage capacity of more than 500 Mm^3 (Skoulikidis et al., 2009).

Aliakmon river basin

The Aliakmon River is the longest river in Greece, and it receives overflow waters from Lake Kastoria. Its main tributaries are rivers Venetikos, Almopeos and Edesseos. The Venetikos Rivers joins Aliakmon River in the rivers upstream, while rivers Almopeos and Edesseos merge with Aliakmon River via long irrigation canal. Together with Axios/Vardar River, Aliakmon forms delta in Aegean Sea (Skoulikidis et al., 2009).

Around 70% of the river flow is modified with large dams. The largest reservoirs, Sfikia, Polyfyto and Asomata, have a storage capacity of around 3 km^3. In the downstream part of the river, the highest discharge occurs in summer while the minimum is reached in spring (Skoulikidis et al., 2009).

Pineiós river basin

The Pineiós River has catchment area in vast Thessaly plain where it flows into Thermaikos Gulf forming 69 km^2 radial-shaped delta. The main tributaries contributing to its discharge are rivers Titarissios, Onochonos and Enipeas. There is only one major dam on Smokovo River tributary (Skoulikidis et al., 2009).

Spercheios river basin

The Spercheios River Basin is the smallest catchment in the Aegean Sea Drainage Basin that spring in Tymfristos Mountain. It flows into the Aegean Sea forming a wide lobate delta. It is a mostly unregulated river with about 69% of its flow originating from snow and 19% from rain (Skoulikidis et al., 2009).

Evrotas river basin

The Evrotas River Basin is a basin in south Greece territory. It enters Aegean Sea in Laconikos Gulf. The river springs in the Mountain Taygetos and flows south to Lanconia basin. While entering Aegean Sea, it forms a small 53 km^2 wide delta (Skoulikidis et al., 2009).

Parts of Evrotas River exhibit an intermittent flow regime and the only stable flow from its tributaries comes from the River Oinous. There is severe water abstraction for irrigation, but the river is mostly unregulated. The karstic outflow and snowmelt represent the highest discharge and it reaches its peak in March (Skoulikidis et al., 2009).

Ionian Sea drainage basin

The analysis of the Ionian Sea Drainage Basin will cover rivers Arachthos, Acheloos and Alfeios (Skoulikidis et al., 2009).

Arachthos river basin

The Arachthos springs are located in the Tszoumerska and Lakmos Mountains. The Arachthos River enters Ionian Sea in Amvrakikos Gulf, where together with the River Louros forms double-delta formation which extends over 350 km^2 creating Greece's largest coastal swamp system (Skoulikidis et al., 2009).

The rivers discharge peaks in December-January while its minimum occurs in August. Two main reservoirs are Pournar I and Pournari II with the coverage area of a 21 km^2 and storage capacity of around 800 Mm^3. Reservoirs, besides being used for hydropower production, also decrease seasonal flow variations (Skoulikidis et al., 2009).

Acheloos river basin

The Acheloos River drains southern Pindos mountain range and then enters Agrinio plain with an average channel width of 25 m. The snowmelt accounts for 19% and rain 71% of the total runoff. There are four large reservoirs built and they have a storage capacity of more than 6.6 km^3. Maximum discharge rate occurs in July and minimum in summer times (Skoulikidis et al., 2009).

Alfeios river basin

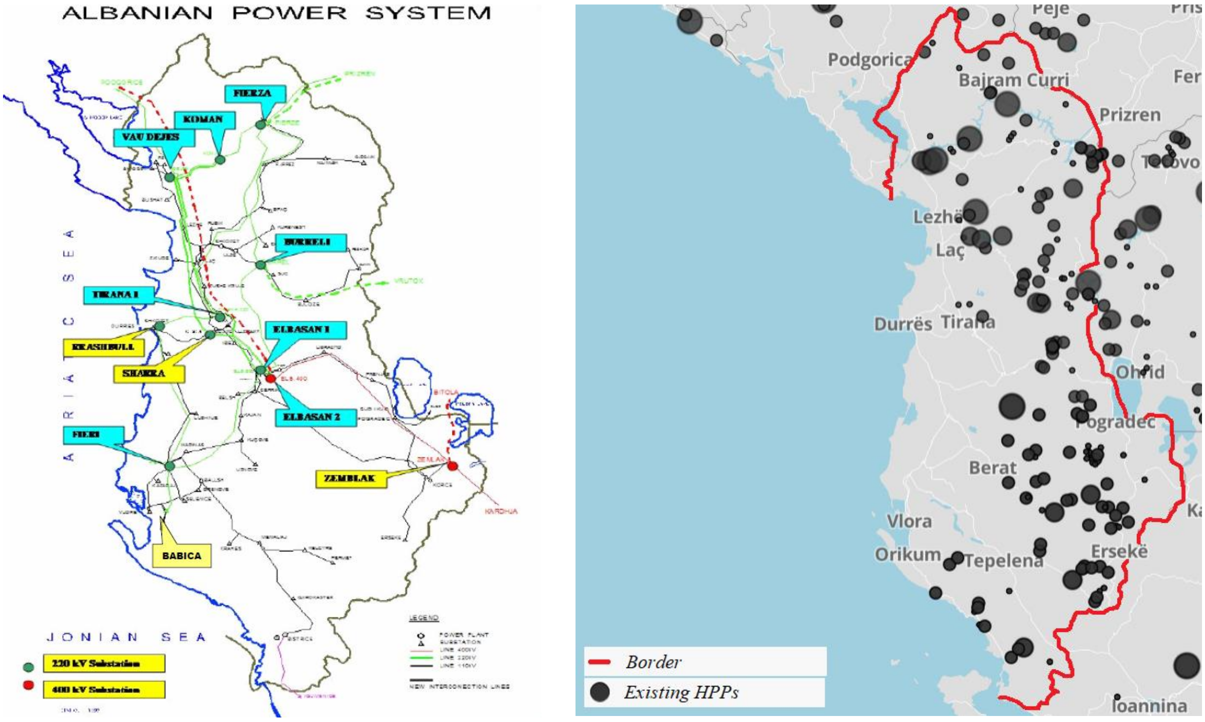
The Alfeios River springs at the Mountain Taygetos and enters Ionian Sea in Kyparissiakos Gulf. Total runoff is partly supplied by karstic runoff and its two main tributaries, Ladon and Lousios contribute with 0.64 and 0.21 km^3/year, respectively. Its maximum discharge peaks in January, while its minimum occurs in August. Small hydropower dam, located along the Ladon River, is used for irrigation and flood control (Skoulikidis et al., 2009).

Annex 2: Overview of the power system in Balkan Peninsula

Albania

The Albanian power system has only one thermal power plant, while the country's power generation relies on hydropower with 1838 MW of active generation capacity. The only thermal power plant, TE Vlora, is out of operation due to technical problems or low profitability. The lack of thermal power generation puts the Albanian power system in a sensitive position when dry hydrological year happens, putting the Albanian security of electricity supply to the test. To compensate for the loss of available hydropower generation, Albania imports electricity from its neighbouring countries (WBIF, 2017), (Balkan Energy Prospect, 2018).

Figure 25. Albanian transmission network with locations of larger power plants (left); Locations of the existing hydropower plants (right)



Source: left (Ministry of The Economy Trade And Energy, 2009); right (Euronatur, 2012)

Table 30. The list of major power plants in Albania

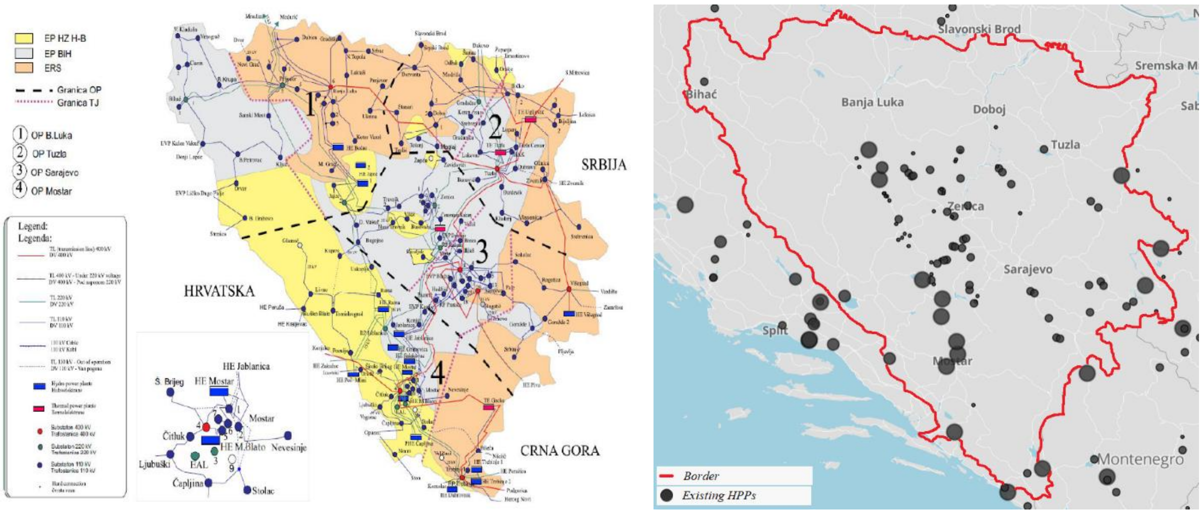
Unit	Power Capacity [MW]	Type(1)	Fuel(1)
TE Vlora	98	STUR	OIL
HE Fierza	500	HDAM	WAT
HE Koman	600	HDAM	WAT
HE Vau i Dejës	250	HDAM	WAT
HE Banje	73	HDAM	WAT
HE Shkopet	24	HDAM	WAT
HE Ulez	25	HDAM	WAT
HE Bistrica I	22.5	HROR	WAT
HE Bistrica II	5	HROR	WAT
HE Tervol	10.6	HROR	WAT
HE Arras	4.8	HROR	WAT
HE Smokthina	9	HROR	WAT
Small HPPs	252	HROR	WAT

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (Balkan Energy Prospect, 2018), (Ministry of The Economy Trade And Energy, 2009), (Duić et al., 2017), (KPMG Hungary, 2010), (AEA, 2012)

Bosnia and Herzegovina

Figure 26. Transmission network of Bosnia and Herzegovina with locations of larger power plants (left); Locations of existing hydropower plants (right)



Source: left (Duić et al., 2017); right (Euronatur, 2012)

The power system of Bosnia and Herzegovina consists of five main coal-fired power plants and a number of hydropower plants (Balkan Energy Prospect, 2018).

Five thermal power plants, TE Gacko, TE Kakanj, TE Tuzla, TE Ugljevik and TE Stanari use lignite coal as an energy source and are built near coal mines which provide them with the needed energy source. The Abid Loloc, Zenica, Kakanj and Breza mines are located near TE Kakanj, Banovići, Đurđevik and Kreka mines near TE Tuzla, Stanari mine is near TE Stanari, Terex Kop and Ugljevik mines near TE Ugljevik and Gacko mine near TE Gacko (Balkan Energy Prospect, 2018).

The main hydropower plants are HE Višegrad, RHE Čapljina, HE Grabovica, HE Trebinje, HE Salakovac, HE Rama, HE Jablanica, HE Bočac, HE Mostar, HE Jajce 1 and HE Jajce2. RHE Čapljina is the only pumped hydro storage unit (Balkan Energy Prospect, 2018), (Duić et al., 2017), (KPMG Hungary, 2010). Major rivers flowing through or passing Bosnia and Herzegovina are Sava, Drina, Neretva, Una, Bosna, Vrbas, Sana and Trebišnjica (KPMG Hungary, 2010).

Beside the two main power generation sources with a total thermal power capacity of 2516 MW and 2180 MW of hydropower generation, Bosnia and Herzegovina has 14 MW of solar capacity and 50.6 MW of wind power with its first wind power plant VE Mesihovina (Balkan Energy Prospect, 2018), (Wikipedia, 2019).

Total energy mix of Bosnia and Herzegovina presented in percentage shows that lignite-fired thermal power plants account for 60%, hydropower plants for 38% and other energy sources for 2% (Balkan Energy Prospect, 2018).

Table 31. The list of major power plants in Bosnia and Herzegovina

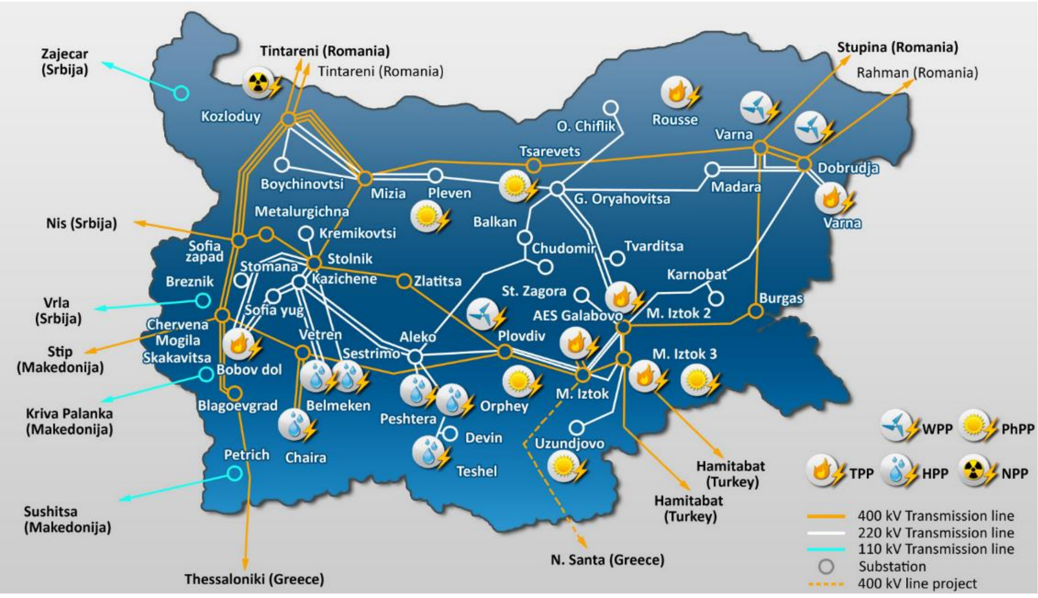
Unit	Power Capacity [MW]	Type[1]	Fuel[1]
TE Tuzla	730	STUR	LIG
TE Kakanj	416	STUR	LIG
TE Ugljevik	269	STUR	LIG
TE Gacko	289	STUR	LIG
TE Stanari	300	STUR	LIG
HE Bočac	110	HDAM	WAT
HE Jablanica	181	HDAM	WAT
HE Rama	161	HDAM	WAT
HE Salakovac	210	HDAM	WAT
HE Trebinje	179	HDAM	WAT
HE Višegrad	315	HDAM	WAT
HE Mostarsko Blato	60	HDAM	WAT
RHE Čapljina	430	HPHS	WAT
HE Grabovica	114	HROR	WAT
HE Mostar	72	HROR	WAT
HE Jajce 1	60	HROR	WAT
HE Jajce 2	30	HROR	WAT

([1]) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (Balkan Energy Prospect, 2018), (Duić et al., 2017), (KPMG Hungary, 2010)

Bulgaria

Figure 27. Transmission network of Bulgaria with locations of larger power plants



Source: (TSO Bulgaria, 2019)

Bulgarian power system consists of 15 thermal power plant, a number of hydropower units, wind power capacity of 701 MW and solar power capacity of 1043 MW (ENTSO-E Transparency Platform, 2018), (TSO Bulgaria, 2019).

The largest power station is Kozloduy nuclear power plant with installed power output of 2000 MW. Power plants Bobov Dol, Maritsa 3, Maritsa Iztok 1 (AES Galabovo), Maritsa Iztok 2, Maritsa Iztok 3, CHP Republika and CHP Brikel are lignite fired thermal power plants with aggregated power output of 4113 MW. Power plants Ruse, Deven, Sviloza and Toplo Ruse use hard coal as power source. Gas fired units are Varna, Sofia, Sofia Iztok, Lukoil Nefto and EVN Plovdiv, with Lukoil Nefto and EVN Plovdiv being CCGT units (ENTSO-E Transparency Platform, 2018), (TSO Bulgaria, 2019).

Hydropower units can be divided to 10 hydro cascades. Batak Cascade consists of hydropower plants Aleko, Batak and Peshtera. Belmeken-Sestrimo-Chaira Cascade consist of hydropower plants Belmeken, Chaira, Sestrimo and Momina Klisoura, with units Belmeken and Chaira being pumped hydropower plants. Power plants Kardzhali, Studen Kladenets and Ivailovgrad form Dolna Arda Cascade. The plan is to construct the upper part of the Arda cascade (Gorna Arda Cascade) which will include hydropower units Madan, Ardino and Sardintza. Dospat-Vancha Cascade consist of units Teshel, Devin, Tsankov Kamak, Orphey, Vancha and Krichim. Hydropower unit Orphey is pumped hydropower plant. Iskar Cascade consist of two smaller cascades formed of units Beli Iskar, Mala Tsarkva and Simeonovo, and units Pasarel and Kokalyane. Rila Cascade is formed out of four units, Kalin, Kamenitsa, Pastra and Rila with net water head of almost 1800 m. Petrohan Cascade consists of smaller hydropower plants Petrohan, Barzia and Klisoura. Pirinska Bistrica Cascade is cascade of two power units, Pirin and Spanchevo. Hydropower plants Koprinka and Stara Zagora form the Koprinka Cascade, while units Popina Laka, Lilyanovo and Sandanski form the Sandanska Bistritsa Cascade (ENTSO-E Transparency Platform, 2018), (Natsionalna Elektricheska Kompania EAD, 2007),.

Based on IEA statistics, the percentage of electricity generation by fuel for the year 2015 shows the usage of coal, nuclear power, hydropower, gas, wind, solar and other energy sources (oil, biofuels, waste) of 46%, 31%, 12%, 4%, 3%, 3% and 1%, respectively (IEA, 2016).

Table 32. The list of major power plants in Bulgaria

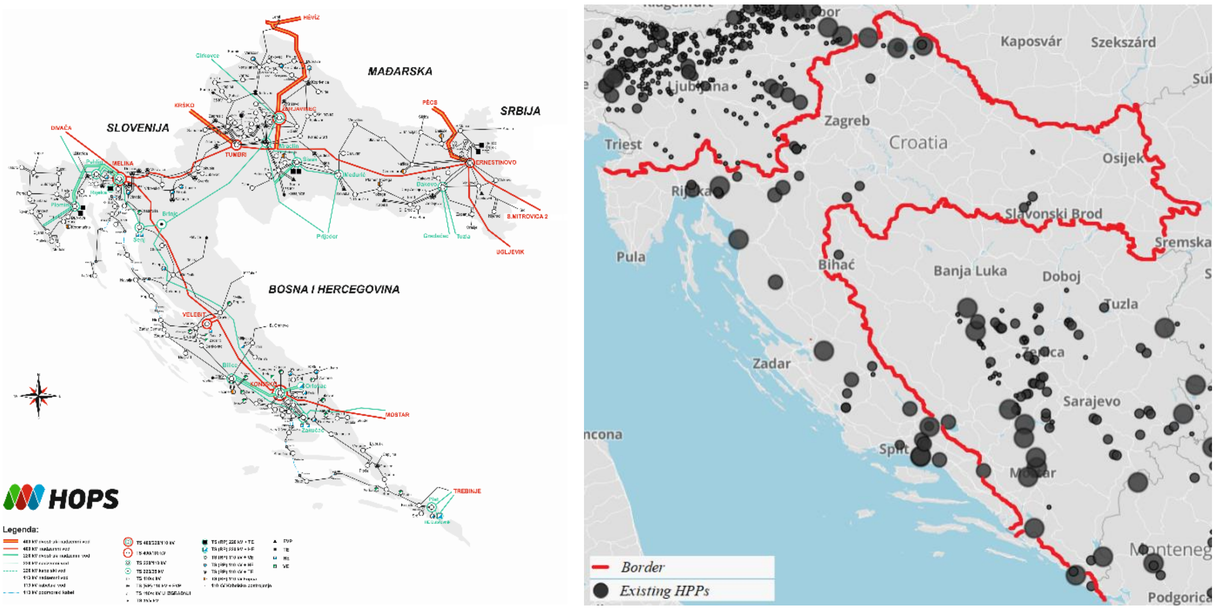
Unit	**Power Capacity [MW]**	**Type**(1)	**Fuel**(1)	**Unit**	**Power Capacity [MW]**	**Type**(1)	**Fuel**(1)
Kozloduy	2000	STUR	NUC	Ivailovgrad	114	HDAM	WAT
Bobov Dol	570	STUR	LIG	Krichim + Vacha I + Vacha II	101	HDAM	WAT
Maritsa 3	120	STUR	LIG	Teshel	60	HDAM	WAT
Maritsa Iztok-1 - AES Galabovo	686	STUR	LIG	Tsankov Kamak	86	HDAM	WAT
Maritsa Iztok-2	1604	STUR	LIG	Devin	88	HDAM	WAT
Maritsa Iztok-3	908	STUR	LIG	Beli Iskar + Mala Tsarkva + Simeonovo	31.3	HDAM	WAT
CHP Republika	105	STUR	LIG	Pasarel	33	HDAM	WAT
CHP Brikel	120	STUR	LIG	Kokalyane	22.4	HDAM	WAT
CHP Lukoil Nefto	257	COMC	GAS	Kalin + Kamenitsa + Pastra + Rila	24.2	HDAM	WAT
CHP EVN Plovdiv	50	COMC	GAS	Petrohan	7.8	HDAM	WAT
Varna	420	STUR	GAS	Barzia	8	HDAM	WAT
Sofia	125	STUR	GAS	Klisoura	3.5	HDAM	WAT
Sofia Iztok	186	STUR	GAS	Pirin	21.2	HDAM	WAT
CHP Ruse	180	STUR	HRD	Spanchevo	28	HDAM	WAT
CHP Deven	132	STUR	HRD	Alexander Stambolyski	10.2	HDAM	WAT
CHP Sviloza	120	STUR	HRD	Koprinka	7	HDAM	WAT
Toplo Ruse	110	STUR	HRD	Popina Laka	21.5	HDAM	WAT
Aleko	71.4	HDAM	WAT	Lilyanovo	20	HDAM	WAT
Batak	46.8	HDAM	WAT	Sandanski I	14.2	HDAM	WAT
Peshtera	135	HDAM	WAT	Belmeken	375	HPHS	WAT
Sestrimo	240	HDAM	WAT	Chaira	864	HPHS	WAT
Momina Klisura	120	HDAM	WAT	Orphey	160	HPHS	WAT
Kardzhali	110	HDAM	WAT	Stara Zagora	22.4	HROR	WAT
Studen Kladenets	81	HDAM	WAT	BG Wind	701	WTON	WIN
				BG Solar	1041	PHOT	SUN

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017) (ENTSO-E Transparency Platform, 2018), (Natsionalna Elektricheska Kompania EAD, 2007) (Bulgarian Energy Holding EAD, 2018), (Natsionalna Elektricheska Kompania EAD, 2018), (NEK EAD, 2008), (Shopova and Niagolov, 2015), (Hydro Review, 2006), (Hydropol, 2018), (Zahariev and Nikolcheva, 2014), (Regional administration Blagoevgrad, 2019)

Croatia

Figure 28. Transmission network of Croatia with locations of larger power plants (left); Locations of existing hydropower plants (right)



Source: left (HOPS, 2019); right (Euronatur, 2012)

Croatian power system is mainly composed of eight larger thermal power plants, a number of hydropower plants and wind power capacity of 582 MW (ENTSO-E Transparency Platform, 2018).

Thermal power plants EL-TO Zagreb, TE-TO Osijek, TE-TO Sisak (BLOK C) and TE-TO Zagreb are CHP units that utilize gas as an energy source. TE-TO Sisak refers to the set of the three units with one of them (BLOK C) being a Combined Cycle Gas Turbine Unit (CCGT) with a power output of 230 MW_e and 50 MWh commissioned in 2015. The other two units of the TE-TO Sisak are steam turbine powered generators that utilize oil as an energy source. KTE Jertovec with a power output of 88 MW is also CCGT unit that uses gas as an energy source. Beside two units of TE-TO Sisak using oil, the thermal power plant TE Rijeka uses the same fuel for electricity generation. The only thermal power plant that uses coal as a power source is TE Plomin (JRC Hydro-power plants database, 2019), (Dispa-SET Balkans, 2019), (ENTSO-E Transparency Platform, 2018), (HEP Proizvodnja, 2018), (Pavičević, Quoilin, and Pukšec, 2018).

Hydropower plants are divided into Southern HPPs, Western HPPs, Northern HPPs and HES Dubrovnik (HEP Proizvodnja, 2018).

Northern HPPs, HE Varaždin, HE Čakovec and HE Dubrava are located on the River Drava. HES Vinodol is a system that includes hydropower plants CHE Fužine, RHE Lepenica and HE Vinodol. Together with hydropower plants HES Senj (HE Senj and HE Sklope), HE Rijeka, HE Zeleni Vir, HE Gojak, HE Lešće and HE Gojak, HES Vinodol forms Western HPPs which utilize waters of the Kupa River (HE Ozalj); Ogulinska Dobra and Zagorska Mrežnica Rivers (HE Gojak); Lokvarka, Križ, Ličanka, Benkovac Rivers and Lokvarsko, Lepenica and Bajer Lakes (HES Vinodol); Riječina River (HE Rijeka), Lika and Gacka Rivers (HES Senj) and Dobra River (HE Lešće) (JRC Hydro-power plants database, 2019), (ENTSO-E Transparency Platform, 2018), (HEP Proizvodnja, 2018), (Lisac, 2015).

Hydropower plants RHE Velebit, HE Miljacka, HE Golubić, HE Jaruga, mHE Krčić, HE Orlovac, HE Peruća, HE Đale, Zakučac and HE Kraljevac form a group of Southern HPPs utilizing waters of the Cetina, Zrmanja and Krka River Basins (JRC Hydro-power plants database, 2019), (HEP Proizvodnja, 2018), (Pavičević, Quoilin, and Pukšec, 2018), (Žužul, 2018), (Konig, 2010).

HES Dubovnik is composed of smaller HE Zavrelje and shared project between Croatia and Bosnia and Herzegovina, HE Dubrovnik, which uses waters of the Trebišnjica River from the Bileća Lake which is located in Bosnia and Herzegovina (JRC Hydro-power plants database, 2019), (HEP Proizvodnja, 2018), (Pavičević, Quoilin, and Pukšec, 2018).

Based on IEA statistics, the percentage of electricity generation by fuel for the year 2015 shows the usage of hydropower, coal, gas, wind, biofuels, oil and other energy sources (solar, waste) of 57%, 20%, 11%, 7%, 2%, 2% and 1%, respectively (IEA, 2016).

Table 33. The list of major power plants in Croatia

Unit	**Power Capacity [MW]**	**Type**(1)	**Fuel**(1)
EL-TO Zagreb	90	STUR	GAS
KTE Jertovec	88	COMC	GAS
TE Plomin	325	STUR	HRD
TE Rijeka	320	STUR	OIL
TE-TO Sisak (BLOK A and B)	396	STUR	OIL
TE TO Sisak (BLOK C)	230	COMC	GAS
TE-TO Zagreb	440	STUR	GAS
TE-TO Osijek	89	STUR/COMC	GAS
HE Kraljevec	46.4	HROR	WAT
HE Varaždin	92.5	HROR	WAT
HE Dubrava	79. 8	HROR	WAT
HE Žakovec	77.4	HROR	WAT
HE Gojak	55.5	HROR	WAT
HE Lešće	41.2	HROR	WAT
HE Rijeka	36.8	HPHS	WAT
HE Miljacka	24	HROR	WAT
mHE Krčić	0.4	HROR	WAT
HE Ozalj	6	HROR	WAT
HE Jaruga	7.2	HROR	WAT
HE Zeleni Vir	1.7	HROR	WAT
HE Zakučac	486	HDAM	WAT
HE Senj	216	HDAM	WAT
HE Dubrovnik	252	HDAM	WAT
HE Vinodol	90	HDAM	WAT
HE Peruća	60	HDAM	WAT
HE Sklope	22.5	HDAM	WAT
HE Đale	40.8	HDAM	WAT
HE Golubić	7.5	HDAM	WAT
HE Zavrelje	2.1	HDAM	WAT
RHE Velebit	276	HPHS	WAT
RHE Orlovac	237	HPHS	WAT
RHE Lepenica	0.8	HPHS	WAT
CHE Fužine	4.6	HPHS	WAT
Wind Power	582	WTON	WIN
Solar Power	52	PHOT	SUN

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (ENTSO-E Transparency Platform, 2018),(HEP Proizvodnja, 2018), (Pavičević, Quoilin, and Pukšec, 2018), (Lisac, 2015), (Žužul, 2018), (Konig, 2010)

Greece

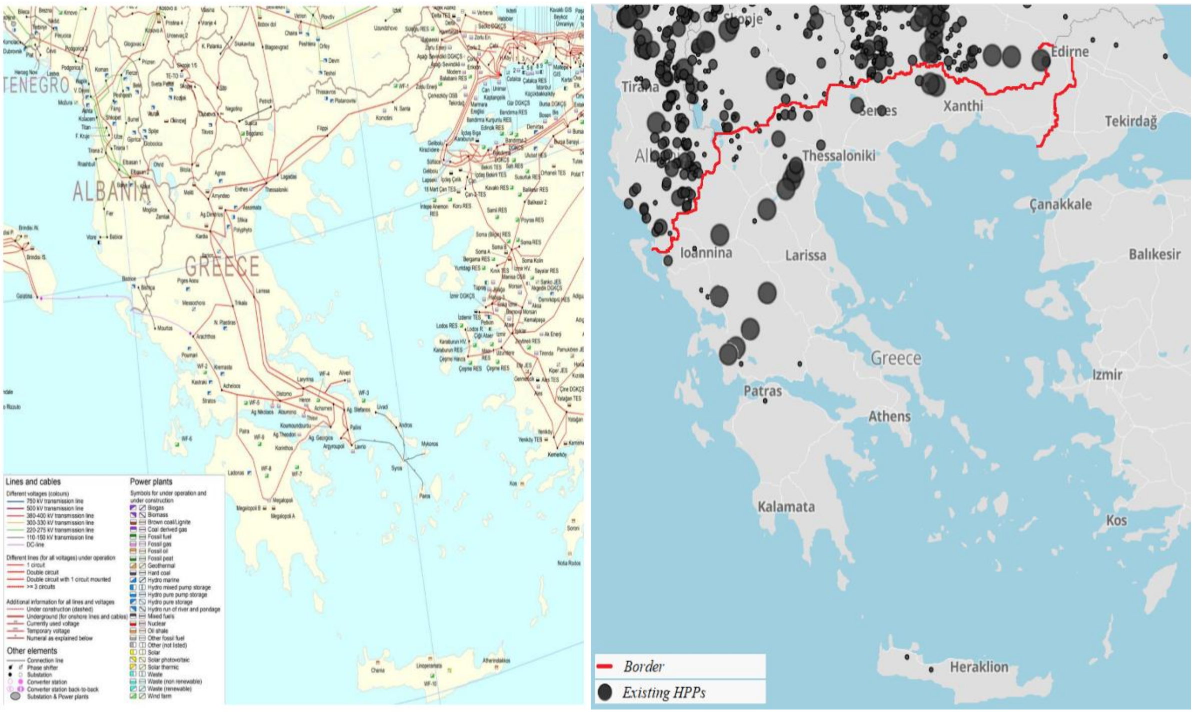
Greek power system consists of 37 thermal power plants, 17 hydropower plants, 2355 MW of wind power capacity, and 2441 MW of solar capacity (Fernandez-Blanco Carramolino et al., 2016),(ENTSO-E Transparency Platform, 2018).

Thermal power plants are lignite- or gas-fired. Thermal power plants Agios Dimitrios, Amyntaio, Kardia, Megalopoli (III and IV) and Florina are lignite-fired units with a total power output of 3912 MW. Thermal power plants Lavrio, Megalopoli V, Komotini, Korinthos, Protegia, Aliveri, Elpedison Thisvi, Thessaloniki, Alouminio, Heron CC and Heron (I,II and III) are gas-fired units. All mentioned gas units, excluding Heron I,II and III, are also CCGT units. The total installed power output of the gas-fired thermal power plants is 4902 MW (Fernandez-Blanco Carramolino et al., 2016),(ENTSO-E Transparency Platform, 2018).

Largest hydropower plants are Asomata, Ilarionas, Kastraki, Kremasta, Ladonas, Pigia Aoos, Plastiras, Platanovrysi, Polyfyto, Pournari I, Pournari I, Stratos, Sfikia, Thesavros, Agras and Edessaios. Most of the mentioned units are conventional dam storage hydropower plants with exception of units Sfikia and Thesavros representing pumped hydropower units, and units Agras and Edessaios representing run-of-river type hydropower plants. Total installed hydropower amounts to 3401 MW (Fernandez-Blanco Carramolino et al., 2016),(ENTSO-E Transparency Platform, 2018),(Argyrakis).

Based on ENTSO-E statistics, the percentage of electricity generation by fuel for the year 2018 shows the usage of coal, gas, hydropower, wind and solar of 35%, 35%, 12%, 11% and 7%, respectively (ENTSO-E Transparency Platform, 2018).

Figure 29. Transmission network of Greece with locations of larger power plants (left); Locations of existing hydropower plants (right)



Source: left (Koltsaklis and Dagoumas, 2018); right (Euronatur, 2012)

Table 34. The list of major power plants in Greece

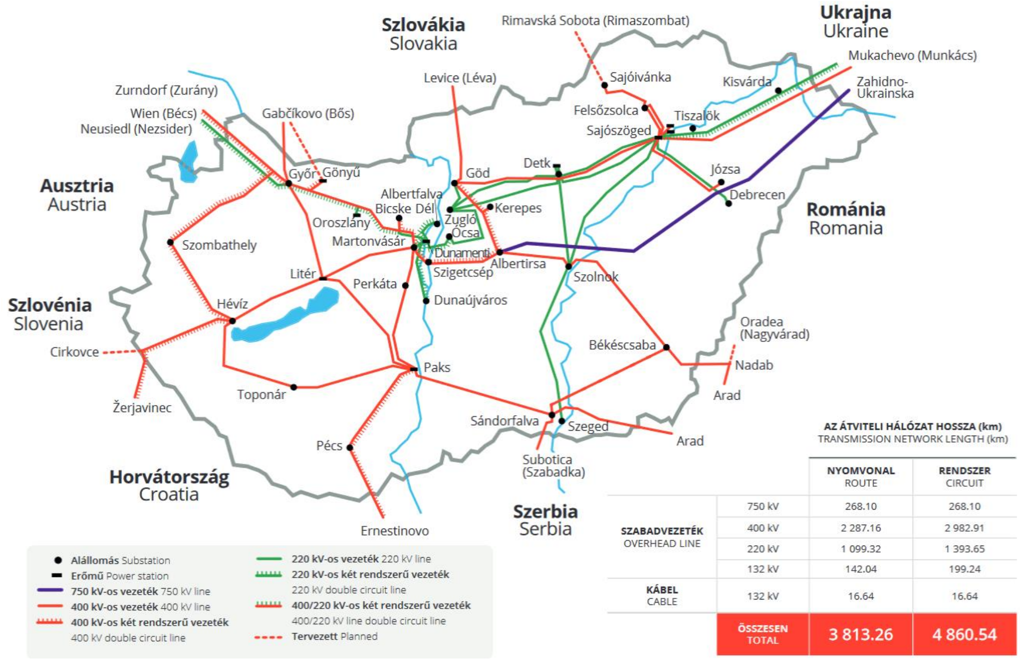
Unit	**Power Capacity [MW]**	**Type**(1)	**Fuel**(1)
Lavrio	928	COMC	GAS
Megalopoli V	500	COMC	GAS
Komotini	476	COMC	GAS
Korinthos	433	COMC	GAS
Protegia CC	432	COMC	GAS
Aliveri	417	COMC	GAS
Thisvi Elpedison	410	COMC	GAS
Thessaloniki	400	COMC	GAS
Alouminio	334	COMC	GAS
Heron CC	422	COMC	GAS
Heron I, II, III	147	GTUR	GAS
Agios Dimitrios	1456	STUR	LIG
Florina	289	STUR	LIG
Kardia	1103	STUR	LIG
Amyntaio	546	STUR	LIG
Megalopoli III, IV	511	STUR	LIG
Asomata	108	HDAM	WAT
Ilationas	154	HDAM	WAT
Kastraki	320	HDAM	WAT
Kremasta	437	HDAM	WAT
Ladonas	70	HDAM	WAT
Pigai Aoos	210	HDAM	WAT
Plastiras	130	HDAM	WAT
Platanovrysi	116	HDAM	WAT
Polyfyto	375	HDAM	WAT
Pournari 1	304	HDAM	WAT
Pournar 2	30	HDAM	WAT
Stratos	150	HDAM	WAT
Sfikia	315	HPHS	WAT
Thesavros	384	HPHS	WAT
Agras	50	HROR	WAT
Edessaios	19	HROR	WAT
Wind Power	2355	WTON	WIN
Solar Power	2441	PHOT	SUN

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (Fernandez-Blanco Carramolino et al., 2016), (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (ENTSO-E Transparency Platform, 2018), (Argyrakis)

Hungary

Figure 30. Transmission network of Hungary with locations of larger power plants



		NYOMVONAL ROUTE	RENDSZER CIRCUIT
SZABADVEZETÉK OVERHEAD LINE	750 kV	268.10	268.10
	400 kV	2 287.16	2 982.91
	220 kV	1 099.32	1 393.65
	132 kV	142.04	199.24
KÁBEL CABLE	132 kV	16.64	16.64
	ÖSSZESEN TOTAL	3 813.26	4 860.54

Source: (MAVIR, 2017)

Hungarian power system consists mostly of thermal power units. Total installed hydropower is 47.7 MW, while wind and solar power capacities are 329 MW and 94 MW, respectively (MAVIR, 2018).

Nuclear power plant Paksi Atomerőmű is the largest power unit with installed power of 2000 MW. The largest lignite-fired power units are Mátrai Erőmű, Oroszlányi Erőmű and Ajkai Hőerőmű with total installed power of 1 181 MW. Hamburger Hungária power plants is the only unit using hard coal as power source. Most units are gas-fired. The largest units are Tiszai Erőmű, Dunamenti Erőmű, Gönyűi Erőmű, Alpiq Csepel Erőmű, Kelenföldi Erőmű, MVM szabályozási központ, Bakonyi Gázturbinás Erőmű, Kispesti Erőmű, Újpesti Erőmű and Debreceni Kombináltciklusú Erőmű with total installed power output of 3207 MW. Smaller gas engines are combined into virtual power plants with largest clusters being ALPIQ szabályzási csoport, VPP szabályozási csoport, VEOLIA szabályozási központ, EONSUM szabályozási központ, GREENERGY szabályozási központ, Sinergy szabályozási központ, Nyíregyházi Kombináltciklusú Erőmű, Tatabánya Erőmű and PLOOP szabályozási központ with power output of 473 MW (ENTSO-E Transparency Platform, 2018),(MAVIR, 2018).

All hydropower plants are located on the River Tisza and the largest units are Kisköre, Tiszalök, Kesznyéten (Hernádvíz) and Ikervár (Association, 2012).

Based on IEA statistics, the percentage of electricity generation by fuel for the year 2015 shows the usage of nuclear power, coal, gas, biofuels, wind and other energy sources (oil, waste, hydro and solar) of 52%, 20%, 17%, 6%, 2% and 3%, respectively. Hydropower represents only 0.77% of total electricity generation (IEA, 2016).

Table 35. The list of major power plants in Hungary

Unit	Power Capacity [MW]	Type (1)	Fuel (1)	Unit	Power Capacity [MW]	Type(1)	Fuel (1)
Paksi Atomerőmű	2000	STUR	NUC	VPP szabályozási csoport	90.4	ICEN	GAS
Mátrai Erőmű	884	STUR	LIG	TE VEOLIA Tercier csoport (Dalkia)	44.1	ICEN	GAS
Ajkai Hőerőmű	101.6	STUR	LIG	EONSUM szabályozási központ	89.2	ICEN	GAS
Oroszlányi Erőmű	240	STUR	HRD	ALPIQ szabályzási csoport	53.9	ICEN	GAS
Mátrai (GT)	66	GTUR	GAS	TE VEOLIA Szekunder csoport (Dalkia)	52.4	ICEN	GAS
Alpiq Csepel Erőmű	292	GTUR	GAS	Sinergy szabályozási központ	50.2	ICEN	GAS
Dunamenti Erőmű	878.7	GTUR	GAS	GREENERGY szabályozási központ	45.8	ICEN	GAS
Bakonyi Gázturbinás Erőmű	116	GTUR	GAS	PLOOP szabályozási központ	10.8	ICEN	GAS
MVM Eszak-Budai	50	GTUR	GAS	Small_GE_Cluster	132.8	ICEN	GAS
Small_GT_Cluster	99.6	GTUR	GAS	Bakonyi Bioerőmű	30	STUR	BIO
Tisza Erőmű	900	STUR	GAS	Pannongreen	49.9	STUR	BIO
Alpiq Csepeli Erőmű	118	STUR	GAS	Pécsi Erőmű	70	STUR	BIO
Tatabánya Erőmű	31.7	STUR	GAS	Small_GE_RES_Cluster	54.7	ICEN	BIO
ISD Power Kft. (CHP)	64.5	STUR	GAS	Small_ST_RES_Cluster	51.3	STUR	BIO
Small_ST_Cluster	74.2	STUR	GAS	Lőrinci Gázturbinás Erőmű	170	GTUR	OIL
Kelenföldi Erőmű	177.8	COMC	GAS	Litéri Gázturbinás Erőmű	120	GTUR	OIL
Kispesti Erőmű	113.3	COMC	GAS	Sajószögedi Gázturbinás Erőmű	120	GTUR	OIL
Újpesti Erőmű	105.3	COMC	GAS	Kisköre	28	HDAM	WAT
Gönyűi Erőmű	433	COMC	GAS	Tiszalök	13.5	HROR	WAT
Debreceni Kombináltciklusú Erőmű	95	COMC	GAS	Kesznyéten (Hernádvíz)	4.4	HROR	WAT
Nyíregyházi Kombináltciklusú Erőmű	47.1	COMC	GAS	Ikervár	1.8	HROR	WAT
Miskolc Hold	39.6	COMC	GAS	HU Solar	29.4	PHOT	SUN
Tatabánya (GE)	18	ICEN	GAS	HU Wind	328.9	WTON	WIN
Miskolc Tatar	19.5	ICEN	GAS				

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (ENTSO-E Transparency Platform, 2018), (MAVIR, 2018)

Kosovo

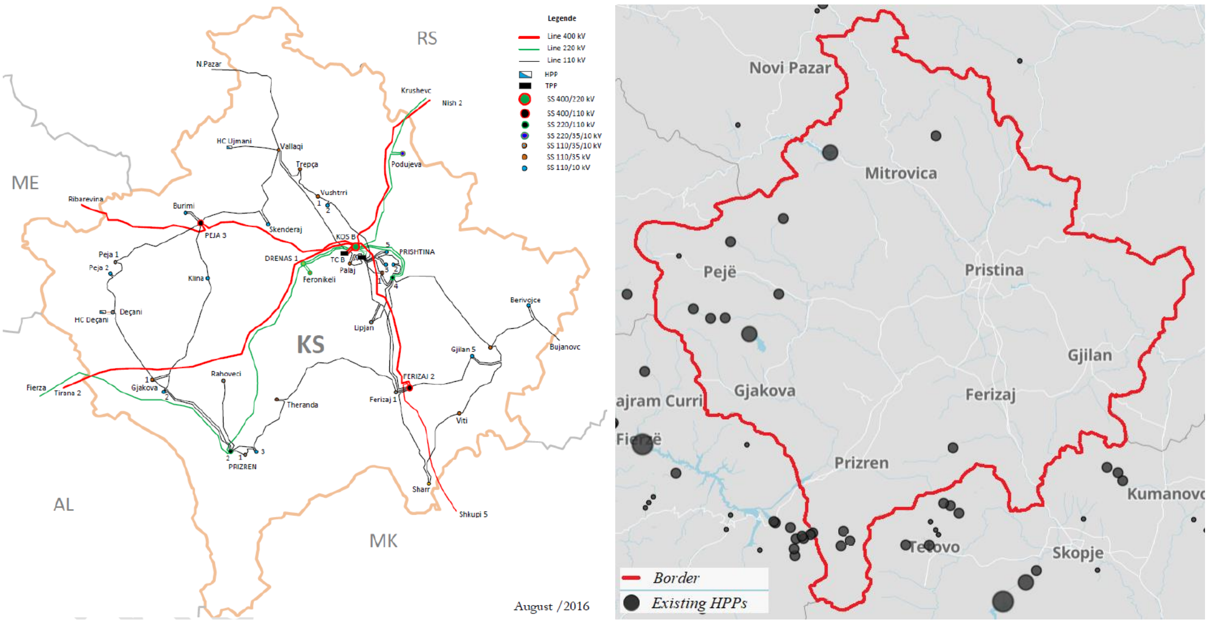
Kosovo power system consists of two thermal power plants and several hydropower plants. Thermal power plants TE Kosovo A and TE Kosovo B are lignite-fired thermal power plants. Thermal power plants utilize the nearby Southwest Sibovc mine (Balkan Energy Prospect, 2018).

The largest hydropower plant is HE Ujmani with a net power output of 35 MW. Ten smaller hydropower plants add up to total 40 MW of power output, which together with HE Ujmani, account for 75 MW of total power capacities (Balkan Energy Prospect, 2018),(KPMG Hungary, 2010).

Putting the wind park VE Kitka in operation, total wind power output rose up to the 33.77 MW.(Balkan Energy Prospect, 2018)

Based on IEA statistics, the percentage of electricity generation by fuel for the year 2015 shows the usage of coal, hydropower and oil of 97%, 2% and 1%, respectively (IEA, 2016).

Figure 31. Transmission network of Kosovo with locations of larger power plants (left); Locations of existing hydropower plants (right)



Source: left (JRC Hydro-power plants database, 2019); right (Euronatur, 2012)

Table 36. The list of major power plants in Kosovo

Unit	Power Capacity [MW]	Type(1)	Fuel(1)
TE Kosovo A	432	STUR	LIG
TE Kosovo B	528	STUR	LIG
HE Ujmani	35	HDAM	WAT
HE Decani	9.9	HROR	WAT
HE Bellaje	8	HROR	WAT
Small HPPs	40	HROR	WAT
Wind Parks	33.7	WTON	WIN

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (Balkan Energy Prospect, 2018), (Duić et al., 2017), (KPMG Hungary, 2010)

Montenegro

The power system of Montenegro consists of one thermal coal-fired thermal power plant, TE Pljevlja, two larger hydropower plants, HE Piva and HE Perućica, with few smaller hydropower plants, HE Bistrica, HE Orah, HE Sekular, HE Pljevlja, HE Glava Zete, HE Slap Zete, HE Muskovica Rijeka, HE Savnik, HE Lijeva Rijeka, HE Podgor and HE Rijeka Crnojevica (Balkan Energy Prospect, 2018), (Duić et al., 2017).

Beside thermal power plant TE Pljevlja (210 MW) and hydropower plants (673 MW), Montenegro has wind power capacity of 72 MW with their first wind power plant Krnovo that started operating in 2017 (Balkan Energy Prospect, 2018), (Bankar.me, 2018).

Total energy mix of Montenegro presented in percentage shows that hydropower plants account for 70%, thermal power plant TE Pljevlja for 23% and other energy sources for 7% (Balkan Energy Prospect, 2018).

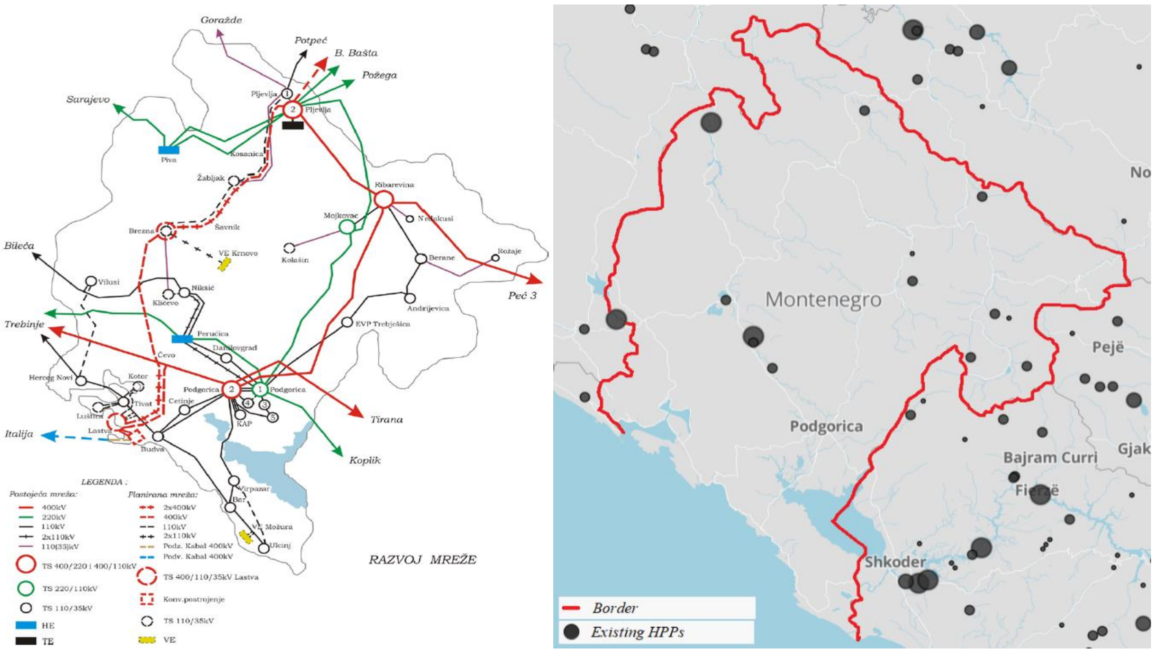
Table 37. The list of major power plants in Montenegro

Unit	Power Capacity [MW]	Type(1)	Fuel(1)
TE Pljevlja	210	STUR	LIG
HE Piva	360	HDAM	WAT
HE Perućica	310	HDAM	WAT
mHE Bistrica	5.1	HROR	WAT
mHE Orah	1.7	HROR	WAT
mHE Sekular	1.7	HROR	WAT
HE Glava Zete	5.4	HROR	WAT
HE Slap Zete	2.4	HROR	WAT
HE Pljevlja	114	HROR	WAT
HE Muskovica Rijeka	0.8	HROR	WAT
HE Savnik	0.2	HROR	WAT
HE Podgor	0.4	HROR	WAT
HE Rijeka Crnojevica	0.6	HROR	WAT

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (Balkan Energy Prospect, 2018), (Duić et al., 2017), (KPMG Hungary, 2010)

Figure 32. Transmission network of Montenegro with locations of larger power plants (left); Locations of existing hydropower plants (right)



Source: left (WBIF, 2017); right (Euronatur, 2012)

North Macedonia

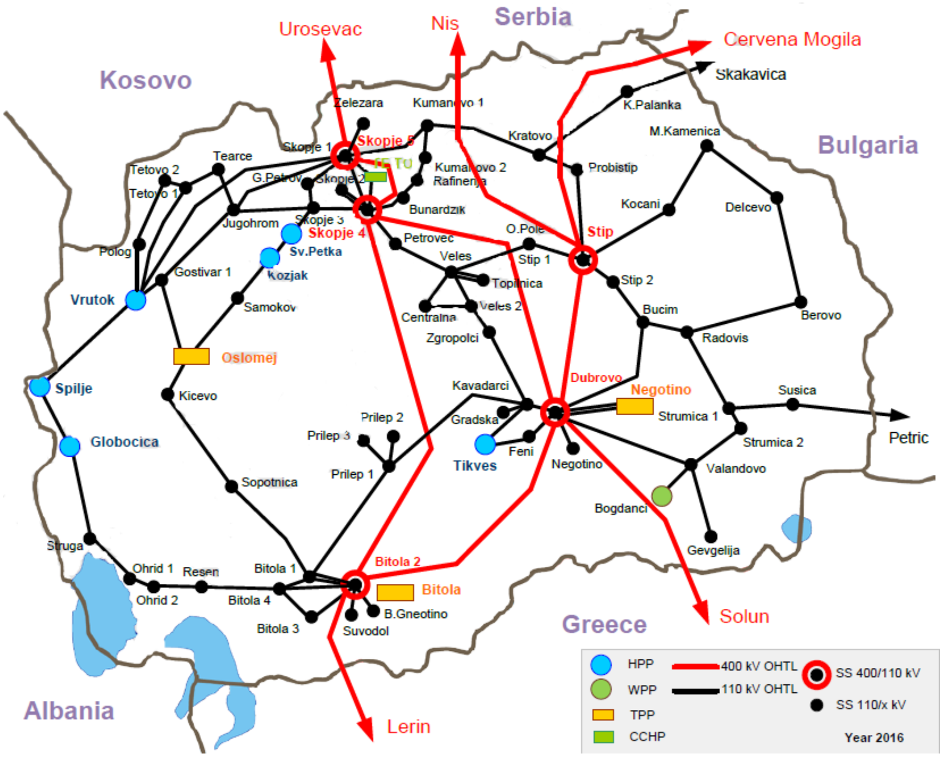
The power system of North Macedonia consists of three thermal power plants and several hydropower plants. Thermal power plants TE Bitola and TE Oslomej are lignite-fired thermal power plants, which utilize nearby coal mines Suvodol and, Oslomej East and West, respectively. The TE-TO AD Skopje is a gas-fired combined cycle cogeneration power plant (Balkan Energy Prospect, 2018).

The largest hydropower plants are HE Tikveš, HE Shpilje, HE Kozjak, HE Globočica, HE Sveta Petka and the Mavrovo Cascade which consists of HE Vrutok, HE Raven and HE Vrben. Besides larger hydropower plants, North Macedonia has a capacity of 97 MW of small hydropower plants (JRC Hydro-power plants database, 2019), (Balkan Energy Prospect, 2018), (Duić et al., 2017), (KPMG Hungary, 2010).

The only wind power plant is Vatren Park Bogdanci with a power output of 35 MW that started operating in 2014 (Balkan Energy Prospect, 2018).

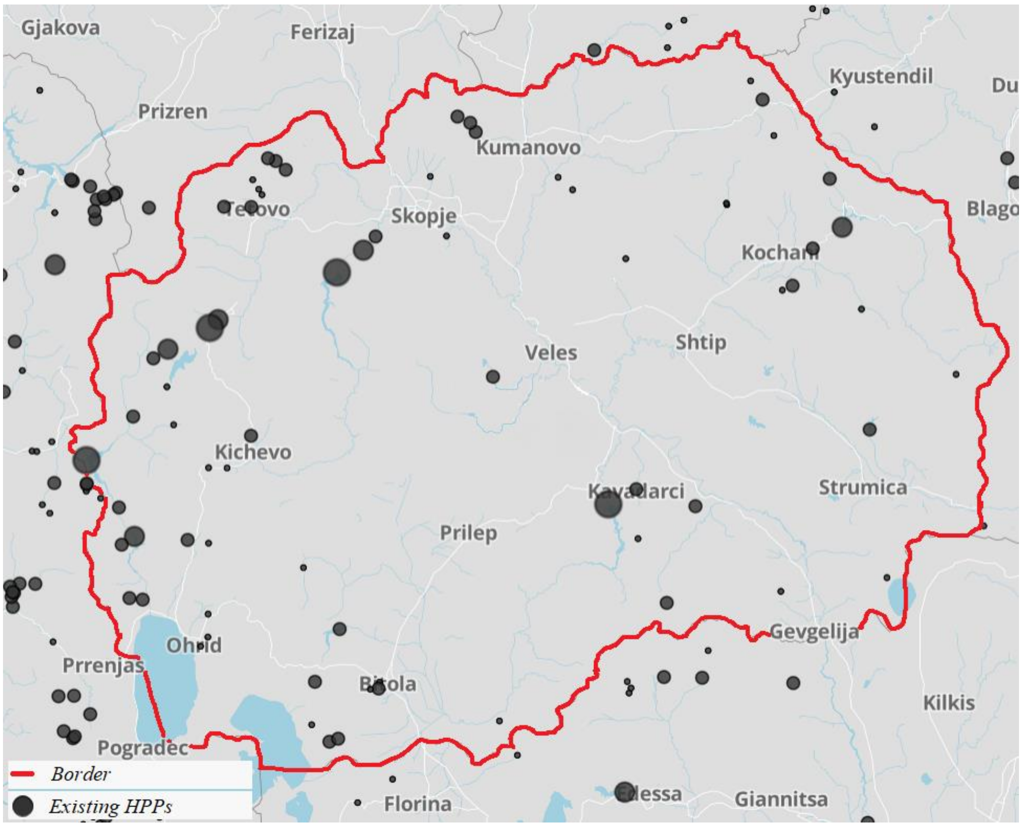
Based on IEA statistics, the percentage of electricity generation by fuel for the year 2015 shows the usage of coal, hydropower, gas, wind and other energy sources of 58%, 33%, 3%, 2% and 4%, respectively (IEA, 2016).

Figure 33. Transmission network of North Macedonia with locations of larger power plants



Source: (WBIF, 2017)

Figure 34. Locations of existing hydropower plants in North Macedonia



Source: (Euronatur, 2012)

Table 38. The list of major power plants in North Macedonia

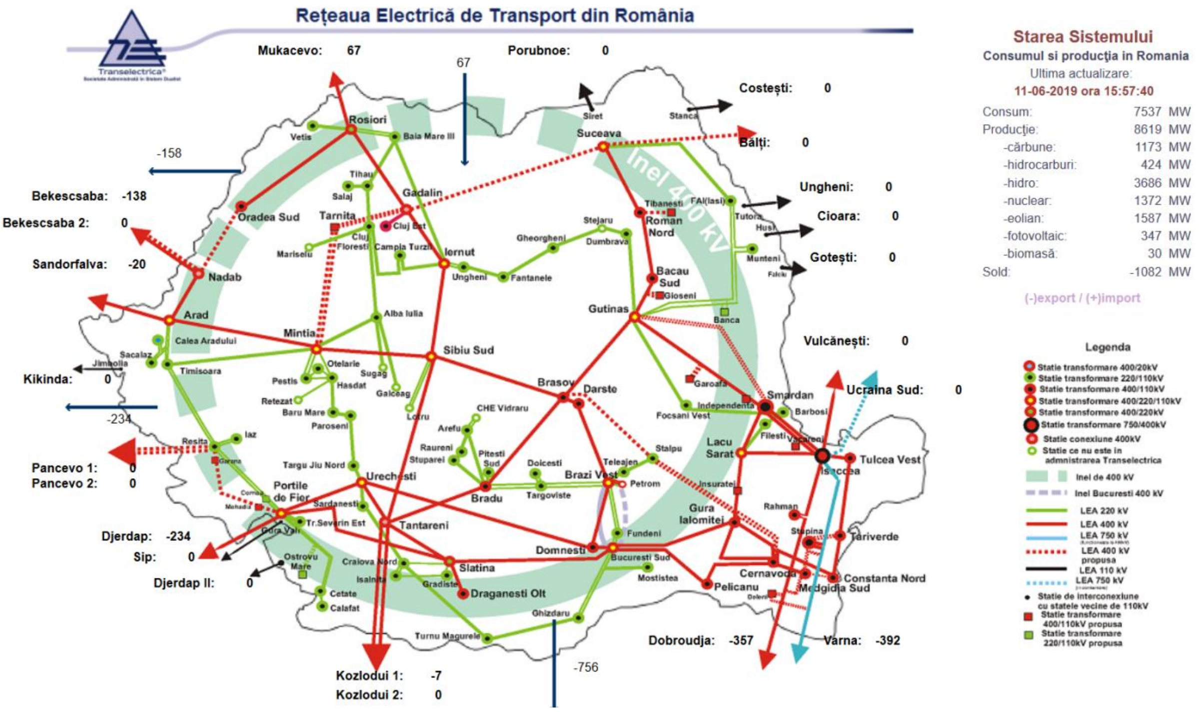
Unit	Power Capacity [MW]	Type[1]	Fuel[1]
TE Bitola	699	STUR	LIG
TE Oslomej	125	STUR	LIG
TE-TO AD Skopje	251	COMC	GAS
Mavrovo Cascade	207	HDAM	WAT
HE Tikveš	114	HDAM	WAT
HE Shpilje	84	HDAM	WAT
HE Kozjak	82	HDAM	WAT
HE Globočica	42	HDAM	WAT
HE Sveta Petka	36.4	HDAM	WAT
HE Kalimanci	13.8	HROR	WAT
HE Matka	8	HROR	WAT
VE Vatren Park Bogdanci	35	WTON	WIN

[1] related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (Balkan Energy Prospect, 2018), (Duić et al., 2017), (KPMG Hungary, 2010)

Romania

Figure 35. Transmission network of Romania with locations of larger power plants



Source: (Transelectrica, 2019)

Romanian power system consists of 24 larger thermal power plants, a large number of hydropower units that can be divided into 11 river basins, and wind and solar capacities of 2978 MW and 1211 MW, respectively (ENTSO-E Transparency Platform, 2018),(Transelectrica, 2019).

There are 8 larger lignite-fired thermal power plants with total installed power of 4199 MW. The largest lignite-fired units are CTE Isalnita, CET Oradea, CTE Rovinari and CTE Turceni. Three units use hard coal as power source, CET Iasi II, CTE Mintia and CET Paroseni (ENTSO-E Transparency Platform, 2018),(Transelectrica, 2019).

Twelve units utilize gas as power source, CET Arad, CTE Borzesti, CTE Braila, CET Brazi, CET Bucuresti sud, CET Bucuresti vest, CET Galati, CET Grozavesti, CET Progresu, CTE Iernut, CET Palas, CCCC Brazi with total installed power of 3751 MW. The unit with the largest power output is nuclear power plant CNE Cernavoda with installed power of 1298 MW (ENTSO-E Transparency Platform, 2018),(Transelectrica, 2019).

Hydropower plants are divided into 11 river basins with total power output of 6352 MW. Largest River Basins are Somes-Tisza, Crisuri, Mures, Banat, Jiu, Olt, Arges, Buzau, Siret, Prut, Dobrogea-Litoral. There is a large number of smaller run-of-river units distributed in river cascades. The largest hydropower plants are CHE Bradisor, CHE Vidraru, CHE Galceag, CHE Lotru, CHE Mariselu, CHE Raul Mare, CHE Ruieni, SHE Stejaru, CHE Sugag, CHE Tismana, CHE Portile De Fier I and CHE Portile De Fier II (ENTSO-E Transparency Platform, 2018),(Transelectrica, 2019).

Based on IEA statistics, the percentage of electricity generation by fuel for the year 2015 shows the usage of coal, hydropower, nuclear, gas, wind, solar and other energy sources (oil, biofuels and waste) of 27%, 26%, 18%, 14%, 11%, 3% and 1%, respectively (IEA, 2016).

Table 39. The list of major power plants in Romania

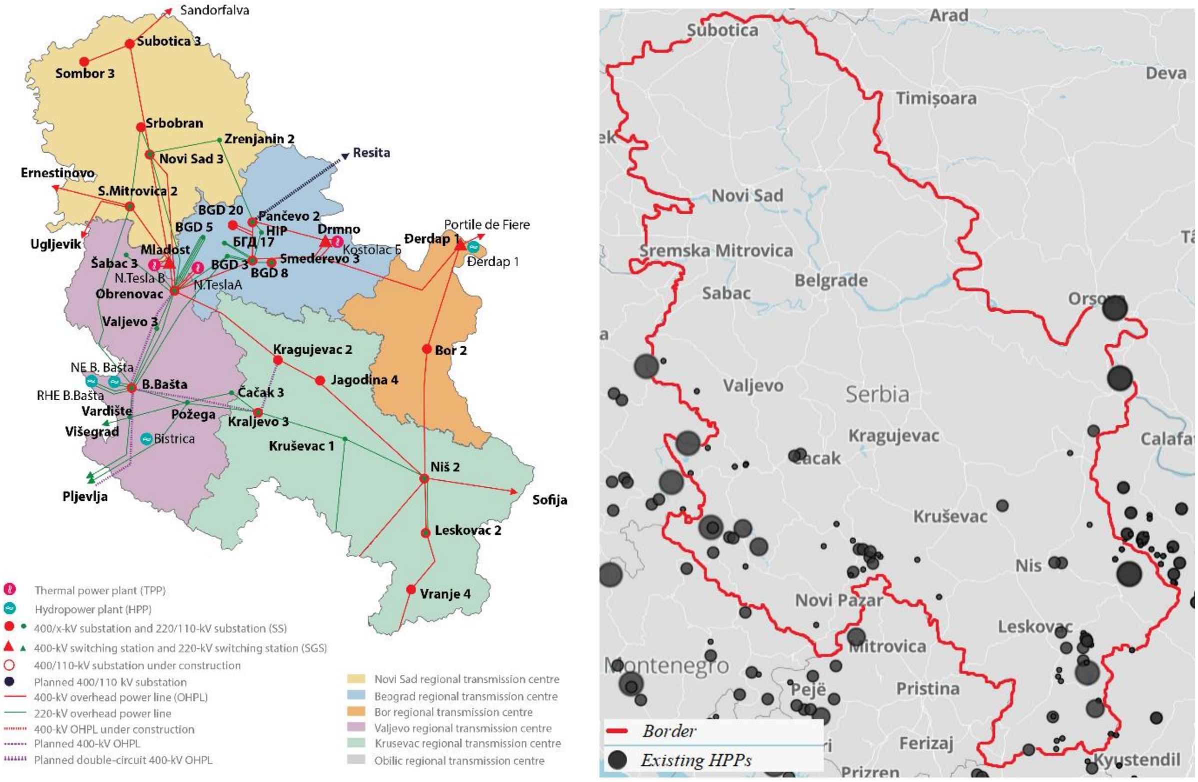
Unit	Power Capacity [MW]	Type (1)	Fuel (1)	Unit	Power Capacity [MW]	Type (1)	Fuel (1)
CET Bacau	60	STUR	LIG	AHE Ialomita	43	HDAM HROR	WAT
CET Craiova II	244	STUR	LIG	AHE Jiu	23.6	HDAM HROR	WAT
CET Drobeta	170	STUR	LIG	AHE Olt	1062	HDAM HROR	WAT
CET Govora	82	STUR	LIG	AHE Dragan -Iad-Remu	158	HDAM HROR	WAT
CTE Isalnita	572	STUR	LIG	AHU Raul Mare	173	HDAM HROR	WAT
CET Oradea I	131	STUR	LIG	AHE Sebes	46	HDAM HROR	WAT
CTE Rovinari	1166	STUR	LIG	AHE Somes	57	HDAM HROR	WAT
CTE Turceni	1774	STUR	LIG	AHE Telajen-Doftana	46	HDAM HROR	WAT
CET Iasi II	42.5	STUR	HRD	CHE Bradisor	115	HDAM	WAT
CTE Mintia	930	STUR	HRD	CHE Stanca (Bistrita 5)	15	HDAM	WAT
CET Paroseni	133	STUR	HRD	CHE Colibita	21	HDAM	WAT
CET Arad	48	STUR	GAS	CHE Vidraru	220	HDAM	WAT
CTE Borzesti	194	STUR	GAS	CHE Galceag	150	HDAM	WAT
CTE Braila	408	STUR	GAS	CHE Gogosu	54	HDAM	WAT
CET Brazi	220	STUR	GAS	CHE Lotru	510	HDAM	WAT
CET Bucuresti sud	270	STUR	GAS	CHE Malaia	18	HDAM	WAT
CET Bucuresti vest	287.7	STUR	GAS	CHE Mariselu	220.5	HDAM	WAT
CET Galati	346	STUR	GAS	CHE Motru	50	HDAM	WAT
CET Grozavesti	82	STUR	GAS	CHE Nehoiasu (Siriu/Surduc)	42	HDAM	WAT
CET Progresu	200	STUR	GAS	CHE Portile De Fier I	1166	HROR	WAT
CTE Iernut	750.8	STUR	GAS	CHE Portile De Fier II	246	HROR	WAT
CET Palas	85	STUR	GAS	CHE Raul Alb	41	HDAM	WAT
CCCC Brazi	860	COMC	GAS	CHE Raul Mare	335	HDAM	WAT
CNE Cernavoda	1298	STUR	NUC	CHE Ruieni	140	HDAM	WAT
AHE Arges	223	HDAM HROR	WAT	CHE Stejaru	210	HDAM	WAT
AHE Bistrita (1,2,3)	244	HDAM HROR	WAT	CHE Sugag	150	HDAM	WAT
AHE Siret	192	HDAM HROR	WAT	CHE Tismana	116	HDAM	WAT
AHE Buzau	35	HDAM HROR	WAT	RO Wind	2987	WTON	WIN
AHE Cris	56	HDAM HROR	WAT	RO Solar	1211	PHOT	SUN
AHE Dambovita	95	HDAM HROR	WAT				

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (ENTSO-E Transparency Platform, 2018), (Transelectrica, 2019)

Serbia

Figure 36. Transmission network of Serbia with locations of larger power plants (left); Locations of existing hydropower plants (right)



Source: left (Elektromreža Srbije, 2019); right (Euronatur, 2012)

Serbian power system consists of ten thermal power plants and several hydropower plants as they represent a big share of electricity generation units. Lignite-fired thermal power plants are TE Kolubara, TE Kostolac A, TE Kostolac B, TE Morava, TE Nikola Tesla A and TE Nikola Tesla B. Lignite is obtained from mines Kostolac and Kolubara. TETO Novi Sad, TETO Zrinjanin and TETO Sremska Mitrovica are combined heat and power thermal power plants that utilize gas as a power source (JRC Hydro-power plants database, 2019),(Balkan Energy Prospect, 2018),(Duić et al., 2017), (Elektroenergetika, 2019).

Major hydropower plants are HE Bajina Bašta, HE Đjerdap 1, HE Đjerdap 2, HE Zvornik. HE Pirot, HE Bistrica, HE Kokin Brod, HE Potpec, HE Uvac, HE Vrla 1-4 and RHE Bajina Bašta. Besides mentioned larger hydropower plants, Serbia has small hydropower capacities with a total 62 MW of power output (JRC Hydro-power plants database, 2019),(Balkan Energy Prospect, 2018),(Duić et al., 2017),(KPMG Hungary, 2010).

With construction completion of Alibunar wind farm in late 2018, the total wind power output of the Serbian power sector reached 67 MW. The largest wind farms are VE Alibunar, VE Malibunar, VE Kula and VE Izbište with a power output of 42 MW, 8 MW, 9.9 MW and 6.6 MW, respectively (Balkan Energy Prospect, 2018), (Tanjug, 2018).

Based on IEA statistics, the percentage of electricity generation by fuel for the year 2015 shows the usage of coal, hydropower and other energy sources (oil, gas, biofuels, waste, solar and wind) of 71%, 28% and 1%, respectively (IEA, 2016).

Table 40. The list of major power plants in Serbia

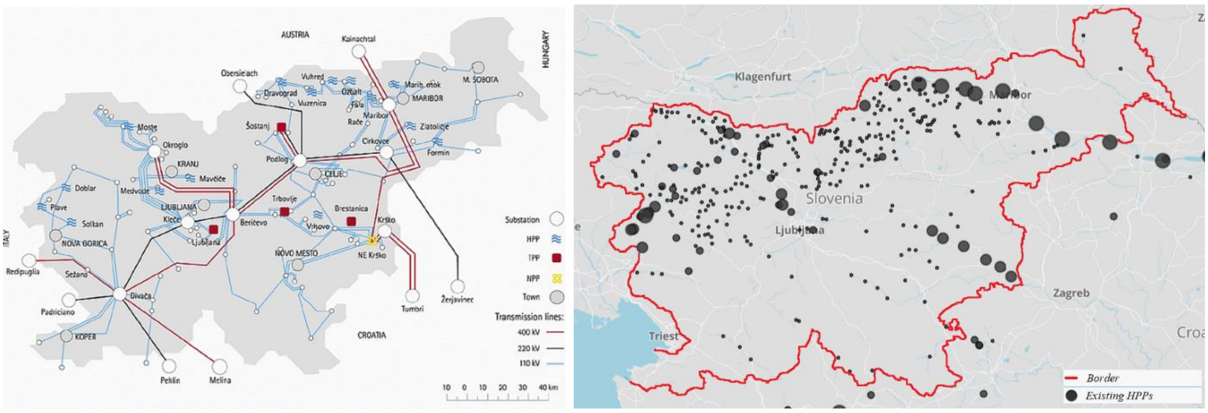
Unit	Power Capacity [MW]	Type[1]	Fuel[1]
TE Kolubara	270	STUR	LIG
TE Kostolac A	310	STUR	LIG
TE Kostolac B	698	STUR	LIG
TE Morava	125	STUR	LIG
TE Nikola Tesla A	1650	STUR	LIG
TE Nikola Tesla B	1240	STUR	LIG
TETO Novi Sad	245	COMC	GAS
TETO Zrenjanin	100	COMC	GAS
TETO Sremska Mitrovica	45	COMC	GAS
HE Bajina Bašta	420	HROR	WAT
HE Đjerdap 1	1083	HROR	WAT
HE Đjerdap 2	270	HROR	WAT
HE Zvornik	96	HROR	WAT
HE Pirot	80	HDAM	WAT
HE Bistrica	102	HDAM	WAT
HE Kokin Brod	22	HDAM	WAT
HE Potpec	54	HDAM	WAT
HE Uvac	36	HDAM	WAT
HE Vrla 1-4	128.6	HDAM	WAT
RHE Bajina Bašta	614	HDAM	WAT

(1) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (Balkan Energy Prospect, 2018), (Duić et al., 2017), (KPMG Hungary, 2010), (Elektromreža Srbije, 2019), (Tanjug, 2018)

Slovenia

Figure 37. Transmission network of Slovenia with locations of larger power plants (left); Locations of existing hydropower plants (right)



Source: left (Defender, 2017); right (Euronatur, 2012)

Slovenian power system mainly consists of three fossil fuel powered thermal power plants, one nuclear power plant and a number of hydropower plants.

TE Šostanj and TE-TO Ljubljana are lignite-fired thermal power plants with both being CHP power stations. Thermal power plant TPP Brestenica utilizes gas as an energy source. The NE Krško nuclear power plant is a shared project between Croatia and Slovenia, which share the output of the plant (JRC Hydro-power plants database, 2019), (HSE Group, 2019), (Agencija za energijo, 2017), (Dispa-SET Balkans, 2019), (TE-TO Ljubljana, 2008), (TPP Brestenica, 2019), (TPP Šoštanj, 2019).

Largest hydropower plants are located on three main rivers in Slovenia, Soča, Sava and Drava. Hydropower plants can be divided into Soča HPP Chain, Sava HPP Chain and Drava HPP Chain, with most of the units being run-of-river type hydropower plants (Kladnik et al., 2011).

The largest hydropower plants on Drava River are HE Dravograd, HE Vuzenica, HE Vuhred, HE Ožbalt, HE Fala, HE Mariborski Otok, HE Zatoličje and HE Formin. The hydropower plants on the Soča River are HE Doblar I, HE Doblar II, RHE Avče, HE Plave I, HE Plave II and HE Solkan with RHE Avče being the only pumped hydropower plant in Slovenia. Main hydropower plants on upper part of the River Sava are HE Moste, HE Mavčiče and HE Medvode, while the largest hydropower plants on the downstream part of Sava River are HE Vrhovo, HE Boštanj, HE Blanca, HE Krško, HE Brežice and HE Mokrice. Besides mentioned larger hydropower plants, Slovenia has a large number of small hydropower plants (Euronatur, 2012),(JRC Hydro-power plants database, 2019),(HSE Group, 2019),(Agencija za energijo, 2017),(Dispa-SET Balkans, 2019),(Kladnik et al., 2011),(Savske Elektrarne Ljubljana).

Slovenia also has smaller capacities of waste or biomass (57 MW), wind power (3 MW) and solar power generation (275 MW) (ENTSO-E Transparency Platform, 2018).

Based on IEA statistics, the percentage of electricity generation by fuel for the year 2015 shows the usage of nuclear energy, coal, hydropower, gas, solar power and other energy sources (wind, biofuels, waste, oil) of 37%, 29%, 27%, 3%, 2% and 2%, respectively (IEA, 2016).

Table 41. The list of major power plants in Slovenia

Unit	**Power Capacity [MW]**	**Type**([1])	**Fuel**([1])
NE Krško	696	STUR	NUC
TE Šostanj	1217	STUR	LIG
TPP Brestanica	297	GTUR	GAS
TETO Ljubljana	134	STUR	HRD
HE Dravograd	21	HROR	WAT
HE Vuzenica	52	HROR	WAT
HE Vuhred	61	HROR	WAT
HE Ožbalt	61	HROR	WAT
HE Fala	57	HROR	WAT
HE Mariborski Otok	60	HROR	WAT
HE Zatoličje	126	HROR	WAT
HE Formin	127	HROR	WAT
HE Doblar I and II	70	HROR	WAT
RHE Avče	185	HPHS	WAT
HE Plave I and II	42	HROR	WAT
HE Solkan	31	HROR	WAT
HE Moste	13	HROR	WAT
HE Mavčiče	38	HROR	WAT
HE Medvode	19	HROR	WAT
HE Vrhovo	34	HROR	WAT
HE Boštanj	32	HROR	WAT
HE Krško	38	HROR	WAT
HE Brežice	45	HROR	WAT
HE Mokrice	28.1	HROR	WAT

([1]) related to Dispa-SET Manual list of unit types and supported fuels (Dispa-SET, 2018)

Source: (Euronatur, 2012), (JRC Hydro-power plants database, 2019), (Kanellopoulos et al., 2017), (HSE Group, 2019) (Agencija za energijo, 2017), (Dispa-SET Balkans, 2019), (TE-TO Ljubljana, 2008), (TPP Brestenica, 2019), (TPP Šoštanj, 2019), (Kladnik et al., 2011), (Savske Elektrarne Ljubljana) (ENTSO-E Transparency Platform, 2018)

Annex 3: Input Data

Dispa-SET Medium-Term Hydrothermal Coordination Input Data

Power plants

The study includes countries of the West Balkan region and neighbouring EU Member States. The year 2015 is selected as the reference year.

The list of power plants was collected from multiple sources. Most of data on existing power plants came from databases (JRC Hydro-power plants database, 2019), (Dispa-SET Balkans, 2019) and (ENTSO-E Transparency Platform, 2018), with the additional information from the national TSO's and energy-related documentation available online. References were mentioned in Annex 2 for each country included in this study.

The thermal, wind and solar power plants for Dispa-SET MTHC were clustered based on fuel chart described in Dispa-SET manual (Kavvadias et al., 2018) and corresponding country. The naming scheme for thermal power plants was: Country_FUEL_Cluster, where Country represents the ISO 3166-1 country code standard to define the country name, and FUEL refers to the mentioned fuel chart in (Kavvadias et al., 2018). The list of country codes is shown in Table 42, while fuel categorization can be seen in Table 43.

Table 42. Country codes defined in Dispa-SET for included region

Code	Country
AL	Albania
BA	Bosnia and Herzegovina
BG	Bulgaria
HR	Croatia
EL	Greece
HU	Hungary
XK	Kosovo
ME	Montenegro
MK	North Macedonia
RO	Romania
RS	Serbia
SI	Slovenia

Source: (Kavvadias et al., 2018)

The clustering method was not used on hydropower plants because the primary goal of the MTHC model is to get results on reservoir levels of storage hydropower plants and hydropower production of run-of-river hydropower plants.

The naming scheme for hydropower plants was: Country_PowerPlantName_Technology, where PowerPlantName refers to the actual power plant name, while Technology refers to defined supported ways of producing electrical energy in the Dispa-SET manual.(Kavvadias et al., 2018).

The list of the supported technologies is represented in Table 44. The list of clustered thermal, wind and solar power plants is shown in Table 45, while hydropower plants are listed in Table 46. The reference column refers to additional data, not related to databases (JRC Hydro-power plants database, 2019), (Dispa-SET Balkans, 2019) and (ENTSO-E Transparency Platform, 2018).

Table 43. Dispa-SET fuel list

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 Excl Blk Liq (Incl Red Liquor, Sludge, Wood,Spent Sulfite Liquor And Oth Liquids, Wood And Wood Waste
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, WellheadGas
GEO	Geothermal steam
HRD	Anthracite, Other Anthracite, Bituminous Coal, Coker By-Product, Coal Gas (From Coal Gasification), Coke, Coal (Generic), Coal-Oil Mixture, Other Coal, Coal And Pet Coke Mi, Coal Tar Oil, Anthracite Coal Waste, Coal-Water Mixture, Gob, Hard Coal / Anthracite, 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, No. 1 Fuel Oil, No. 2 Fuel Oil, No. 3 Fuel Oil, No. 4 Fuel Oil, No. 5 Fuel Oil, No. 6 Fuel Oil, Furnace Fuel, Gas Oil, 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 (Sewage Sludge 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: (Kavvadias et al., 2018)

The variable generation cost of available technologies is collected from multiple sources. In (Šarić, 2016) the comparison of the conventional and non-conventional electricity production is studied, with a list of costs for electricity production from wind, solar, biomass, geothermal, hydropower, nuclear power plants, gas and coal-fired thermal power plants. In (DECC, 2012) detailed analysis on the estimation of costs and technical specifications for different generation technologies is studied. The cost data is broken into detailed expenditure for the lifetime of power plants. In (Samadi, 2017) the social cost of electricity is studied with the categorization of relevant types of costs differentiating between plant-level, system and external costs. In (Radonjić and Vujošević, 2013) the key factors affecting the economics of electricity generation is studied with projected costs for electricity production from different energy sources.

Table 44. Dispa-SET technologies

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

Source: (Kavvadias et al., 2018)

Table 45. List of clustered thermal, solar and wind power plants for the reference year

Cluster	Nominal power [MW]	Cluster	Nominal power [MW]
AL_OIL_Cluster	98	HR_SUN_Cluster	44
BA_LIG_Cluster	1704	MK_LIG_Cluster	1076
BA_OIL_Cluster	98	MK_WIN_Cluster	35
ME_LIG_Cluster	210	SI_GAS_Cluster	490
EL_GAS_Cluster	4913	SI_LIG_Cluster	1228
EL_LIG_Cluster	4459	SI_NUC_Cluster	696
EL_OIL_Cluster	718	SI_WST_Cluster	35
EL_WIN_Cluster	1613	SI_BIO_Cluster	16
EL_SUN_Cluster	2429	SI_WIN_Cluster	3
HR_GAS_Cluster	743	SI_SUN_Cluster	262
HR_OIL_Cluster	950	RS_LIG_Cluster	5263
HR_HRD_Cluster	325	RS_GAS_Cluster	311
HR_WST_Cluster	6	XK_LIG_Cluster	960
HR_BIO_Cluster	25	BG_GAS_Cluster	1038
HR_WIN_Cluster	429	BG_HRD_Cluster	482
BG_LIG_Cluster	4113	HU_WIN_Cluster	329
BG_NUC_Cluster	2000	HU_SUN_Cluster	29.4
BG_WIN_Cluster	701	RO_GAS_Cluster	4861
BG_SUN_Cluster	1041	RO_HRD_Cluster	1348
HU_GAS_Cluster	4309	RO_LIG_Cluster	4524
HU_HRD_Cluster	240	RO_NUC_Cluster	1300
HU_LIG_Cluster	986	RO_BIO_Cluster	92
HU_NUC_Cluster	1887	RO_WIN_Cluster	2919
HU_OIL_Cluster	410	RO_SUN_Cluster	1248
HU_BIO_Cluster	256		

Source: (JRC Hydro-power plants database, 2019), (Dispa-SET Balkans, 2019), (ENTSO-E Transparency Platform, 2018)

Table 46. List of hydropower plants for the reference year

Unit	Nominal Power [MW]	Nominal head [m]	Water storage [Mm^3]	Additonal references
AL_Koman_HDAM	600	96	430	(Duić et al., 2017)
AL_Fierza_HDAM	500	118	2700	(Duić et al., 2017)
AL_Banje_HDAM	73	301	178	(WBIF, 2017)
AL_Vau Dejes_HDAM	250	52	560	(Duić et al., 2017)
AL_Ulez_HDAM	25.2	54	124	(Duić et al., 2017)
AL_Shkopet_HDAM	24	38.5	15	(Duić et al., 2017)
BA_Bocac_HDAM	110	66	52.1	(Duić et al., 2017)
BA_Jablanica_HDAM	181	94	290	(Duić et al., 2017)
BA_Rama_HDAM	161	285	487	(Duić et al., 2017)
BA_Salakovac_HDAM	210	42	68	(Duić et al., 2017)
BA_Trebinje_HDAM	179	104	1100	(Duić et al., 2017)
BA_Visegrad_HDAM	315	43	161	(Duić et al., 2017)
BA_Mostar_HDAM	72	21	10.9	(Duić et al., 2017)
BA_Mostarsko Blato_HDAM	60	178	1.6	(Duić et al., 2017)
BA_Pec Mlini_HDAM	30	110	0.8	(Duić et al., 2017)
BA_Jajce 1_HDAM	60	92.5	24	(Duić et al., 2017)
BA_Capljina_HPHS	430	228	7.1	(Duić et al., 2017)
ME_Piva_HDAM	342	150	824	(Duić et al., 2017)
ME_Perucica_HDAM	307	550	225.2	(Duić et al., 2017)
EL_ASOMATA_HDAM	108	42	14	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_ILARIONAS_HDAM	154	104	270	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_KASTRAKI_HDAM	320	75	98	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_KREMASTA_HDAM	437	132	3222	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_LADONAS_HDAM	70	239	47	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_P_AOOU (Pigai Aoos)_HDAM	210	675	170	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_PLASTIRAS_HDAM	130	577	400	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_PLATANOVRYSI_HDAM	116	74	15	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_POLYFYTO_HDAM	375	146	1300	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_POURNARI 1_HDAM	304	79	304	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_POURNARI 2_HDAM	30	14	11	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_STRATOS1_HDAM	150	37	15	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_SFIKIA_HPHS	315	60	20	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_THESAVROS_HPHS	384	154	677	(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
HR_Zakucac_HDAM	486	250.4	6.8	(HEP Proizvodnja, 2018)
HR_Senj_HDAM	216	410	1.6	(HEP Proizvodnja, 2018)
HR_Dubrovnik_HDAM	216	272	9.3	(HEP Proizvodnja, 2018)
HR_Vinodol_HDAM	90	648	1.5	(HEP Proizvodnja, 2018)
HR_Peruca_HDAM	60	47	570.9	(HEP Proizvodnja, 2018)

Unit	Nominal Power [MW]	Nominal head [m]	Water storage [Mm³]	Additonal references
HR_Sklope_HDAM	22.5	60	142	(HEP Proizvodnja, 2018)
HR_Djale_HDAM	40.8	21	3.7	(HEP Proizvodnja, 2018)
HR_Golubic_HDAM	7.5	59	5	(HEP Proizvodnja, 2018)
HR_Zavrelje_HDAM	2.1	76	5	(HEP Proizvodnja, 2018)
HR_Velebit_HPHS	276	538	16.4	(HEP Proizvodnja, 2018)
HR_Orlovac_HPHS	237	380	800	(HEP Proizvodnja, 2018)
HR_Lepenica (Vinodol)_HPHS	0.8	12.2	4.5	(HEP Proizvodnja, 2018)
HR_Fuzine_HPHS	4.6	49	34.5	(HEP Proizvodnja, 2018)
MK_Vrutok+Raven_HDAM	207	525	357	(Duić et al., 2017)
MK_Tikvesh_HDAM	114	91.3	479	(Duić et al., 2017)
MK_Shpilje_HDAM	84	85.2	506	(Duić et al., 2017)
MK_Kozjak_HDAM	82	95	550	(Duić et al., 2017)
MK_Globacica_HDAM	42	97.5	55.3	(Duić et al., 2017)
MK_Sveta Petka_HDAM	36.4	40	9.1	(ESM, 2018)
RS_Pirot_HDAM	80	211.5	180	(Duić et al., 2017)
RS_Bistrica_HDAM	104	361.5	7.6	(Duić et al., 2017)
RS_Kokin Brod_HDAM	22.5	54	250	(Duić et al., 2017)
RS_Potpec_HDAM	52	38	27.5	(Duić et al., 2017)
RS_Uvac_HDAM	36	75	213	(Duić et al., 2017)
RS_Vrla 1-4_HDAM	128.6	242.8	172.3	(Duić et al., 2017)
RS_Bajina Basta_HPHS	614	555	170	(Duić et al., 2017)
SI_Avche_HPHS	185	520	2.17	(SENG, 2019)
XK_Ujmani_HDAM	35	100	390	(Duić et al., 2017)
BG_Aleko_HDAM	71.4	272	0.2	(Natsionalna Elektricheska Kompania EAD, 2007),(Bulgarian Energy Holding EAD, 2018)
BG_Batak_HDAM	46.8	421	87.7	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Peshtera_HDAM	135	586	310	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Sestrimo_HDAM	240	534	0.4	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Momina Klisura_HDAM	120	251	0.2	(Natsionalna Elektricheska Kompania EAD, 2007),(Bulgarian Energy Holding EAD, 2018)
BG_Kardzhali_HDAM	110	93	540	(Natsionalna Elektricheska Kompania EAD, 2007),(Bulgarian Energy Holding EAD, 2018)
BG_Studen Kladenets_HDAM	81	65.8	388	(Natsionalna Elektricheska Kompania EAD, 2007),(Bulgarian Energy Holding EAD, 2018)
BG_Ivailovgrad_HDAM	114	52	157	(Natsionalna Elektricheska Kompania EAD, 2007),(Bulgarian Energy Holding EAD, 2018)
BG_Krichim + Vacha I + Vacha II_HDAM	101	172	20.3	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Teshel_HDAM	60	341	449.2	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Tsankov Kamak_HDAM	86	135.4	111	(Natsionalna Elektricheska Kompania EAD, 2007),(NEK EAD, 2008)
BG_Devin_HDAM	88	156	1.4	(Natsionalna Elektricheska Kompania EAD, 2007)

Unit	Nominal Power [MW]	Nominal head [m]	Water storage [Mm^3]	Additonal references
BG_Beli Iskar + Mala Tsarkva + Simeonovo_HDAM	31.3	1160	15.1	(Natsionalna Elektricheska Kompania EAD, 2007),(Bulgarian Energy Holding EAD, 2018)
BG_Pasarel_HDAM	33	116	655.3	(Natsionalna Elektricheska Kompania EAD, 2007),(Bulgarian Energy Holding EAD, 2018)
BG_Kokalyane_HDAM	22.4	98.5	2.7	(Natsionalna Elektricheska Kompania EAD, 2007),(Bulgarian Energy Holding EAD, 2018)
BG_Kalin + Kamenitsa + Pastra + Rila_HDAM	24.2	1800	2.2	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Petrohan_HDAM	7.8	529	0.2	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Barzia_HDAM	8	251	0.03	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Klisoura_HDAM	3.5	124.6	0.05	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Pirin_HDAM	21.2	456	0.06	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Spanchevo_HDAM	28	438	0.04	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Alexander Stambolyski_HDAM	10.2	50	200	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Koprinka_HDAM	7	25	142.4	(Natsionalna Elektricheska Kompania EAD, 2007),(Shopova and Niagolov, 2015)
BG_Popina Laka_HDAM	21.5	532	0.05	(Hydro Review, 2006),(Hydropol, 2018),(Zahariev and Nikolcheva, 2014)
BG_Lilyanovo_HDAM	20	250	0.05	(Hydro Review, 2006),(Regional administration Blagoevgrad, 2019)
BG_Sandanski I_HDAM	14.2	230	0.03	(Hydro Review, 2006),(Regional administration Blagoevgrad, 2019)
BG_Belmeken_HPHS	375	640	43.6	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Chaira_HPHS	864	690	100.4	(Natsionalna Elektricheska Kompania EAD, 2007)
BG_Orphey_HPHS	160	65.8	226.1	(Natsionalna Elektricheska Kompania EAD, 2007)
HU_Kiskore_HDAM	28	6.3	228.6	(MAVIR, 2018)
RO_VALCELE_MERISANI_HDAM	26.9	18	54.8	(Transelectrica, 2019)
RO_BUDEASA_BASCOV_HDAM	19.2	13.5	54.9	(Transelectrica, 2019)
RO_GOLESTI (Calinesti)_HDAM	8	11.5	65	(Transelectrica, 2019)
RO_MIHAILESTI_HDAM	10	11.5	80	(Transelectrica, 2019)
RO_LERESTI_HDAM	19	180	100	(Transelectrica, 2019)
RO_PIATRA NEAMT_HDAM	11	15	10	(Transelectrica, 2019)
RO_GALBENI_HDAM	29.5	15	38.8	(Transelectrica, 2019)
RO_RACACIUNI_HDAM	45	15	103.7	(Transelectrica, 2019)
RO_BERESTI_HDAM	43.5	15	12	(Transelectrica, 2019)
RO_CALIMANESTI (Siret)_HDAM	40	15	44.3	(Transelectrica, 2019)
RO_MOVILENI_HDAM	33.9	15	10	(Transelectrica, 2019)
RO_LUGASU_HDAM	18	15	65.4	(Transelectrica, 2019)

Unit	Nominal Power [MW]	Nominal head [m]	Water storage [Mm^3]	Additonal references
RO_TILEAGD_HDAM	18	15	52.9	(Transelectrica, 2019)
RO_CLABUCET_HDAM	64	100	100	(Transelectrica, 2019)
RO_VACARESTI_HDAM	4.8	15	20	(Transelectrica, 2019)
RO_SCROPOASA_DOBRESTI_HDAM	28	205	119.4	(Transelectrica, 2019)
RO_VADENI_HDAM	11.8	13.5	4.8	(Transelectrica, 2019)
RO_DAESTI_HDAM	37	13.5	11.2	(Transelectrica, 2019)
RO_Rm.VALCEA_HDAM	46	13.5	19	(Transelectrica, 2019)
RO_RAURENI_HDAM	48	13.5	10	(Transelectrica, 2019)
RO_GOVORA_HDAM	45	13.5	18.5	(Transelectrica, 2019)
RO_BABENI_HDAM	37	13.5	59.7	(Transelectrica, 2019)
RO_IONESTI_HDAM	38	13.5	24.9	(Transelectrica, 2019)
RO_ZAVIDENI_HDAM	38	13.5	500	(Transelectrica, 2019)
RO_DRAGASANI_HDAM	45	13.5	40	(Transelectrica, 2019)
RO_STREJESTI_HDAM	50	13.5	225	(Transelectrica, 2019)
RO_ARCESTI_HDAM	38	13.5	43.4	(Transelectrica, 2019)
RO_SLATINA_HDAM	26	13.5	19.2	(Transelectrica, 2019)
RO_IPOTESTI_HDAM	53	13.5	110	(Transelectrica, 2019)
RO_DRAGANESTI_HDAM	53	13.5	76	(Transelectrica, 2019)
RO_FRUNZARU_HDAM	53	13.5	96	(Transelectrica, 2019)
RO_RUSANESTI_HDAM	53	13.5	78	(Transelectrica, 2019)
RO_IZBICENI_HDAM	53	13.5	74	(Transelectrica, 2019)
RO_VOILA_HDAM	14.2	13.5	12.3	(Transelectrica, 2019)
RO_VISTEA_HDAM	14.2	13.5	4.3	(Transelectrica, 2019)
RO_ARPASU_HDAM	14.2	13.5	7.4	(Transelectrica, 2019)
RO_SCOREIU_HDAM	14.2	13.5	45.8	(Transelectrica, 2019)
RO_AVRIG_HDAM	14.2	13.5	10.8	(Transelectrica, 2019)
RO_RACOVITA_HDAM	31.5	15.5	14.8	(Transelectrica, 2019)
RO_ROBESTI_HDAM	27.1	11	6.2	(Transelectrica, 2019)
RO_REMETI_HDAM	100	335	112	(Transelectrica, 2019)
RO_OSTROVU MIC_OSTROVU MARE_HDAM	31.8	20	20	(Transelectrica, 2019)
RO_PACLISA_HDAM	15.9	15	20	(Transelectrica, 2019)
RO_HATEG_ORLEA_HDAM	27.1	19	12.5	(Transelectrica, 2019)
RO_SUBCETATE_HDAM	12.2	15	25	(Transelectrica, 2019)
RO_SASCIORI_HDAM	42	100	3.9	(Transelectrica, 2019)
RO_PETRESTI_HDAM	4.3	9.5	1.4	(Transelectrica, 2019)
RO_TARNITA_HDAM	45	81	74	(Transelectrica, 2019)
RO_SOMES CALD_GILAU (I and II)_HDAM	25.5	64	22.5	(Transelectrica, 2019)
RO_PALTINU_HDAM	10.4	100	53.7	(Transelectrica, 2019)
RO_MANECIU_HDAM	10	100	60	(Transelectrica, 2019)
RO_CHE BRADISOR_HDAM	115	100	39.7	(Transelectrica, 2019)
RO_CHE STANCA (Bistrita 5, Costesti)_HDAM	16	25	225	(Transelectrica, 2019)
RO_COLIBITA_HDAM	21	320	75.2	(Transelectrica, 2019)
RO_CHE VIDRARU (CORBENI)_HDAM	220	324	469	(Transelectrica, 2019)
RO_CHE GALCEAG _HDAM	150	456	136	(Transelectrica, 2019)
RO_CHE GOGOSU_HDAM	54	25	800	(Transelectrica, 2019)

Unit	Nominal Power [MW]	Nominal head [m]	Water storage [Mm^3]	Additonal references
RO_CHE LOTRU (CIUNGET)_HDAM	510	809	340	(Transelectrica, 2019)
RO_CHE MALAIA_HDAM	18	100	3.4	(Transelectrica, 2019)
RO_CHE MARISELU_HDAM	220.5	469	212	(Transelectrica, 2019)
RO_CHE MOTRU_HDAM	50	100	100	(Transelectrica, 2019)
RO_CHE NEHOIASU (Siriu/Surduc)_HDAM	42	493	155	(Transelectrica, 2019)
RO_CHE RAUL ALB_HDAM	41	230	17	(Transelectrica, 2019)
RO_CHE RAUL MARE (Retezat)_HDAM	335	582	220	(Transelectrica, 2019)
RO_CHE RUIENI_HDAM	140	355	96	(Transelectrica, 2019)
RO_CHE STEJARU (BICAZ)_HDAM	210	143.5	1230	(Transelectrica, 2019)
RO_CHE SUGAG_HDAM	150	381	21	(Transelectrica, 2019)
RO_CHE TISMANA_HDAM	116	205	4.8	(Transelectrica, 2019)
AL_Ashta_HROR	53	6		(Duić et al., 2017)
AL_Bistrica_HROR	27.5	80		(Duić et al., 2017)
BA_Grabovica_HROR	114	34		(Duić et al., 2017)
BA_Jajce 2_HROR	30	42.5		(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_AGRAS_HROR	50	156		(Fernandez-Blanco Carramolino et al., 2016),(Argyrakis)
EL_EDESSAIOS_HROR	19	125		(HEP Proizvodnja, 2018)
HR_Kraljevac_HROR	46.4	108		(HEP Proizvodnja, 2018)
HR_Varazdin_HROR	92.5	21.9		(HEP Proizvodnja, 2018)
HR_Dubrava_HROR	79.8	17.5		(HEP Proizvodnja, 2018)
HR_Cakovec_HROR	77.4	17.5		(HEP Proizvodnja, 2018)
HR_Gojak_HROR	55.5	118		(HEP Proizvodnja, 2018)
HR_Lesce_HROR	41.2	38.2		(HEP Proizvodnja, 2018)
HR_Rijeka_HROR	36.8	212.7		(HEP Proizvodnja, 2018)
HR_Miljacka_HROR	24	102		(HEP Proizvodnja, 2018)
HR_Krcic_HROR	0.4	3.8		(HEP Proizvodnja, 2018)
HR_Ozalj_HROR	6	9.2		(HEP Proizvodnja, 2018)
HR_Jaruga_HROR	7.2	26		(HEP Proizvodnja, 2018)
HR_Zeleni Vir_HROR	1.7	50		(HEP Proizvodnja, 2018)
SI_Formin_HROR	127	29		(Wikipedia, 2019)
SI_Zatolicje_HROR	126	33		(Wikipedia, 2019)
SI_Blanca 1_HROR	38	9.3		(HESS, 2019)
SI_Bostanj_HROR	32	7.5		(HESS, 2019)
SI_Doblar 1_HROR	70	45.5		(SENG, 2019)
SI_Dravograd 1_HROR	21	8.9		(DEM, 2019)
SI_Fala 1_HROR	57	14.6		(DEM, 2019)
SI_Krsko 1_HROR	38	9.1		(HESS, 2019)
SI_Mariborski otok 1_HROR	60	14.2		(DEM, 2019)
SI_Mavcice 1_HROR	38	19.5		(Wikipedia, 2019)
SI_Medvode 1_HROR	19	19.1		(IBE, 2019)
SI_Moste 1_HROR	13	65		(SEL, 2019)
SI_Ozbalt 1_HROR	61	17.4		(DEM, 2019)
SI_Plave_HROR	42	29		(SENG, 2019)
SI_Solkan _HROR	31	20.6		(SENG, 2019)

Unit	Nominal Power [MW]	Nominal head [m]	Water storage [Mm³]	Additonal references
SI_Vrhovo _HROR	34	10.5		(GEO, 2019)
SI_Vuhred _HROR	61	17.4		(DEM, 2019)
SI_ Vuzenica 1_HROR	52	13.8		(Wikipedia, 2019)
RS_Bajina Basta_HROR	420	66		(Duić et al., 2017)
RS_Djerdap 1_HROR	1083	27.2		(Duić et al., 2017)
RS_Djerdap 2_HROR	270	9		(Duić et al., 2017)
RS_Zvornik_HROR	96	21.6		(Duić et al., 2017)
BG_Stara Zagora_HROR	22.4	135		(Natsionalna Elektricheska Kompania EAD, 2007),(Shopova and Niagolov, 2015)
HU_Tiszalok_HROR	13.5	4.5		(MAVIR, 2018)
HU_Kesznyeten (Hernadviz)_HROR	4.4	14		(MAVIR, 2018)
HU_Ikervar_HROR	1.8	8		(MAVIR, 2018)
RO_CUMPANITA_HROR	4.8	25		(Transelectrica, 2019)
RO_VALSAN_HROR	5	5.5		(Transelectrica, 2019)
RO_OIESTI_HROR	15	20.5		(Transelectrica, 2019)
RO_ALBESTI_CERBURENI _HROR	30	20.5		(Transelectrica, 2019)
RO_VALEA IASULUI_CURTEA DE ARGES_HROR	22.7	17		(Transelectrica, 2019)
RO_NOAPTES_HROR	15.4	20.5		(Transelectrica, 2019)
RO_ZIGONENI_HROR	15.4	20.4		(Transelectrica, 2019)
RO_BAICULESTI_HROR	15.4	20.3		(Transelectrica, 2019)
RO_MANICESTI_HROR	11.5	15.1		(Transelectrica, 2019)
RO_PITESTI_HROR	7.7	10.5		(Transelectrica, 2019)
RO_VOINESTI_HROR	5.2	25		(Transelectrica, 2019)
RO_PANGARATI_VADURI_ HROR	67	25		(Transelectrica, 2019)
RO_VANATORI_ROZNOV_ HROR	28	25		(Transelectrica, 2019)
RO_ZANESTI_HROR	14	25		(Transelectrica, 2019)
RO_COSTISA_HROR	14	25		(Transelectrica, 2019)
RO_BUHUSI_HROR	11	25		(Transelectrica, 2019)
RO_RACOVA_HROR	23	25		(Transelectrica, 2019)
RO_GARLENI_HROR	23	25		(Transelectrica, 2019)
RO_LILIECI_HROR	23	25		(Transelectrica, 2019)
RO_BACAU_HROR	30	25		(Transelectrica, 2019)
RO_CINDESTI_HROR	11.5	25		(Transelectrica, 2019)
RO_VERNESTI_HROR	11.8	25		(Transelectrica, 2019)
RO_SIMILEASCA_HROR	11.7	25		(Transelectrica, 2019)
RO_SACADAT_HROR	10	25		(Transelectrica, 2019)
RO_FUGHIU_HROR	10	25		(Transelectrica, 2019)
RO_RUCAR_HROR	23	25		(Transelectrica, 2019)
RO_DRAGOSLAVELE_HRO R	7.7	25		(Transelectrica, 2019)
RO_MOROIENI_HROR	15	233		(Transelectrica, 2019)
RO_TG.JIU_HROR	11.8	25		(Transelectrica, 2019)
RO_GURA LOTRULUI_HROR	24.9	25		(Transelectrica, 2019)
RO_TURNU_HROR	70	24		(Transelectrica, 2019)
RO_CALIMANESTI (Olt)_HROR	38	25		(Transelectrica, 2019)

Unit	Nominal Power [MW]	Nominal head [m]	Water storage [Mm^3]	Additonal references
RO_CAINENI_HROR	26.9	12		(Transelectrica, 2019)
RO_CORNETU_HROR	34.4	14		(Transelectrica, 2019)
RO_MUNTENI I_HROR	58	25		(Transelectrica, 2019)
RO_CLOPOTIVA_HROR	14	25		(Transelectrica, 2019)
RO_CARNESTI I,II_HROR	27.4	25		(Transelectrica, 2019)
RO_TOTESTI I,II_HROR	31.8	25		(Transelectrica, 2019)
RO_PLOPI_HROR	12	15		(Transelectrica, 2019)
RO_BRETEA_HROR	12	25		(Transelectrica, 2019)
RO_FLORESTI (I and II)_HROR	7.2	10		(Transelectrica, 2019)
RO_IZVOARELE_HROR	16	25		(Transelectrica, 2019)
RO_VALENII DE MUNTE_HROR	10	25		(Transelectrica, 2019)
RO_CHE PORTILE DE FIER I_HROR	1166	28.5		(Transelectrica, 2019)
RO_CHE PORTILE DE FIER II_HROR	246	10.5		(Transelectrica, 2019)

Source: (JRC Hydro-power plants database, 2019), (Dispa-SET Balkans, 2019), (ENTSO-E Transparency Platform, 2018)

Demand profiles

Demand profiles for all countries have been obtained from the ENTSO-E Power Statistic Platform, except for demand profile of Kosovo, which was obtained from (Dispa-SET Balkans, 2019).

Figure 38. Demand profiles of the studied countries for the year 2015

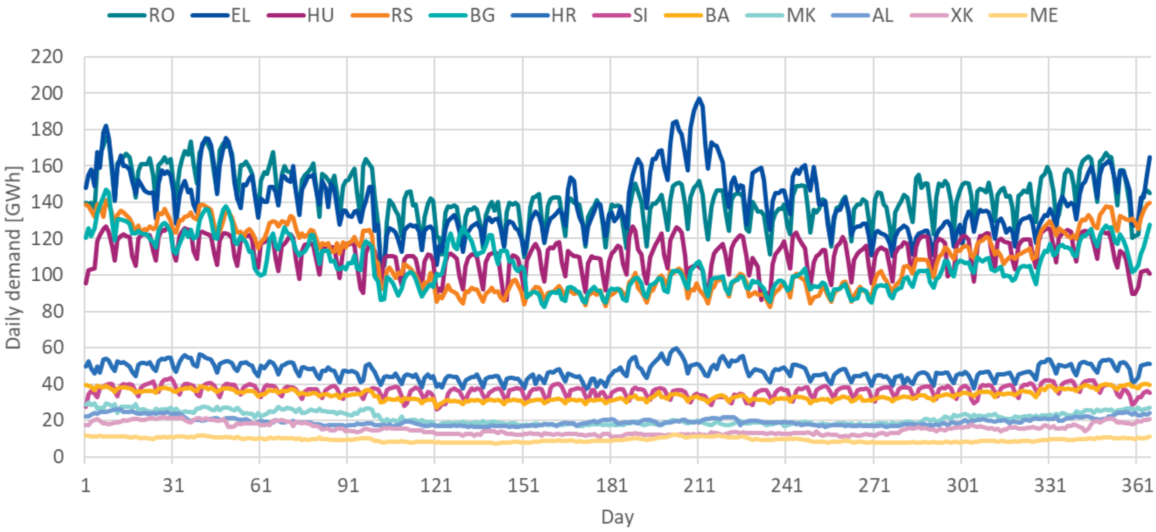


Table 47. Demand profiles for the reference year, 2015

Country	**Average demand [GWh/day]**	**Peak demand [GWh/day]**
Albania	19.42	26.11
Bosnia and Herzegovina	33.88	40.26
Bulgaria	105.82	147.02
Croatia	47.10	59.69
Greece	140.62	197.28
Hungary	111.65	126.88
Kosovo	15.85	23.89
Montenegro	9.37	12.07
North Macedonia	21.47	29.92
Romania	143.32	175.84
Serbia	108.23	141.30
Slovenia	36.24	43.31

The average and peak demand of each country can be seen in Table 47. The highest average demand is for Romania, Greece and Serbia with values of 143.32, 140.62 and 108.23 GWh/day, respectively. The highest daily demand peaked in Greece, Romania and Bulgaria with values of 197.28, 175.84 and 147.02 GWh/day.

Water inflows

Net water inflows have been provided by the JRC from the rainfall-runoff hydrological LISFLOOD model. The assumption is that provided water inflows represent the total runoff at studied catchment level. Figure 4 represents the total sum of inflows for the included hydropower plant locations for the period between 1990 and 2016. The yellow highlighted line represents the runoff for the dry, green highlighted for the average and red for the wet year. The wet, average and dry years are 2010, 2015 and 2007, respectively. The average runoff values for wet, average and dry years are 37 010, 24 847 and 20 793 m^3/s, respectively, while the runoff peaked at 70 154, 38 119 and 35 087 m^3/s, respectively.

Wind and solar power profiles

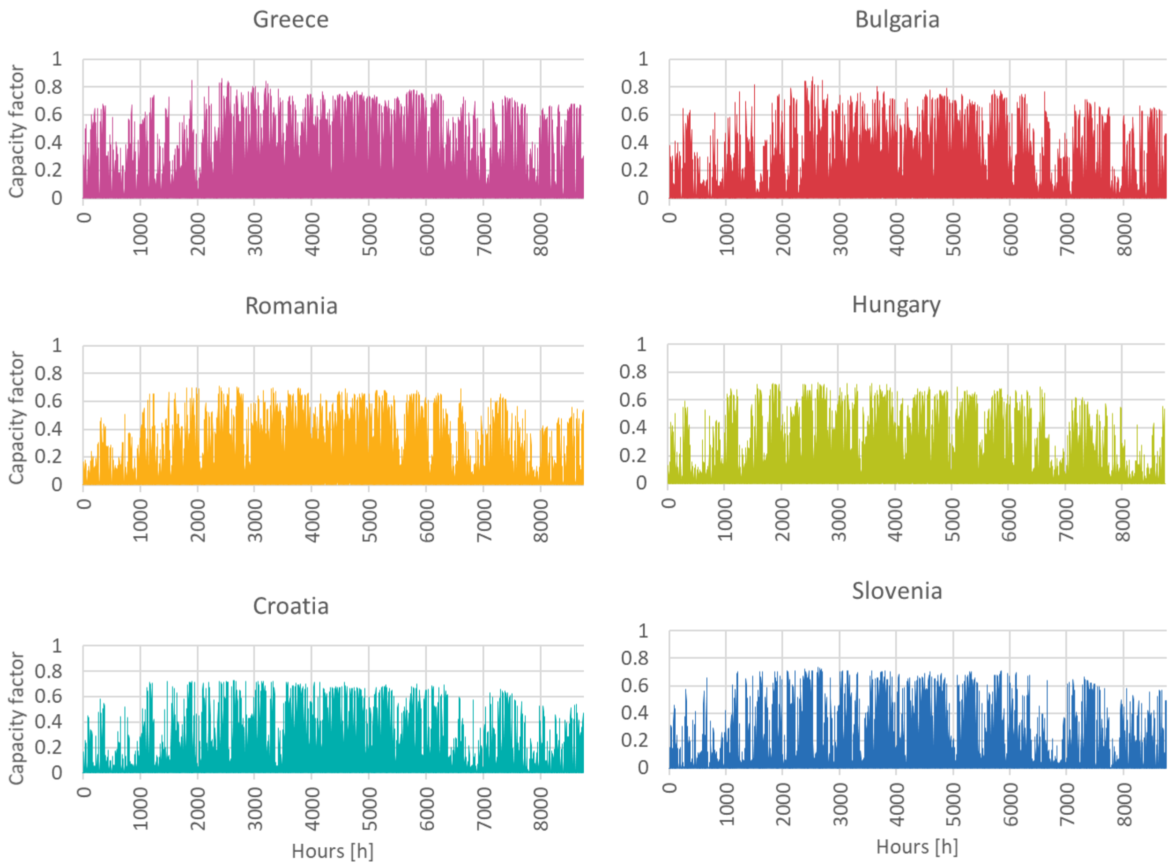
Wind power capacities are present in Romania, Greece, Bulgaria, Croatia, Hungary, North Macedonia and Slovenia, with total installed power capacity of 2919, 1613, 701, 429, 329, 35 and 3 MW, respectively. Solar power capacities are present in Greece, Romania, Bulgaria, Slovenia, Croatia and Hungary, with a total installed power capacity of 2429, 1248, 1041, 262, 44 and 29 MW, respectively. Data on total installed power capacity for the solar and wind power was obtained from ENTSO-E Transparency Platform (ENTSO-E Transparency Platform, 2018).

Data on power generation from solar and wind power plants were obtained from the EMHIRES dataset in the form of capacity factors (Gonzalez Aparicio, 2019).

Figure 39 represents yearly capacity factor values for solar power plants in Bulgaria, Croatia, Greece, Hungary, Romania and Slovenia, while Figure 41 shows yearly capacity factor values for wind power plants in Bulgaria, Croatia, Greece, Hungary, North Macedonia, Romania and Slovenia.

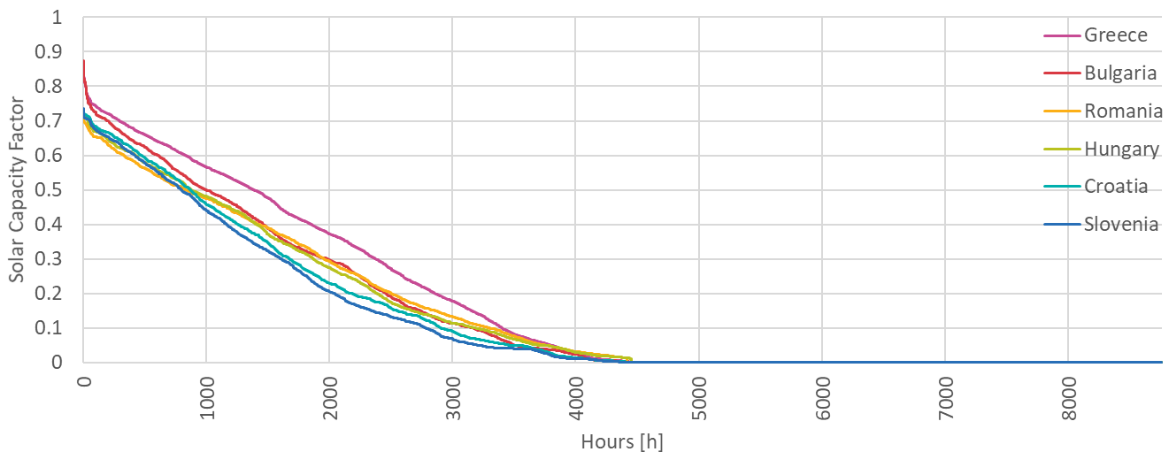
Load duration curves for solar and wind capacities can be seen in Figure 40 and Figure 42, respectively. Solar load duration curve shows that solar capacities in Greece stand out when compared to similar load duration curves for Romania, Bulgaria and Hungary. On the other side, Croatian and Slovenian solar capacities fall short when compared to the Romania, Bulgaria and Hungary. Wind load duration curve shows steeper slope for Slovenian and North Macedonian wind capacities, while other countries experience steadier decline.

Figure 39. Capacity factor values of solar power plants in Bulgaria, Greece, Croatia, Hungary, Romania and Slovenia for the year 2015



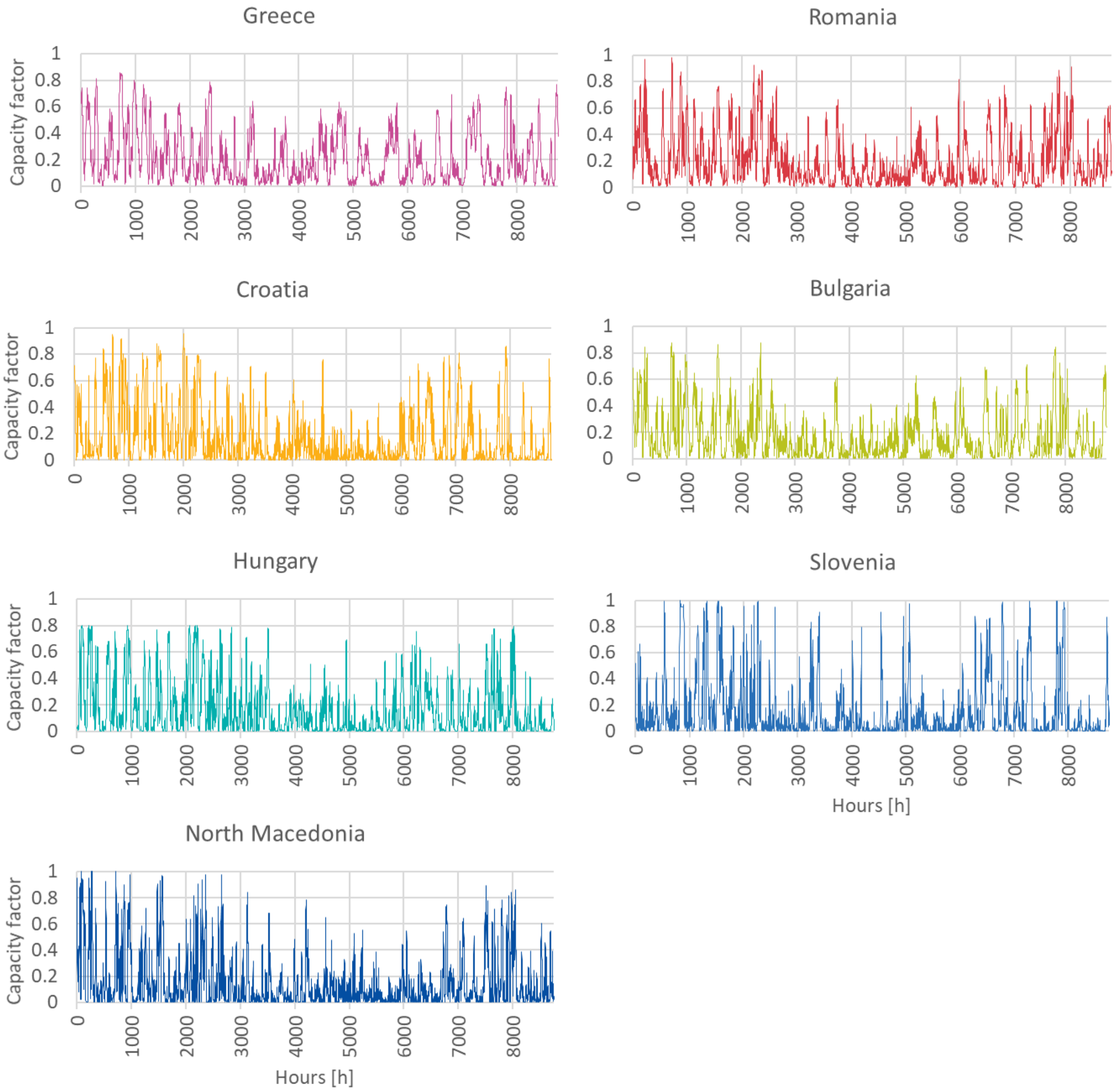
Source: (Gonzalez Aparicio, 2019)

Figure 40. Load duration curve for solar capacities in form of capacity factor for the year 2015



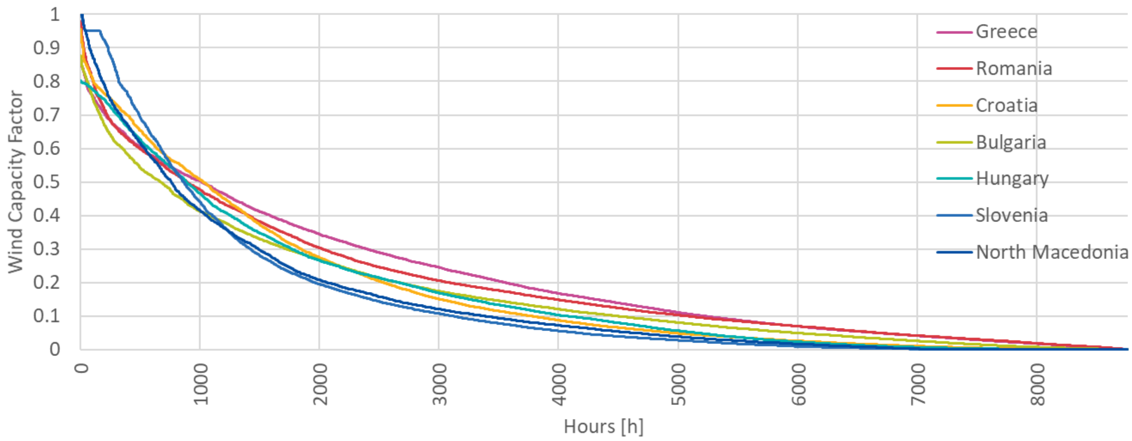
Source: (Gonzalez Aparicio, 2019)

Figure 41. Capacity factor values of wind power plants in Bulgaria, Greece, Croatia, Hungary, North Macedonia, Romania, and Slovenia for the year 2015



Source: (Gonzalez Aparicio, 2019)

Figure 42. Load duration curve for wind capacities in form of capacity factor for the year 2015



Source: (Gonzalez Aparicio, 2019)

Line capacities

Data on line capacities in the form of net transfer capacities (NTC) were obtained from values (SECI TSP, 2014). Data on NTC values for Kosovo were obtained from (Dispa-SET Balkans, 2019) (Table 48).

Table 48. NTC Values for studied region in MW

	Export															
Import	**AL**	**BA**	**BG**	**HR**	**EL**	**HU**	**XK**	**ME**	**MK**	**RO**	**RS**	**SI**	**AT**	**IT**	**TR**	**UA**
AL		/	/	/	683	/	550	430	/	/	327	/	/	/	/	/
BA	/		/	1076	/	/	/	1088	/	/	1278	/	/	/	/	/
BG	/	/		/	987	/	/	/	412	1814	745	/	/	/	1684	/
HR	/	569	/		/	2597	/	/	/	/	1078	880	/	/	/	/
EL	440	/	1693	/		/	/	/	879	/	/	/	/	500	2260	/
HU	/	/	/	789	/		/	/	/	2006	1401	/	400	/	/	650
XK	671	/	/	/	/	/		440	440	/	680	/	/	/	/	/
ME	383	746	/	/	/	/	440		/	/	534	/	/	/	/	/
MK	/	/	1185	/	636	/	440	/		/	870	/	/	/	/	/
RO	/	/	891	/	/	1924	/	/	/		999	/	/	/	/	2280
RS	671	731	1635	669	/	872	680	311	441	830		/	/	/	/	/
SI	/	/	/	1402	/	/	/	/	/	/	/		1645	893	/	/
AT	/	/	/	/	/	400	/	/	/	/	/	1162		n.a.	/	/
IT	/	/	/	/	500	/	/	/	/	/	/	774	n.a.		/	/
TR	/	/	1457	/	913	/	/	/	/	/	/	/	/	/		/
UA	/	/	/	/	/	450	/	/	/	442	/	/	/	/	/	

Source: (Dispa-SET Balkans, 2019), (SECI TSP, 2014)

Topology

Topology defines connections between hydropower plants in a river network. It is used for the model to determine upstream inflow for hydropower plants that utilize the same river water resources. The following list contains the hydropower cascades considered in the study:

— Gojak → Lešće
— Golubić + Krčić → Miljacka → Jaruga
— Peruća + Orlovac → Đale → Zakučac + Kraljevac
— Rama → Jablanica → Grabovica → Salakovac → Mostar
— Trebinje → Dubrovnik
— Uvac → Kokin Brod
— Kokin Brod + Piva + Potpec → Višegrad → Bajina Bašta → Zvornik
— Jajce 1 → Jajce 2 → Bočac
— Moste → Mavčiče → Medvode → Vrhovo → Boštanj → Blanca → Krško
— Doblar → Avče → Plave → Solkan
— Dravograd → Vuzenica → Vuhred → Ožbalt → Fala → Mariborski Otok → Zatoličje → Formin → Varaždin → Čakovec → Dubrava
— Globačica → Shpilje → Fierza → Komani → Vau Dejes → Ashta
— Kozjak → Sveta Petka
— Thisavros → Platanovrisi
— Ilarionas → Polyphyton → Sfikia → Asomata
— Pigai Aoos → Pournari 1 → Pournari 2
— Plastira → Kremasta → Kastraki → Stratos

- Agras → Edessaios
- Belkmen → Sestrimo → Momina Klisoura
- Teshel → Devin → Tsankov Kamak → Orpheus → Vancha I → Krichim → Vancha II
- Batak → Peshtera → Aleko
- Kardjali → Studen Kladenets → Ivailovgrad
- Pasarel → Kokalyane
- Koprinka → Stara Zagora
- Tiszalok → Kiskore
- Petrohan → Barzia → Klisoura
- Pirin → Spanchevo
- Cumpanita → Vidraru → Oiesti → Albesti&Cerbureni → Valea Iasului&Curtea De Arges → Noaptes → Zigoneni → Baiculesti → Manicesti → Valcele&Mersiani + Valsan → Budeasa&Bascov + (Leresti → Vionesti) → Pitesti → Golesti → Mihailesti
- Stejaru (Bicaz) → Pangarat&Vaduri → Piatra Neamt → Vanatori&Roznov → Zanesti → Costisa → Buhusi → Racova → Garleni → Lilieci → Bacau → Galbeni → Racaciuni → Beresti → Calimanesti (Siret) → Movileni
- Nehoiasu (Siriu/Surduc) → Cindesti → Vernesti → Simileasca
- Lugasu → Tileagd → Sacadat → Fughiu → Tisza
- Clabucet → Rucar → Dragoslavele → Vacaresti
- Scropoasa → Dobresti → Moroieni
- Voila → Vistea → Arpasu → Scoreiu → Avrig → Racovita → Caineni → Robesti → Cornetu → Gura Lotrului + Bradisor → Turnu → Calimanesti (Olt) → Daesti → Rm. Valcea → Raureni → Govora → Babeni → Ionesti → Zavideni → Dragasani → Strejesti → Arcesti → Slatina → Ipotesti → Draganesti → Frunzaru → Rusanesti → Izbiceni
- Raul Mare → Clopotiva → Ostrovu Mic& Ostrovu Mare → Carnesti I&II → Paclisa → Totesti I&II → Hateg&Orlea → Subcetate → Plopi → Bretea
- Galceag → Sugag → Sasciori → Petresti
- Mariselu → Tarnita → Somes Cald&Gilau → Floresti
- Maneciu → Izvorale → Valenii De Munte
- Lotru → Malaia → Bradisor
- Motru → Tismana

Water demand

Water demand can be divided into water used for hydropower production, water used for cooling thermal power plants and water used for other non-energy-related purposes like agriculture, irrigation industry, drinking water supply etc. Due to the lack of data on water withdrawal and water consumption besides hydropower generation, other water withdrawal and consumption for activities mentioned above were taken into account setting a minimum amount of water reservoir level (defined as 20% of the maximum reservoir level for each hydropower unit with accumulation). Data on water withdrawal and consumption for other activities than hydropower generation is quite important, and should be included in future work.

Dispa-SET Unit Commitment and Dispatch Input Data

Power plants

Additionally to data covered in Annex 2, common fields needed for all units are shown in Table 49. All data related to power plants for Dispa-SET UTC were obtained from (JRC Hydro-power plants database, 2019) and (Dispa-SET Balkans, 2019), with the addition of power plants data for Greece from (Fernandez-Blanco Carramolino et al., 2016).

Additionally, related to storage units, some parameters must be added and are shown in Table 50 (Quoilin and Kavvadias, 2018).

For CHP units, additional data, dependent on CHP type, is needed as input. Types of CHP covered in Dispa-SET UCD are extraction/condensing, backpressure and power-to-heat units. Additional data with the description, field name and units are shown in Table 51. Mandatory fields based on CHP type are shown in Table 52 (Quoilin and Kavvadias, 2018).

Table 49. Common fields needed for all units

Description	**Field name**	**Units**
Unit name	Unit	
Commissioning year	Year	
Technology	Technology	
Fuel	Primary fuel	
Zone	Zone	
Capacity	PowerCapacity	MW
Efficiency	Efficiency	%
Efficiency at minimum load	MinEfficiency	%
CO_2 intensity	CO2Intensity	TCO_2/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 downtime	MinDownTime	h
No load cost	NoLoadCost	€/h
Start-up cost	StartUpCost	€
Ramping cost	RampingCost	€/MW
Presence of CHP	CHP	y/n

Source: (Quoilin and Kavvadias, 2018)

Table 50. Additional storage specific fields

Description	**Field name**	**Units**
Storage capacity	STOCapacity	MWh
Self-discharge rate	STOSelfDischarge	%/h
Maximum charging power	STOMaxChargingPower	MW
Charging efficiency	STOChargingEfficiency	%

Source: (Quoilin and Kavvadias, 2018)

Table 51. Additional specific fields for CHP units

Description	**Field name**	**Units**
CHP Type	CHPType	Extraction/back-pressure/p2h
Power-to-heat ratio	CHPPowerToHeat	
Power loss factor	CHPPowerLossFactor	
Maximum heat production	CHPMaxHeat	MW(th)
Capacity of heat storage	STOCapacity	MWh(th)
% of storage heat loss pet	STOSelfDischarge	%

Source: (Quoilin and Kavvadias, 2018)

Table 52. Mandatory fields based on CHP Type, (X: mandatory, ○: optional)

Description	**Extraction**	**Backpressure**	**Power to heat**
CHP Type	X	X	X
Power-to-heat ratio	X	X	
Power loss factor	X		X
Maximum heat production	○	○	X
Capacity of heat storage	○	○	○
% of storage heat loss pet	○	○	○

Source: (Quoilin and Kavvadias, 2018)

Power plants outages

In the current version of Dispa-SET UTC, planned and unplanned outages are not distinguished, and are defined by an “OutageFactor” parameter for each unit. The parameter is equal to zero if there are no outages, and one if the unit is out of operation. The data on unit outages were obtained from ENTSO-E Transparency platform and nationally related TSO’s web sites, collected in the database (Dispa-SET Balkans, 2019), (ENTSO-E Transparency Platform, 2018).

Hydro data

Additional data needed as input for the Dispa-SET UCD model are results from Dispa-SET MTHC model. Additional data are hydropower production of run-of-river units and reservoir levels of hydropower plants with storage (Quoilin and Kavvadias, 2018).

Hydropower production of run-of-river units is defined through the availability factor (AF), which has the same definition as the capacity factor for wind and solar power generation. It is described as energy generated in one hour divided by the total installed power of the unit and it ranges from zero to one, depending on the availability of energy source. It is exogenous time series defined for all renewable power generation units, which generated energy cannot be stored and it is fed to the grid or curtailed. (Quoilin and Kavvadias, 2018).

Because of the tendency of the model to empty reservoir storage at the end of the optimization horizon, due to emptying the storage having zero marginal cost, additional input of reservoir level for the last hour of each horizon is needed. The input to Dispa-SET UCD is defined as a normalized value with respect to the maximum storage capacity, so its minimum value is zero, and the maximum is one.

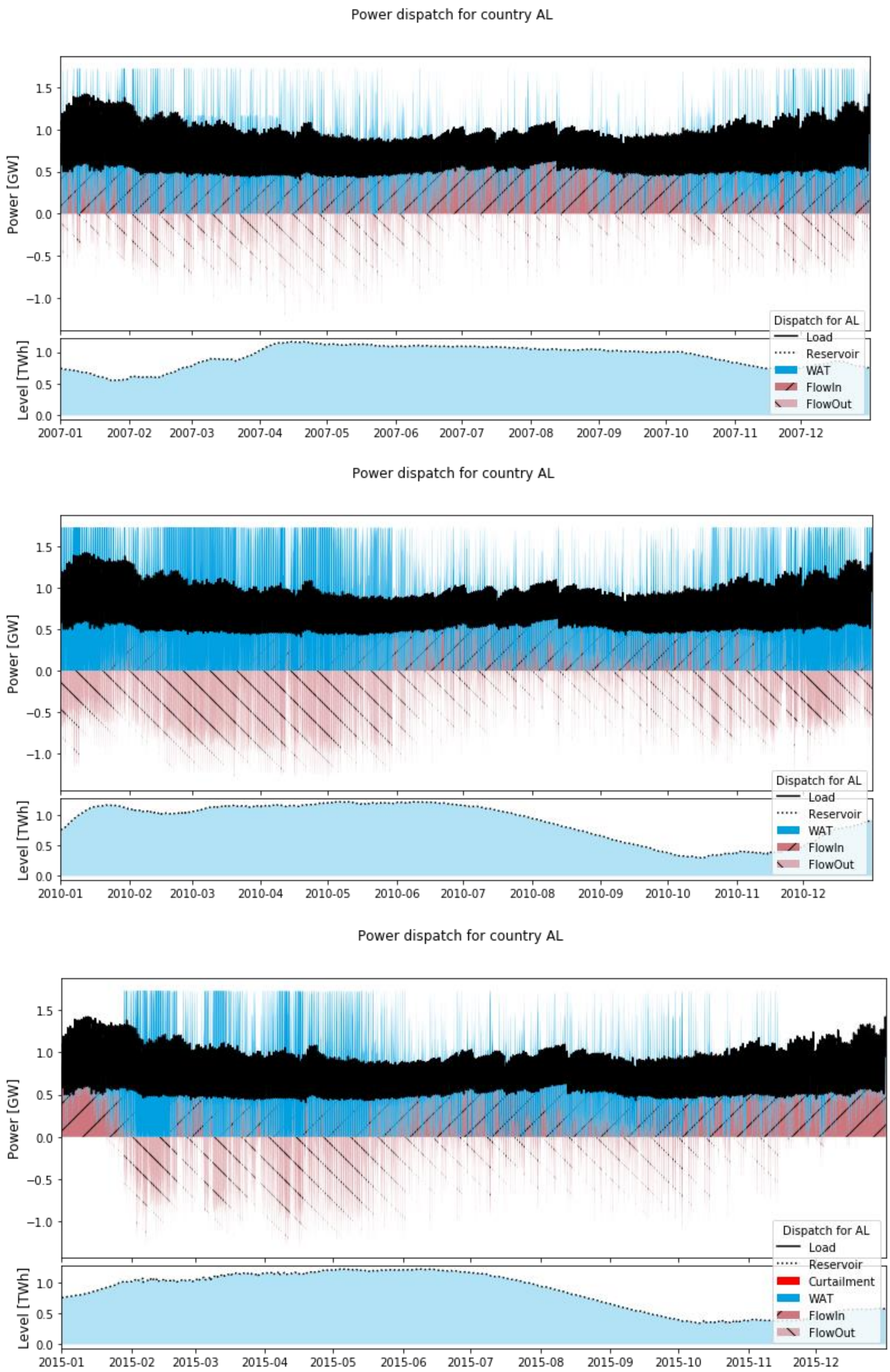
Power flows

The power flow between simulated region and outer zones cannot be modelled endogenously, so it must be provided as exogenous input. Data for this study were obtained from the ENTSO-E Transparency Platform (ENTSO-E Transparency Platform, 2018), (Dispa-SET Balkans, 2019) and (Quoilin and Kavvadias, 2018).

Annex 4: Power dispatch

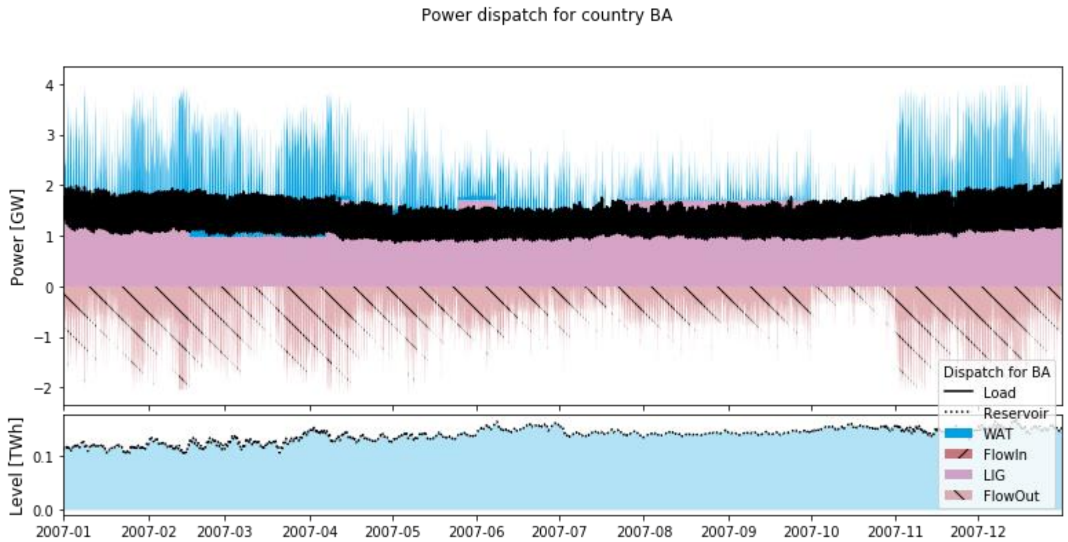
Albania

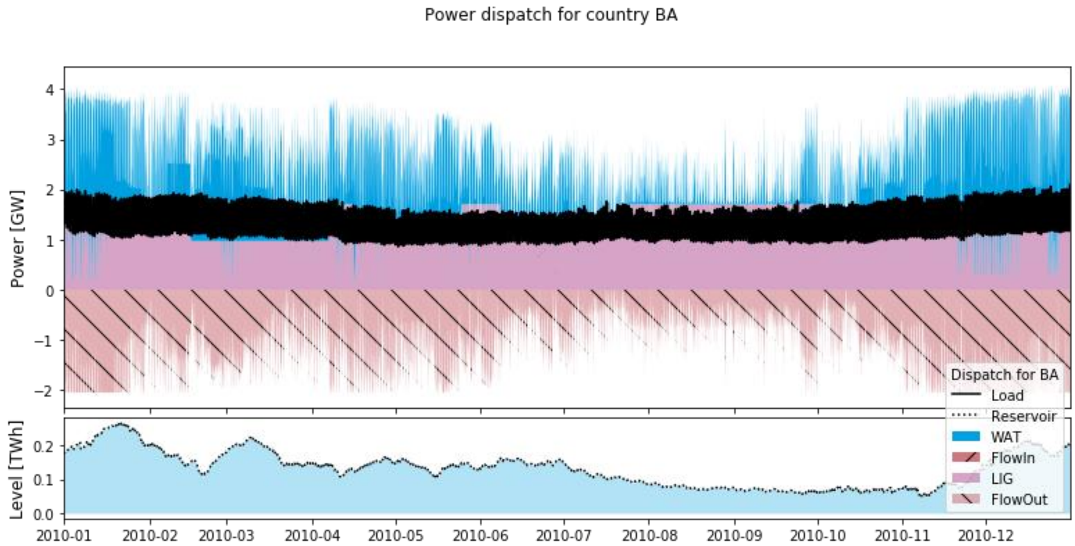
Figure 43. Power dispatch for Albania

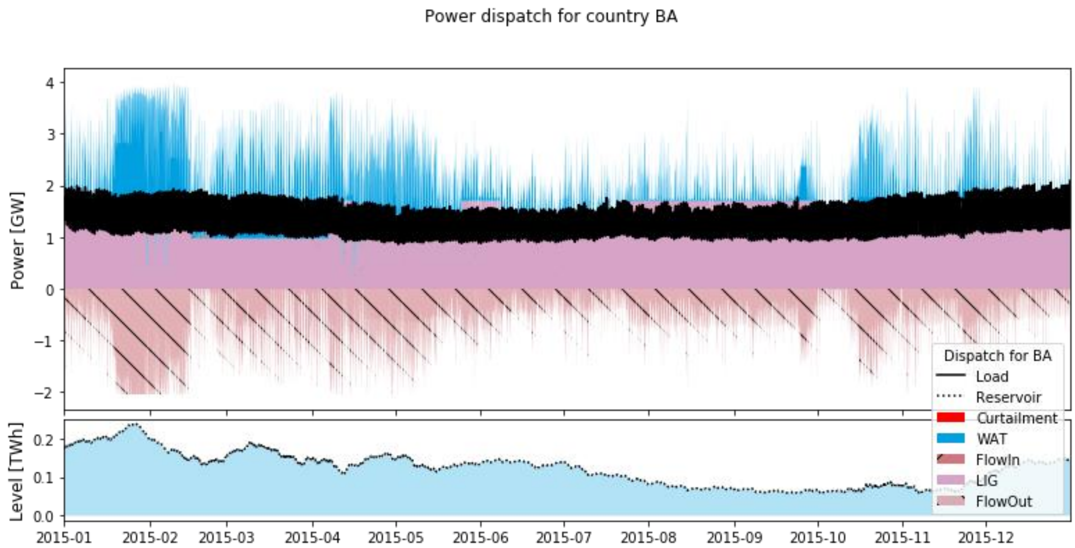


Bosnia and Herzegovina

Figure 44. Power dispatch for Bosnia and Herzegovina

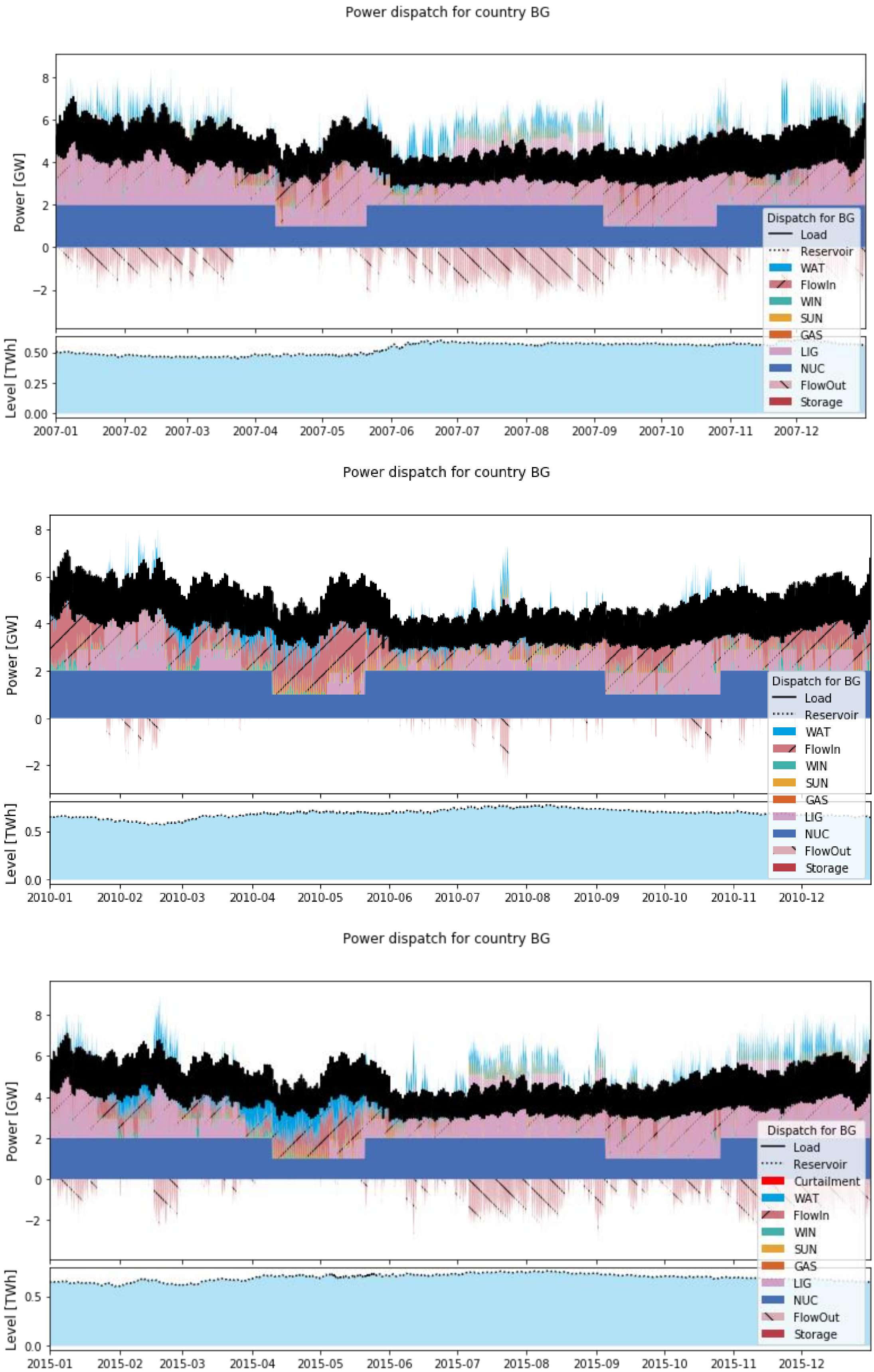






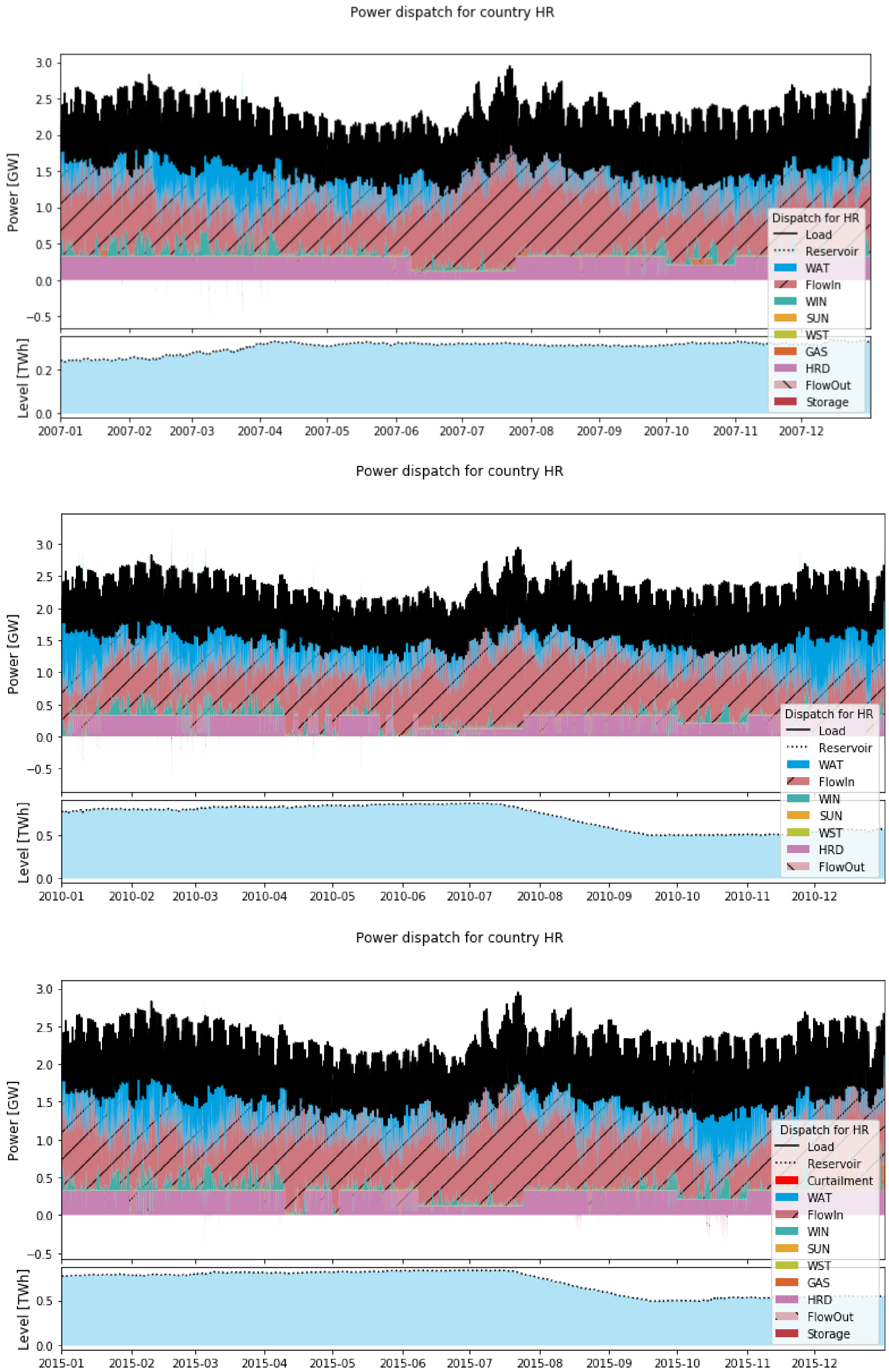
Bulgaria

Figure 45. Power dispatch for Bulgaria



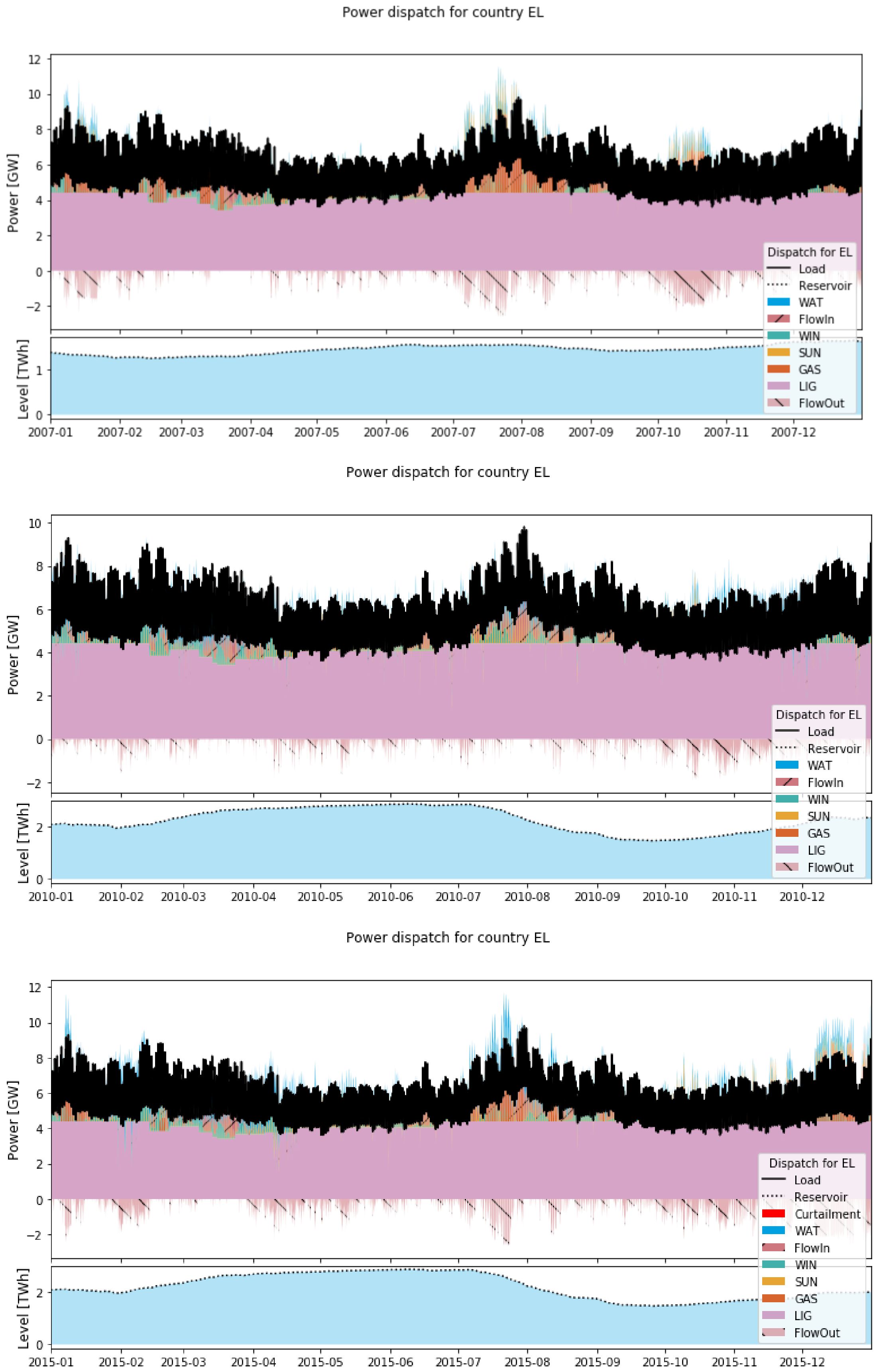
Croatia

Figure 46. Power dispatch for Croatia



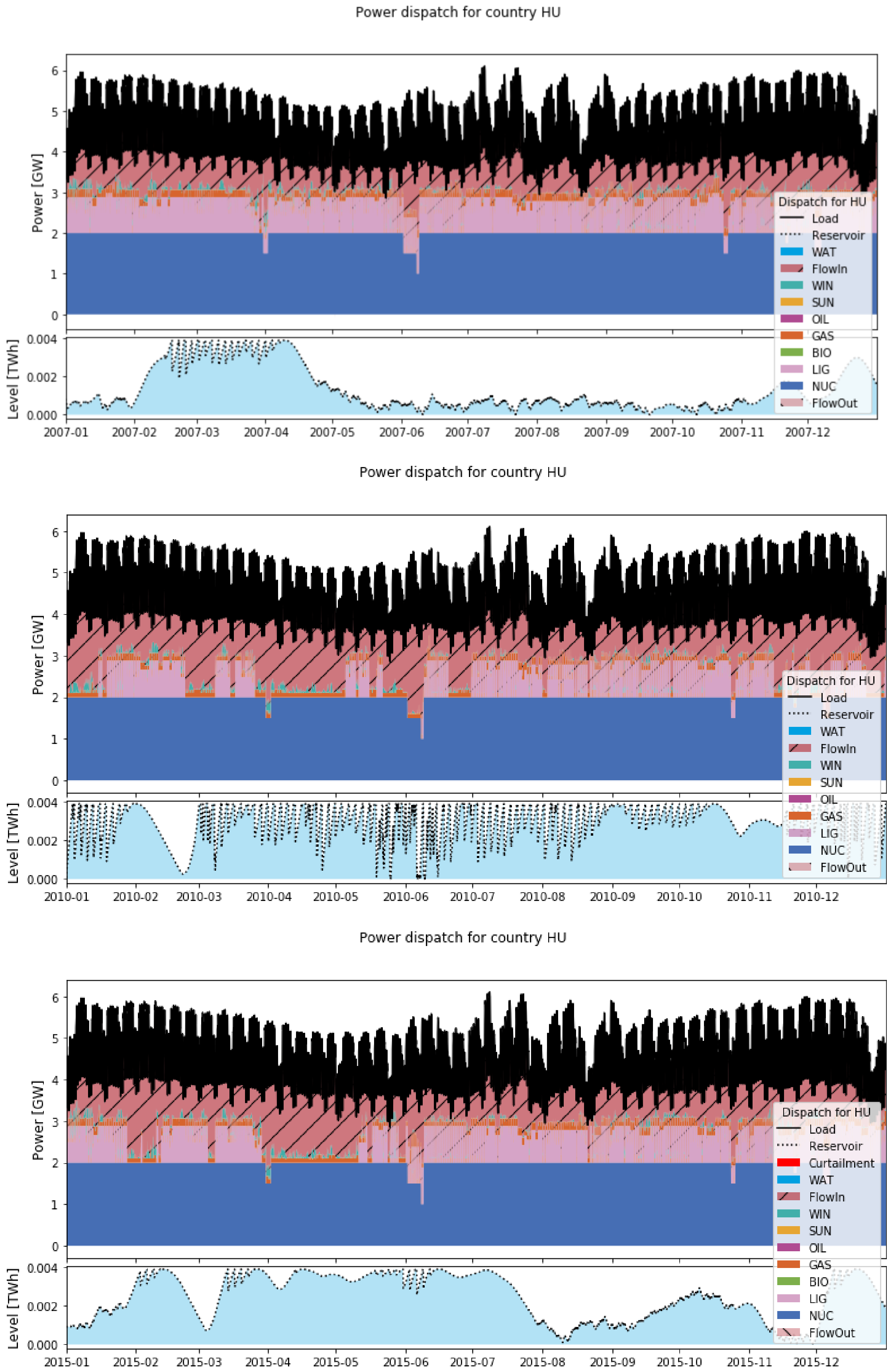
Greece

Figure 47. Power dispatch for Greece



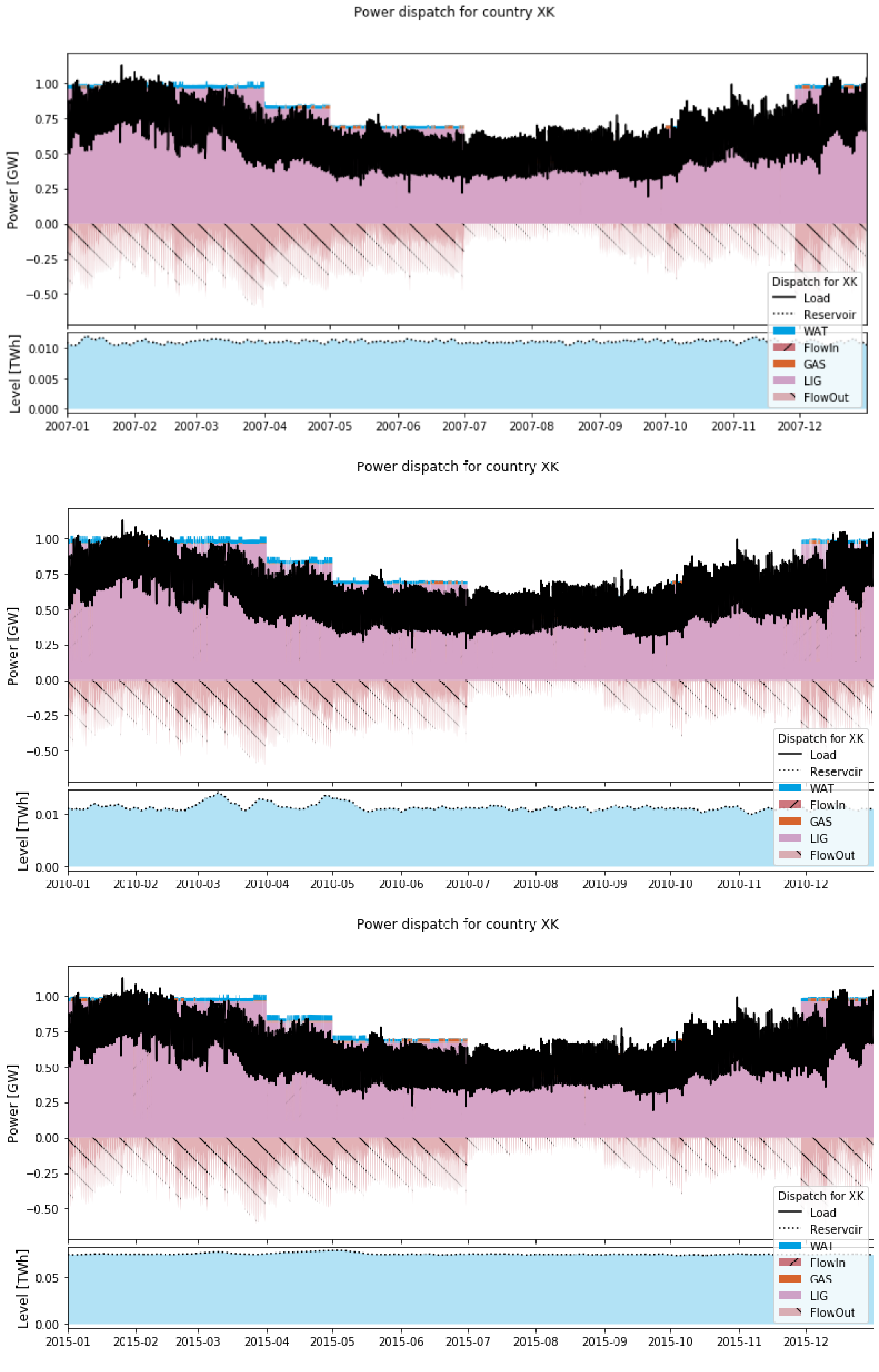
Hungary

Figure 48. Power dispatch for Hungary



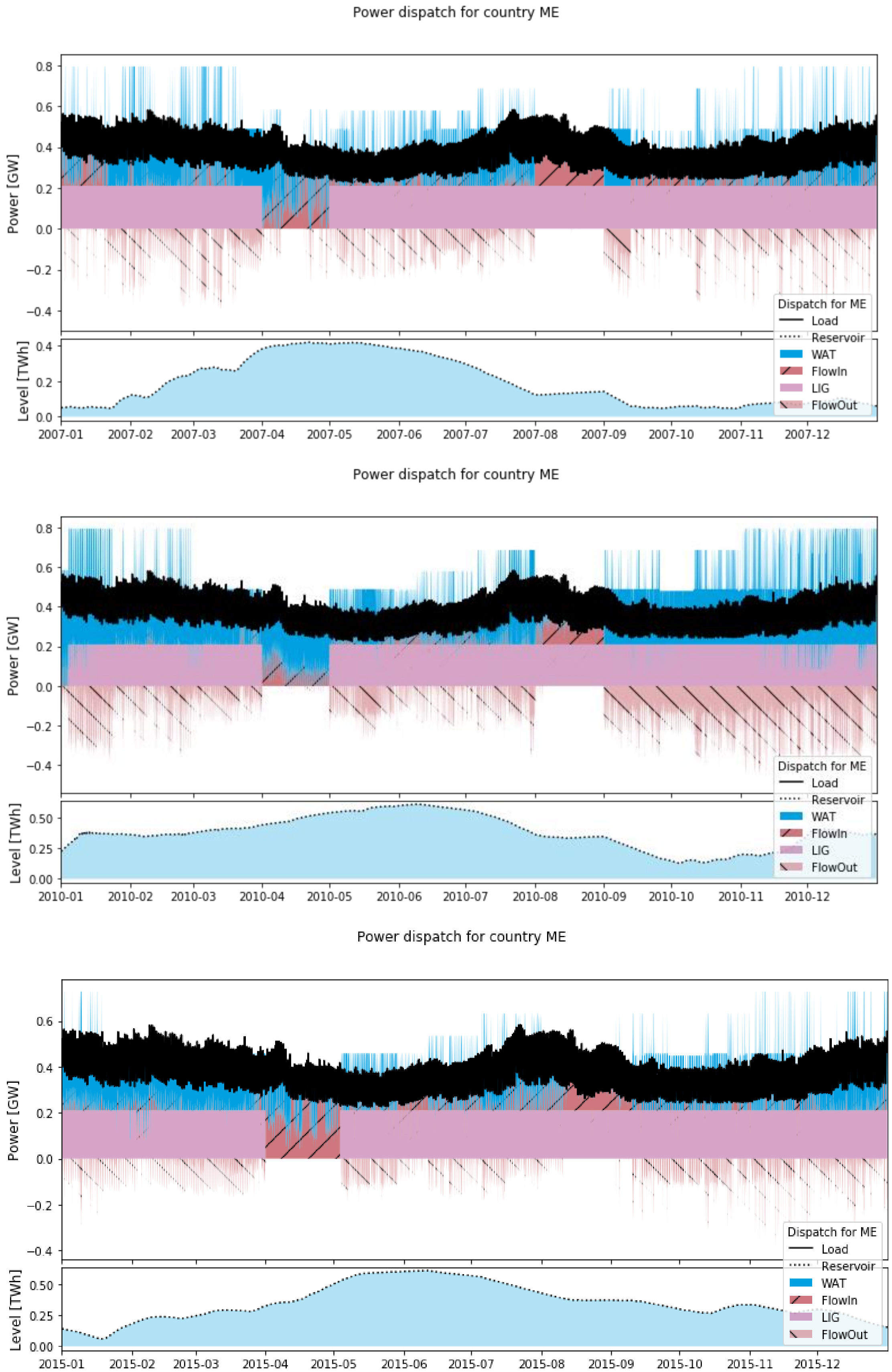
Kosovo

Figure 49. Power dispatch for Kosovo



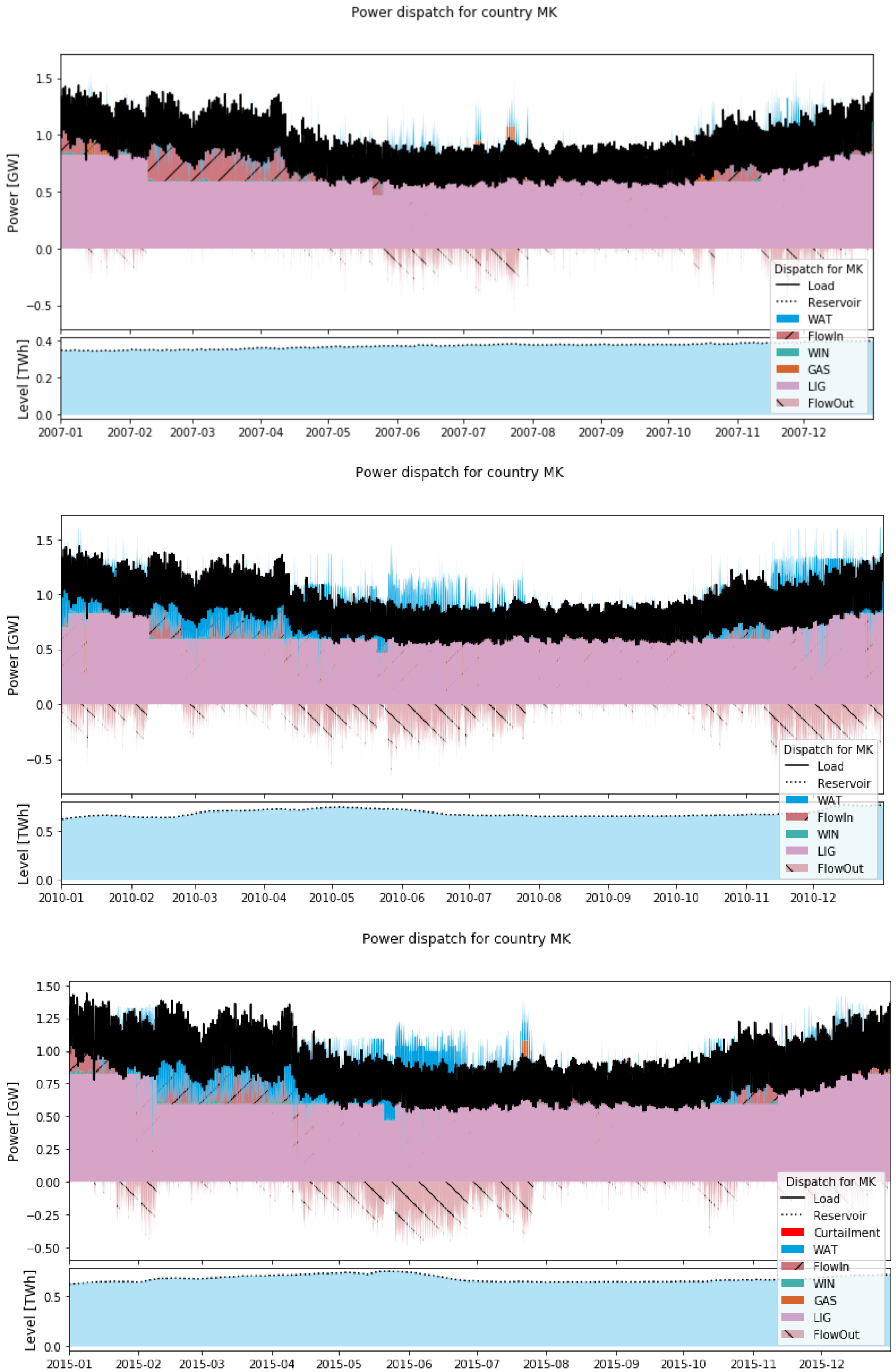
Montenegro

Figure 50. Power dispatch for Montenegro



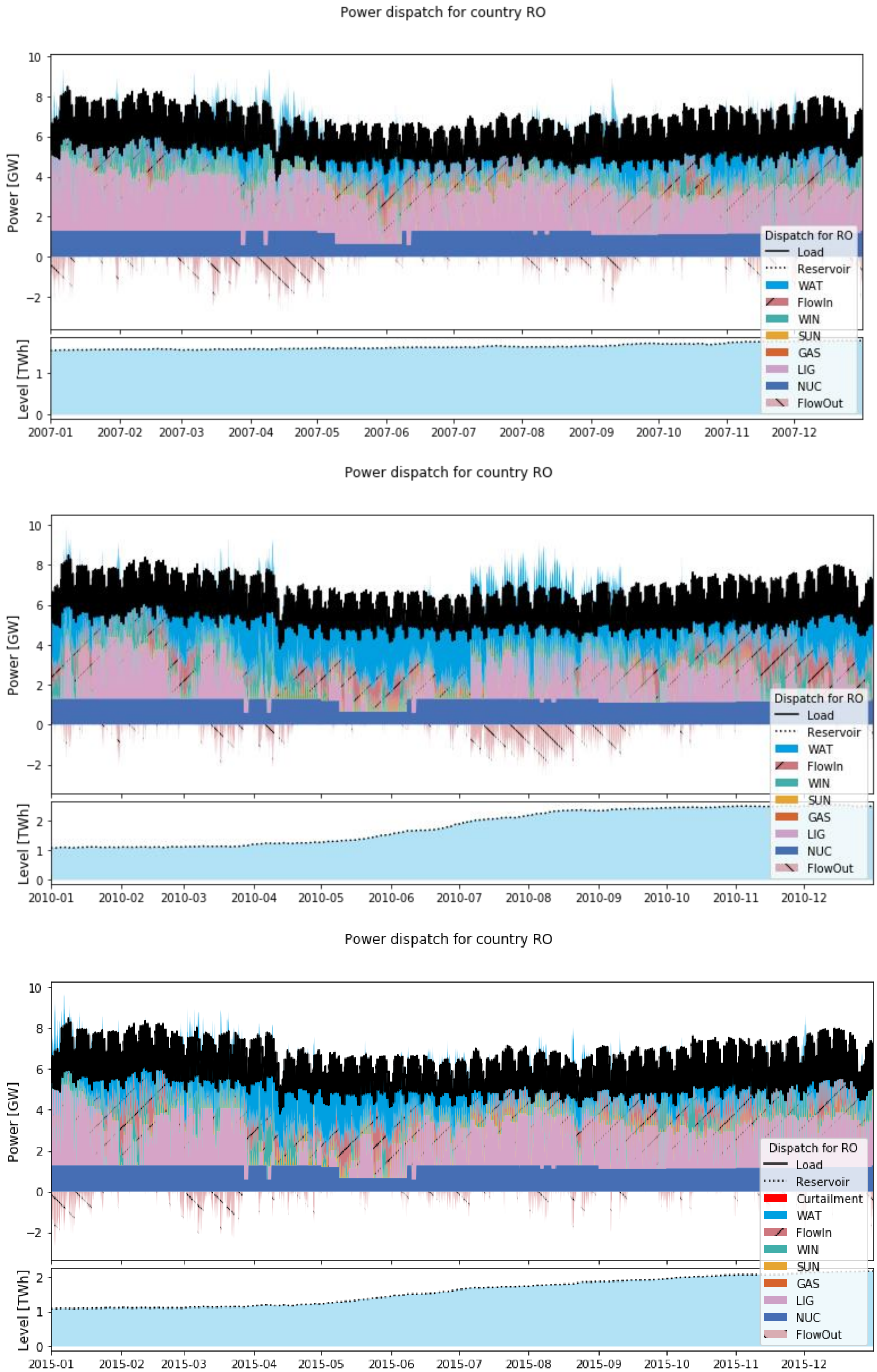
North Macedonia

Figure 51. Power dispatch for North Macedonia



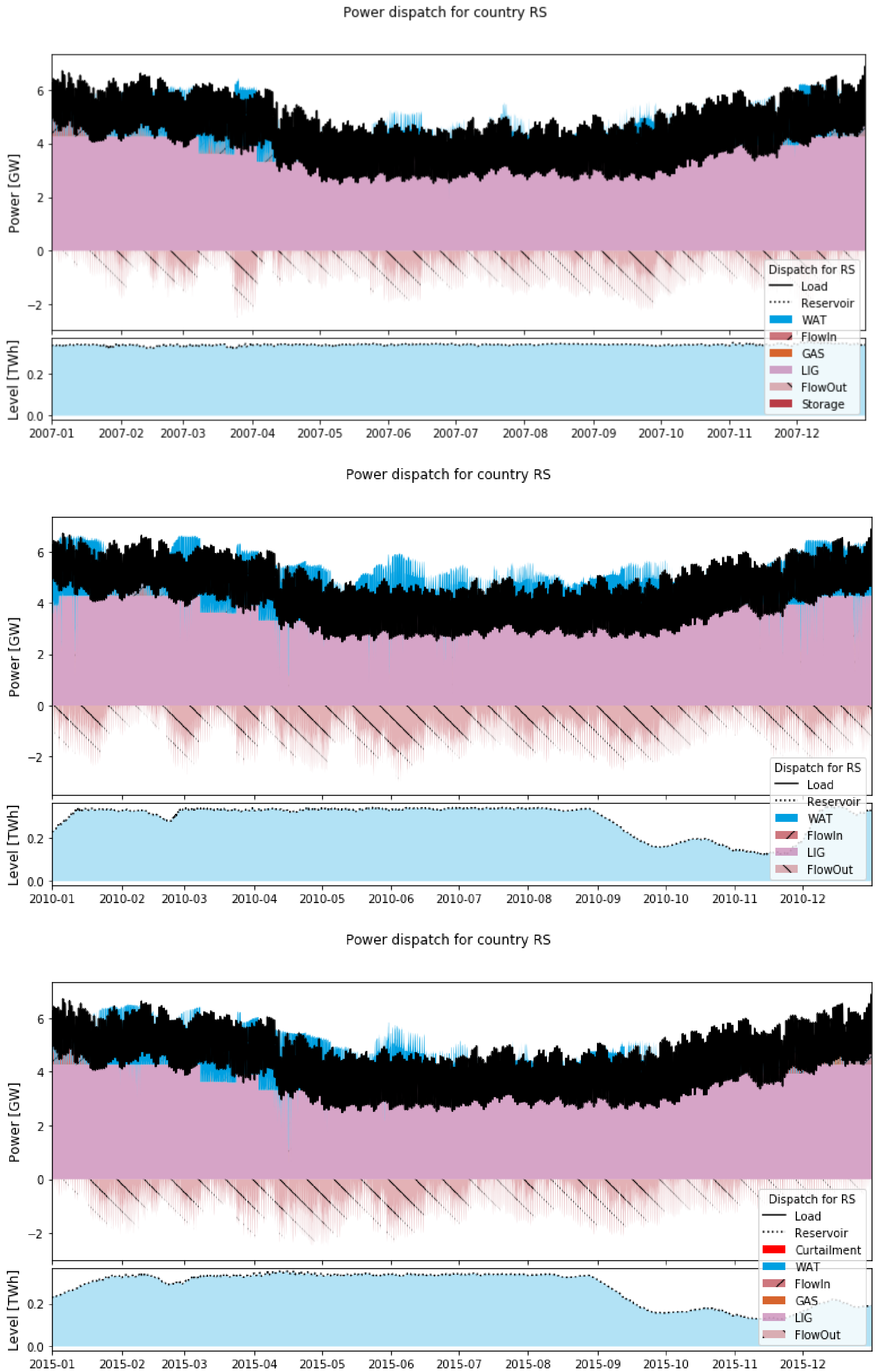
Romania

Figure 52. Power dispatch for Romania



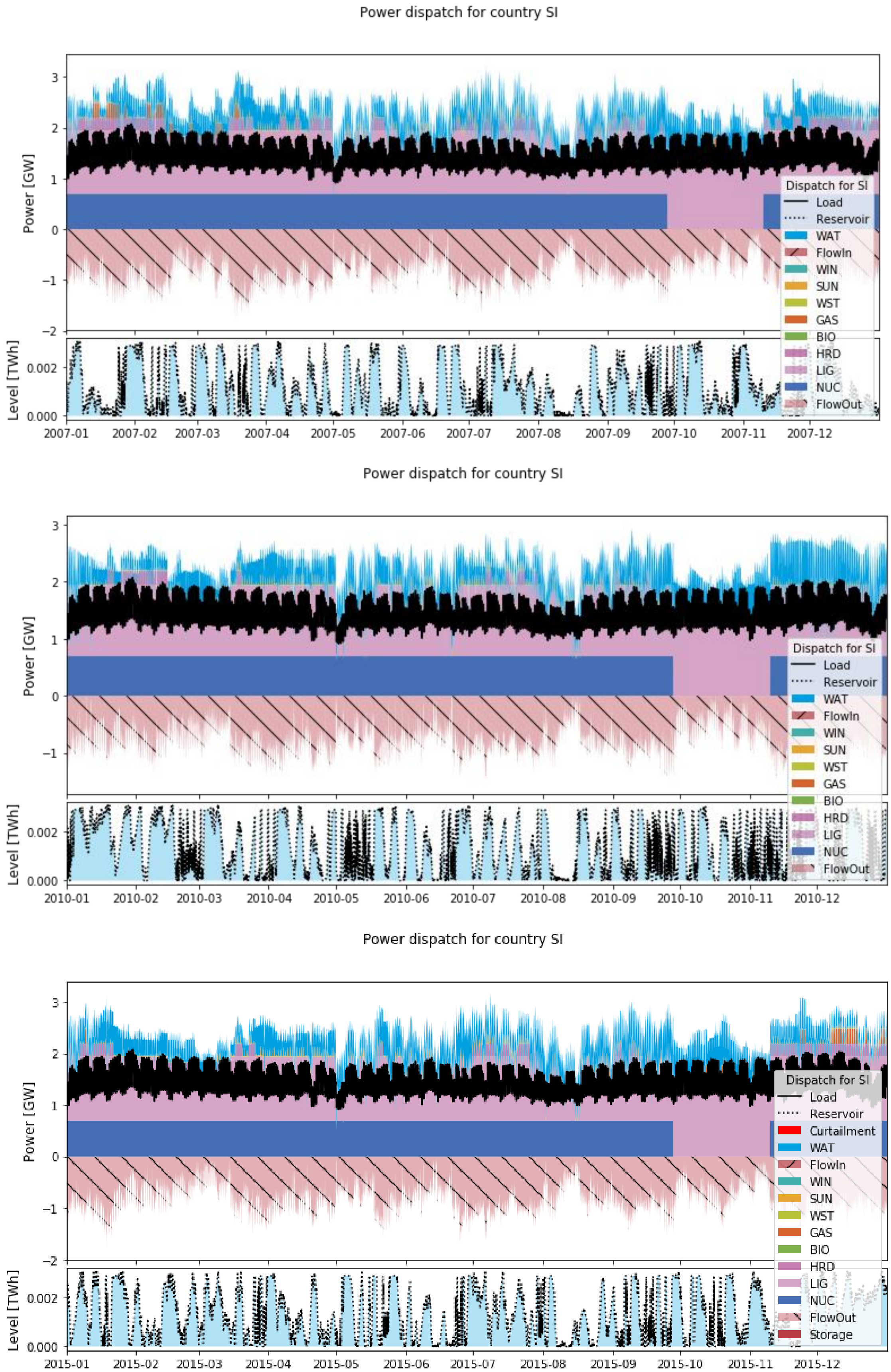
Serbia

Figure 53. Power dispatch for Serbia



Slovenia

Figure 54. Power dispatch for Slovenia



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