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The role of energy-water nexus to motivate transboundary cooperation: An indicative analysis of the Drina River Basin

Youssef Almulla1*, Eunice Ramos[1], Francesco Gardumi[1], Constantinos Taliotis[1], Annukka Lipponen[2] and Mark Howells[1]

[1]*KTH Royal Institute of Technology, Brinellvägen 68, 100 44 Stockholm, Sweden*
[2]*The United Nations Economic Commission for Europe (UNECE), Bureau S411, Palais des Nations, 1211 Geneva 10, Switzerland*

ABSTRACT

Low-carbon hydropower is a key energy source for achieving Sustainable Development Goal 7 - sustainable energy for all. Meanwhile, the effects of hydropower development and its operation are complex - and potentially a source of tension on Transboundary Rivers. This paper explores solutions that consider both energy and water to motivate transboundary cooperation in the operation of hydropower plants (HPPs) in the Drina River Basin (DRB) in South-East Europe. Here the level of cooperation among the riparian countries is low. The Open Source energy Modeling System-OSeMOSYS was used to develop a multi-country model with a simplified hydrological system to represent the cascade of HPPs in the DRB; together with other electricity options, including among others: energy efficiency. Results show that improved cooperation can increase electricity generation in the HPPs downstream without compromising generation upstream. It also demonstrates the role of inexpensive hydropower to enhance electricity trade in the region. Implementing energy efficiency measures would reduce the generation from coal power plants, thereby mitigating CO_2 emissions by as much as 21% in 2030 compared to the 2015 levels. In summary, judicious HPP operation and electricity system development will help the Western Balkans reap significant gains.

Keywords:

Energy-Water Nexus;
Transboundary Cooperation;
Hydropower;
Drina River Basin;
CLEWs;
OSeMOSYS;

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1. Introduction

Improving cooperation in the management of transboundary waters has been an important goal in the international community for decades. Bilateral and regional agreements on transboundary waters have been in place for more than 100 years [1] with more than 400 treaties adopted to manage transboundary rivers and lakes [2]. Since 1948, about 295 international water agreements have been negotiated and signed [3]. The Convention on the Protection and Use of Transboundary Watercourses and International Lakes "Water Convention" was adopted in 1992 and entered into force in 1996 [4]. However, around two-thirds of the world's transboundary rivers lack a cooperative management framework [3].

The analysis of individual systems such as energy and water is undertaken routinely [5] and is often focused only on a single resource [6]. In the early 1970s, some aspects of integrated system thinking were introduced in the study *The Limits to Growth* by [7]. Around the same time, a second study focused on connected resources: water, energy, land, materials and manpower (WELMM) [8].

Further noticeable studies were introduced in the last two decades such as [5], [6], [9], and in 2011 the Bonn Nexus conference took place [10], where the nexus approach was presented as an integrated assessment

[1]Corresponding author - e-mail: almulla@kth.se

framework that supports the transition to green economy [11]. The Climate, Land-use, Energy, Water systems (CLEWs) framework was also introduced to study conflicting objectives and identify synergies and trade-offs between sectors which otherwise may not be revealed [12]. While the definitions and scoping of nexus analysis vary, it is often presented as the integration of multiple sectoral elements of energy, water, and food production within an overarching governance approach [13].

The nexus approach is broader than established 'integrated' sectoral policy approaches, such as Integrated Water Resource Management (IWRM)[i]. The latter considers all water uses and the energy sector is an important water user [15]. However, energy is also used to pump and supply water. Thus, in times of water shortage, the energy system can be strained to reduced hydropower production, this is in turn compounded as energy demand for water pumping can concurrently increase. This and other phenomena are not captured without considering both water and energy systems scenarios simultaneously [16]. This typically falls outside of the scope of (Integrated Resource Planning) IRPs for electricity [17] or IWRMs for water management. Water as well as electricity and energy carriers often "flow" across State borders and developments in water and energy infrastructures have transboundary impacts, making cooperation crucial. If either water or energy can bring together the basin countries to look at both sectors together, cooperation could potentially provide a broader set of benefits.

In September 2015, the United Nations (UN) General Assembly declared the 'Sustainable Development Goals (SDGs). Out of the 17 SDGs, this work is focused on three of them, namely SDG6, 7 and 17. SDG 6 aims at ensuring availability and sustainable management of water and sanitation for all. It has clearly highlighted the importance of transboundary cooperation in the sustainable management of water and sanitation in target 6.5[ii]. Hydropower is a key low cost (affordable) renewable energy technology (RET). RET is needed to achieve SDG 7, specifically target 7.1 on universal access to affordable, reliable and modern energy service and target 7.2 on increasing the share of renewable energy in the global energy mix. Since SDGs can not be achieved independently. SDG 17 aims at strengthening global partnership and its target 17.14 focuses specifically on enhancing policy coherence for sustainable development [18] to integrate different dimensions of sustainability in policymaking in a balanced way.

Furthermore, in 2016 the Paris agreement on climate change was signed [19]. This agreement requires all countries to contribute to the mitigation of Greenhouse Gases (GHG) emissions by bringing forward their Nationally Determined Contributions (NDCs) and to strengthen these efforts in the years ahead. Again, the importance of RET and thus hydropower is underlined.

The United Nations Economic Commission for Europe (UNECE), under the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention), conducted several assessments of the "water-energy-food-ecosystem nexus" on transboundary water basins such as: Alazani/Ganykh, Syr Darya, Isonzo/Soča and Sava river basins [20]. Among other benefits, these efforts led to the development of the Transboundary River Basin Nexus Approach (TRBNA) [16], which will be used in this study to zoom into the Sava river's main tributary – the Drina River. (An analysis for the broader Sava river basin is forthcoming [21]). This approach employs 'nexus dialogues' between different stakeholders in the study area in the form of workshops, bilateral meetings and online exchanges of information [22]. These happen at various stages of the study. The workshops bring together representatives from water, energy, agriculture and environment sectors coming from ministries or NGOs or utilities. Each sectoral representative sketches scenarios for that sector's development. Draws and impacts on other sectors are identified. From these an integrated picture is developed and then quantified in a nexus assessment (and modelling effort). Stresses plus opportunities (due to the linkages between sectors) are jointly identified and solutions co-created. Additionally, the interactions with stakeholders facilitate data collection and/or suggest reasonable assumptions and finally, the findings of the nexus assessment are consolidated through these dialogues.

1.1. The Drina River Basin (DRB)

The Drina River Basin (DRB) is located in Southeast Europe and has a surface area of 20,320 km^2 [23][iii] . The Drina river is formed by the Piva and Tara rivers, both flowing from Montenegro and converging at the border with Bosnia and Herzegovina to form the Drina river, which continues flowing northwards to feed into the Sava river as shown in Figure 1 [25]. The DRB is almost evenly distributed between three of the four riparian countries. It covers the northern half of Montenegro (32% of the river basin), part of the east of Bosnia and

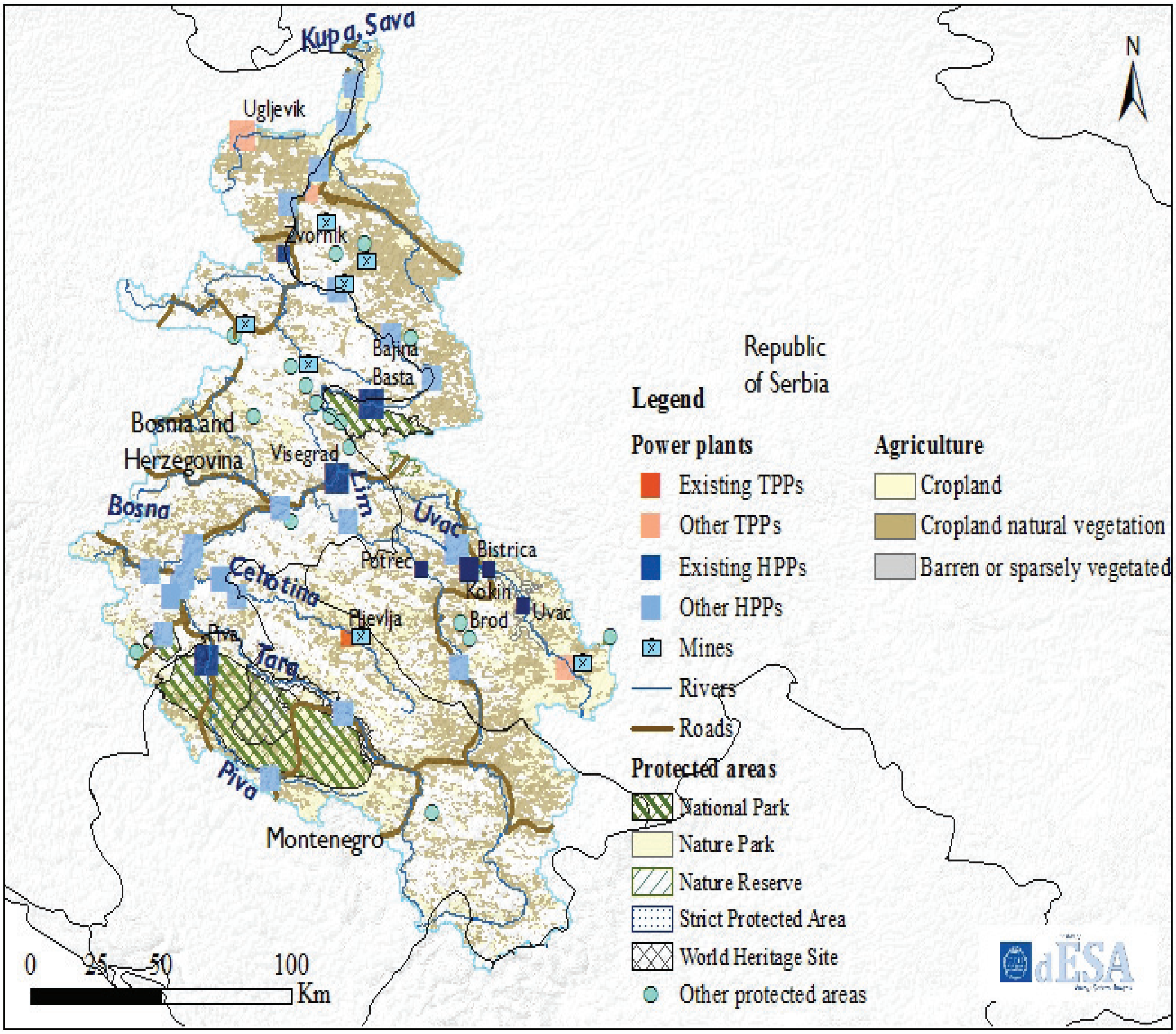

Figure 1: Map of the Drina River Basin (DRB) showing the key nexus overlap between energy, land-use and agriculture [27]

Herzegovina (36% of the river basin), part of the west of Serbia (31% of the river basin) and a very small part of the north of Albania (less than 1% of the river basin area) [26]. This study will focus on the first three riparian countries only.

The hydropower system in the DRB was built between the 1960s and 1990 [25] when the countries were part of the former Socialist Federal Republic of Yugoslavia. The operation of the HPPs system was planned and managed so to work in an optimised manner, with the flow regime controlled to minimise impacts of lower and higher flows attenuating natural extremes [28]. This coordination was not maintained after the breakup of Yugoslavia, and there is currently low (or rather, informal and not institutionalised) cooperation among the countries on the operation of HPPs in the DRB. Flow regulation is sub-optimal because most HPPs in the basin mostly operate independently [29] rather than being coordinated through a single entity or arrangement that coordinates the operation of all HPPs between various operators. Effective regulation of river flow through reservoir operation and scheduled water releases can secure appropriate ecological flows, therefore minimising the impacts of low flows (in dry seasons) and provide flood protection (in wet seasons) [25]. This is unfortunately not the case in the DRB, where the uncoordinated operation of HPPs has a negative impact on the river flow by imposing a fluctuating flow regime along the river. This fluctuation affects water availability and electricity generation in the HPPs downstream, which became more vulnerable to both lower and higher flows. Moreover, there is an urgent need to mitigate the risk of floods [30], and the uncoordinated operation of the hydropower plants with significantly associated reservoir capacity may cause or aggravate high water levels.

In addition to the ecological flow regulations, the European Fish Directive [31], [32] aims to protect and improve the quality of fresh water. This is to protect fish and wildlife habitat from sudden and large fluctuations in water temperature. The directive differentiates between two types of fresh water, salmonid water and cyprinid water, and sets different limits on each type to regulate thermal discharge from thermal power plants to the river. Such limits can curtail thermal power plants output, especially during droughts – or times of high ambient and river temperatures. The curtailment of thermal power plants generation due to thermal discharge constraints can result. This can increase the demand for hydropower generation, which, in seasons of low water availability, would put the security of supply at risk. Based on this, a recent study suggests the importance of relaxing these constraints in extreme weather conditions (i.e. hot droughts) to secure electricity supply [33]. The full coordination of cascaded hydropower plants through the smart management of reservoirs discharges has the potential to regulate flow and temperature of rivers and may significantly reduce the need for curtailments of thermal generation in extreme weather conditions [34]. The benefits may be magnified if such coordination is allowed on the transboundary level. (Typically control and thus coordination can be at national or utility level).

Electricity trade plays an important role in the DRB countries and in the Balkan region in general. The creation of a regional electricity market among Western Balkan countries, Contracting Parties of the Energy Community, is one of the priority clusters of the EnC Treaty [35]. Additionally, the regional market development is foreseen to be integrated into the Pan-European electricity Market [36]. Given the high share of electricity generation by hydropower plants, these play a key role in determining the electricity trade potential of each country in the Drina sub-basin. Furthermore, the level of export is related to the quantity of energy used domestically by each country and will, therefore, be affected by actions aimed to improve energy efficiency.

1.2. Aims and objectives

This paper gives an example of implementing the TRBNA to support cooperation in transboundary water management and electricity generation using the case study of the Drina River Basin (DRB). Through this approach, informed by the nexus dialogue with stakeholders in the basin, several nexus issues have been identified [26]. Selected issues are addressed in the paper by the use of a modelling framework, with the aim to achieve the following specific objectives:

1) Quantify the benefits of optimised production from the hydropower plants in the DRB through enhanced cooperation;
2) Explore the impact of cooperation on the generation output of hydropower plants and on electricity trade between the DRB countries and neighbouring countries;
3) Investigate the impacts of the implementation of (additional to 1&2) energy efficiency measures on emission mitigation and achieving the countries NDCs.

The modelling framework is meant to provide long-term insights on the impacts and benefits that would derive for the countries in the river basin if cooperation and energy efficiency were to be enhanced. It is not intended to suggest specific short-term operational decisions by the power plant operators or new regulations, which are left to the relevant decision makers. Currently, such decision makers consist of the regulatory authorities of each country, since much of the electricity system is controlled by state-owned.

2. Methodology

2.1. OSeMOSYS

The Drina River Basin Energy-Water Model was developed for this analysis using the Open Source energy MOdelling SYStem (*OSeMOSYS*), which is a bottom-up long-range energy system optimisation tool [37]. It includes the whole electricity system, from demand to supply and trade. It dynamically determines the electricity generation mix (in terms of technology portfolio and electricity generation) which minimises the net present cost of electricity generation over the entire modelling period, considering constraints related to resource availability, electricity demand, capacity adequacy and production limits. Specific resource availability limits are introduced to simulate water constraints. In previous studies [38],[39],[40], water constraints have been introduced in OSeMOSYS but as exogenous model inputs. This study employs a water balance to replicate a simplified ‘hydrological’ model that is introduced for the first time in OSeMOSYS.org, and for the first time in any model application in the basin. Several studies have been carried out on the basin power plants. Most studies, however, considered smaller parts of the Drina basin and certain selections of power plants [41],[42],[43] or focused on hydrological aspects only [37],[43],[45]. There is no study that investigates the long-term impacts of energy and water nexus considering all HPPs in the DRB using the method applied here.

The aforementioned objectives of this analysis can only be achieved if the full electricity system of the three riparian countries is modelled rather than a simplified representation of the power plants in the basin only, and that is mainly due to to the facts that:

1) All the hydropower plants in the basin are linked to the electricity grid in each of the three riparian countries and contribute to meeting the electricity demand on a country level. Hence, any changes in the operation of the hydropower plants will affect the national supply system[iv] and, vice versa, any increased electricity demand can probably cause extra stress on the hydropower plants in the basin.
2) Electricity trade opportunities can be seen in the national context. Since there is no basin level electricity trade market, the DRB contributes to the surpluses that can be traded in each country on the national level.
3) Energy efficiency measures are related to national targets and affect the overall electricity system and are not limited to the basin level.

2.2. Model structure

The Drina River Basin Water Energy Model developed for this nexus analysis consists of two main systems: the 'electricity system' and a simplified 'hydrological system'. The first system is the most common model type generated by 'OSeMOSYS model generator', focusing primarily on energy. It does not capture hydrological characteristics [46] such as water balance in different parts of a river. Therefore, the second system is introduced in this analysis to allow for water balance accounting along the cascade of the existing hydropower plants in the Drina river basin.

The '*electricity system*' was derived from a previous multi-country modelling effort of the electricity systems of the countries sharing the Sava River basin developed by [47] and used in the transboundary nexus assessment of the Sava River basin [38] as well as a forthcoming paper [21]. It represents the electricity system of each riparian country from primary resources to power supply technologies, transmission and distribution networks down to the final electricity demand. The model is essentially constituted by so-called 'technologies' and 'fuels'. The technologies represent any (aggregated or not) process transforming one energy carrier into another. The fuels represent the energy carriers flowing between technologies. For example, coal flows from a resource technology at the primary level to a thermal power plant to generate electricity at the secondary level with a certain efficiency. In turn, the electricity flows to the transmission and distribution network (with associated losses) to meet the final demand as shown in Figure A 1 of Appendix A. As far as the power supply technologies are concerned, all thermal power plants are aggregated by type of fuel they use. They are however split between country and within each country, they are split between power plants inside and outside the Drina river basin. Non-hydro renewable power plants, namely solar, wind and biomass are included in the model as indicated in the National Renewable Energy Action Plans (NREAP) of each country [48], [49], [50]. Hydropower plants in the three countries are considered in the model as will be described in the 'hydrological system'. Finally, the interconnections between the countries sharing the basin and those with other countries are represented in the model as shown in Table A 5. Each power supply technology is characterised by economic, technical and environmental parameters (such as capital costs, variable and fixed operating costs, efficiency, emission rates, input and output fuels, availability, maximum load factors, etc.) which are user-defined. Most of the parameters fed to the model are time-dependent and can be adjusted over the time domain of the study, which extends from 2017 to 2030. Detailed modelling assumptions and technology inputs are given in Appendix A.

The '*hydrological system*' represents the Drina River (downstream) and its main tributaries (upstream): Uvac, Lim, Piva, Tara and Ćehotina as shown in Figure 2. In this system, water flows from an upstream tributary (or river segment), it passes through a reservoir and a HPP and it reaches the downstream river (or river segment). When a dam is present in a certain part of a river, it is allowed to fill up the reservoir. Inflows are a function of upstream water runoff, extraction of upstream HPP and dam operation. They generally depend on the season. Outflows are a function of over-flows, other discharges and associated HPP operation. Historical data from gauging stations [51] are used to calculate the average

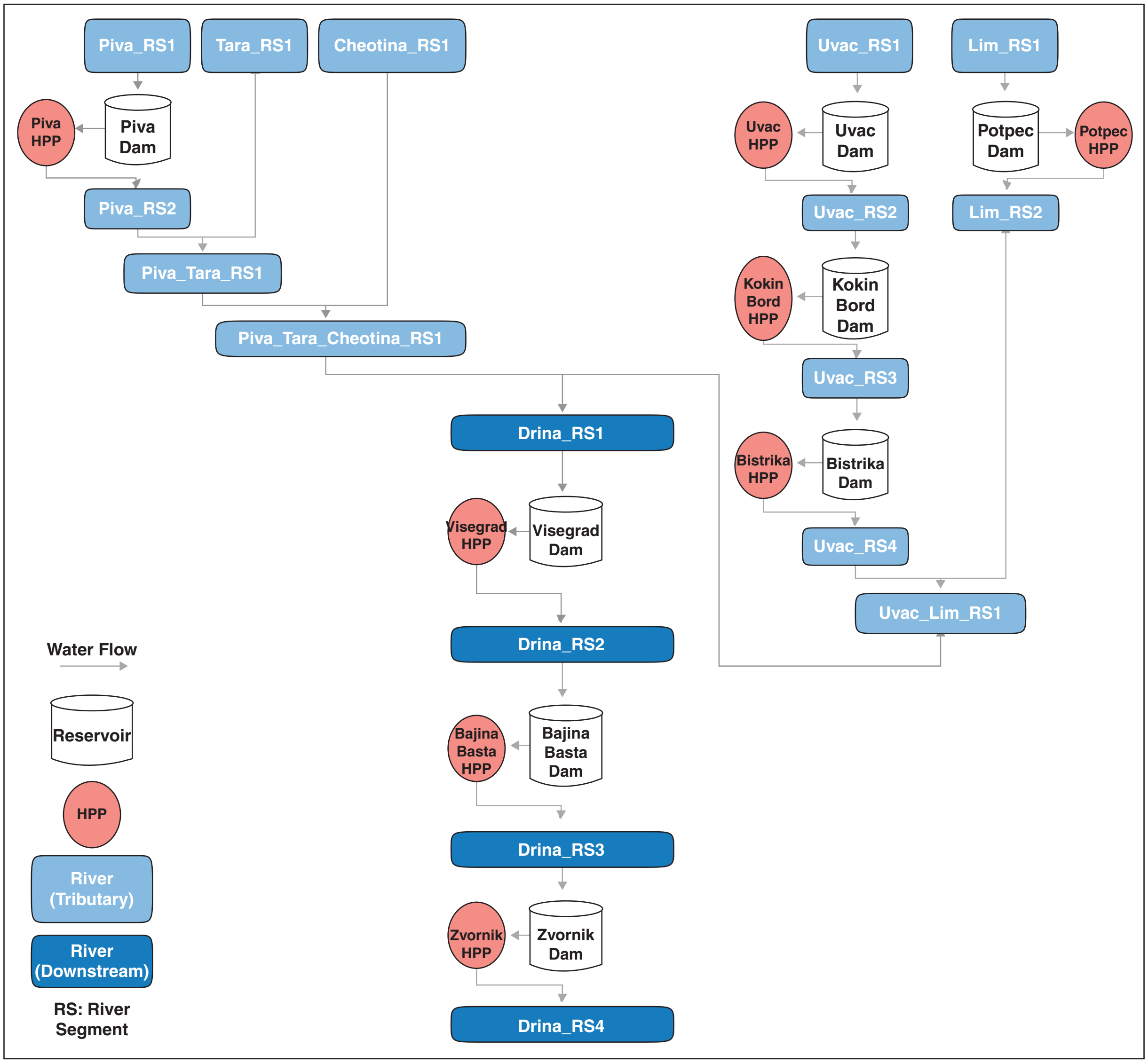

Figure 2: Schematic representation of the Hydrological system of the Drina River Basin Water-Energy model

and maximum annual discharge in each tributary and segment of the river system. Interpolation is done wherever data were missing from hydrological stations (see Table A 7) to derive the values for the missing river segments. Minimum environmental flow levels were respected in all scenarios and at different segments of the river based on data provided by the observatory commission, the International Sava River Basin Commission (ISRBC) [52] as shown in Table A 9. The average and maximum annual discharges were used in the model to constrain the water availability in each segment of the river.

The connecting elements between the electricity and water systems in the model are the HPPs. They form a part of both the water balance (as water passes through them when they operate) and the electricity balance (as when they operate electricity is fed onto the grid as one of several suppliers, used to meet domestic and export and demand requirements). The model computes the electricity generation from each HPP respecting the mass balances of water passing through the turbine and generating electricity, based on the following correlation:

$$E = P\ t;$$
$$P = p\ q\ g\ h$$

Where: E = Energy (GWh), P = power (GW), t=time (h), p = density (kg/m$_3$) (~ 1000 kg/m^3 for water), q = water flow (m^3/s), g = acceleration of gravity

(9.81 m/s^2) and h = head (m), assumed constant in this study and equal to the difference between reservoir height and the Dead Storage. This is an important simplification. And while it is used in several applications such as [54], it should be revisited in future work.

The electricity system takes the hydrological system as a constraint and computes the optimal scheduling of (i) existing and new capacity of both hydro and thermal power plants to meet the electricity demand; while simultaneously (ii) managing the mass balance of water along the rivers and within the dams. Hence, by providing limited insight into simultaneous operation aspects of both the energy and water system, elements of the water-energy nexus are explicitly included OSeMOSYS. The mass balance of water is computed in OSeMOSYS for different river segments and for each of the reservoirs based on water inflow and outflow at the location of interest.

The Drina basin hosts about 1700 MW[vi] of hydropower capacity from the three countries [26] (see Figure A 3 for an overview of the installed capacity in the three countries). Since the focus of the study is on the existing HPPs in the Drina river basin, the eight major existing hydropower plants in the Drina river basin are represented individually and in cascade in the model (see Table 1). All the eight HPPs have dams and are used for electricity generation only. Their cumulative capacity reaches about 63% of DRB total hydro capacity. The rest 36% of hydro capacity consists of the Bajina Bašta Pump Storage HPP (PSHPP) with 614 MW, which is pumping water to the 'Laziçi' dam and reservoir from the small tributaries downstream 'Laziçi' [52] therefore its operation is not dependent on the water flow in the Drina river. Additionally, there is a number of small-scale HPPs (less than 10MW), with a total capacity of 25 MW (1% of the total capacity in the basin). The Bajina Bašta PSHPP, the small-scale HPPs as well as all of HPPs outside Drina basin are modelled in a simplified fashion (as run-of-river HPPs) due to their limited dependence on the water flow in the study area, the DRB.

The three countries of the DRB have plans to expand their hydro capacity and utilise the untapped potential in the DRB. However, there is high uncertainty about the implementation of these future projects [27]. Provisions for these potential new hydropower installations are added in the model, which is allowed to decide if investment in new hydro capacities would be cost optimal for the overall energy and water system of the three countries.

Table A 8 shows the list of future power infrastructure projects considered in this study.

2.3. Scenario description

In order to achieve the objectives of this study related to the quantification of the impact of enhanced cooperation and energy efficiency measures, a range of scenarios was developed. These were developed based on available information on the status in the DRB derived from literature and nexus dialogue with stakeholders:

1) *Base scenario (BASE)*. Corresponds to a Business as Usual scenario and describes what may happen if the current status of low cooperation between countries continues in the next decade. Historically, the operation of the upstream Piva power plant took limited consideration of the impact on downstream power plants. However,

Table 1: List of reservoirs and hydropower plants cascaded in the hydrological system of the Drina River Basin Water Energy model [52],[55],[56]

Name	*River*	*Reservoir size (MCM)*	*Installed Capacity (MW)*	*Country**	*Location with respect to Drina River*
HPP Uvac	*Uvac*	*213*	*36*	*RS*	*Upstream*
HPP Kokin Brod	*Uvac*	*250*	*22*	*RS*	*Upstream*
HPP Bistrica	*Uvac*	*7.6*	*102*	*RS*	*Upstream*
HPP Potpec	*Lim*	*27.5*	*51*	*RS*	*Upstream*
HPP Piva	*Piva*	*880*	*360*	*ME*	*Upstream*
HPP Visegrad	*Drina*	*161*	*315*	*BA*	*Downstream*
HPP Bajina Bašta**	*Drina*	*218*	*106*	*RS*	*Downstream*
HPP Zvornik	*Drina*	*89*	*96*	*RS*	*Downstream*

* **BA**: Bosnia and Herzegovina, **ME**: Montenegro and **RS**: Republic of Serbia.

** The rehabilitation of Bajina Bašta HPP increased the total capacity its four units in operation to 422 MW [57].

the flow regime in the entire Drina river is affected by the operation of Piva HPP [58]. It alters the amount and timing of water flow downstream. To simulate this, the base scenario imposes an arbitrary (from the point of view of the system) restriction on upstream HPPs. Based on discussions with stakeholders [48,52] it was decided to focus on the impact of Piva HPP since it has the biggest reservoir size and the highest impact on water flow in Drina river (compared to others upstream). The Piva reservoir was assumed to operate with minimum outflow to the rivers downstream for one month of the year, which simulates an extreme historical situation. During that time it does not alter its level to improve the operation of the cascading system. The downstream plants (and the rest of the power system) are operated in a cost-optimal manner to accommodate this 'independence' of Piva's operation. For the other eleven months of the year, the system is assumed to operate optimally.

2) *Co-Operation scenario* (*COP_REF*). This aims to show what differences arise (with respect to the Base scenario) in the least cost energy mix and operation profiles when a cooperative planning of the operation of all the hydropower plants in the basin is carried out. In this case, no power plant operates 'independently' and the operation profiles of all the hydropower plants are optimised, in order to guarantee the minimum discounted cost for the whole region along the time domain of the study. Again, the water balance along the cascade constrains the availability of water and the operational limits of the hydropower plants and the electricity trade is bound to historical levels.
3) *Increased electricity trade scenario (COP_TRD)*. This scenario has the same structure as the Co-operation scenario. Additionally, it explores the possibility for the three countries in the Drina river basin to magnify the benefit from cooperation in the operation of hydropower plants and low-cost electricity generation by improving interconnections and trade of electricity between them and with neighbouring countries.
4) *Energy Efficiency scenario (COP_EE)*. This scenario investigates the impacts of implementing energy efficiency measures on achieving the DRB countries NDCs. The electricity demand projections for this scenario are obtained from the National Renewable Energy Action Plans (NREAP) of each country [41,42,50]. The plans project electricity demand up to 2020, therefore the demand for the following period up to 2030 is estimated based on the average annual trend in electricity demand in the last five years (2016–2020) (see Figure A 2).
5) If energy efficiency measures are implemented in the electricity sector, NREAPs assume energy savings of 0.7 TWh for Bosnia and Herzegovina, 0.2 TWh for Montenegro and 3.2 TWh in Serbia by 2020, which correspond to between 4% and 8% reduction of gross electricity demand. The rest of the assumptions in this scenario are the same as in the Co-operation scenario. This scenario provides some insight related to deeper policy coherence, a target of SDG17.

3. Results and discussion

This section presents selected results from the scenario analysis. The first subsection compares the first two scenarios while the other subsections compare Scenarios 3 and 4 with Scenario 2.

3.1. Impact of cooperation among countries on the operation of dams in the Drina River basin

The comparison between the base scenario (*BASE*) and the higher-cooperation scenario (*COP_REF*) shows considerable cumulative electricity generation gains in the power plants downstream in the latter. Under the assumptions and the conditions of these scenarios (BASE and COP_REF), the analysis shows that the annual generation of Piva HPP remains unchanged[viii], but the monthly release/generation does change. The cooperative management allows for timely water availability for power plants downstream at the desired time, which leads to generation gains and optimal operation of the overall system. As shown in Figure 3, the cumulative electricity

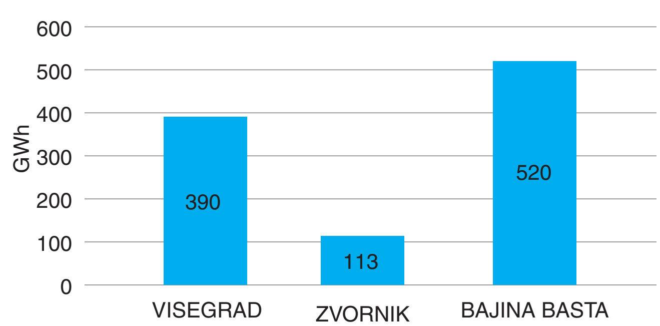

Figure 3: Cumulative difference in electricity generation (gains) between the COP_REF scenario and the BASE scenario for the hydropower plants downstream Piva in GWh.

generation gains between 2017 and 2030 in Bajina Bašta HPP can reach about 520 GWh, which is equivalent to 30% of its average generation in one year. In Bosnia and Herzegovina, Visegrad HPP can gain an extra 390 GWh cumulatively during the same years. The size of the reservoir (see Table 1) and its location along Drina River (see Figure 1 and Figure 2) cause the gains in electricity generation between the two scenarios to be different in different power plants downstream of Piva HPP. This is clear in the case of Zvornik HPP, which is further downstream in Drina River with smaller reservoir size. It has the least gains in electricity generation among others but still increases its generation by 113 GWh during the same time interval. In other words, the share of annual electricity gains to the annual power plant output would represent about 3.1% in Visegrad, 2.9% in Zvornik and 3.05% in Bajina Bašta.

3.2. Extended electricity trade opportunities in a cooperation scenario

In the BASE and COP_REF scenarios, the amount of electricity that can be traded between the countries is constrained to the historical recorded maximum values between 2008 and 2014 [60]. In the cooperative scenario with extended trade *(COP_TRD)*, the model is allowed to increase the amount of electricity trade between the countries by up to 40%. This increase is allowed gradually from 2022 to 2025 and maintained thereafter. The representative value of 40% constitutes an assumption[ix], to provide sensitivity about the potential increase in electricity generation and therefore cooperation between the countries. Since the model is a cost optimisation model, the actual level of trade expansion will be decided based on its cost-effectiveness (noting that marginal generation costs are determined endogenously for the three countries considered).

Comparing the electricity trade profile between the historical limits and the extended trade under the *(COP_TRD)* scenario (Figure 4), it can be noticed that all countries tend to increase the amount of electricity traded, which highly depends on low-cost electricity surplus produced from hydro and coal. The ratio between hydro and coal in this increase depends on how flexible hydropower plants are in increasing their operation levels. The contribution of non-hydro renewables to the increased trade opportunity is expected to be marginal in all the countries if their penetration is not assumed higher than the NREAP targets. Bosnia and Herzegovina will continue to be mainly a net exporter of electricity, to Montenegro and Croatia.

In the case of Serbia, the massive hydro and coal potentials can play an important role in increasing export opportunities from 2021 onward. However, this growth in exports is affected by the decommissioning of 'Kostolac' coal power plant in 2027 (1135 MW - installed in 1967) which could create a steep-decrease in the net export level by roughly 4 TWh (15 PJ).

Montenegro increases both electricity import and export during the same period. The planned 415 km 1 GW high voltage DC cable connecting Montenegro with Italy will increase Montenegro's trade potential [49].

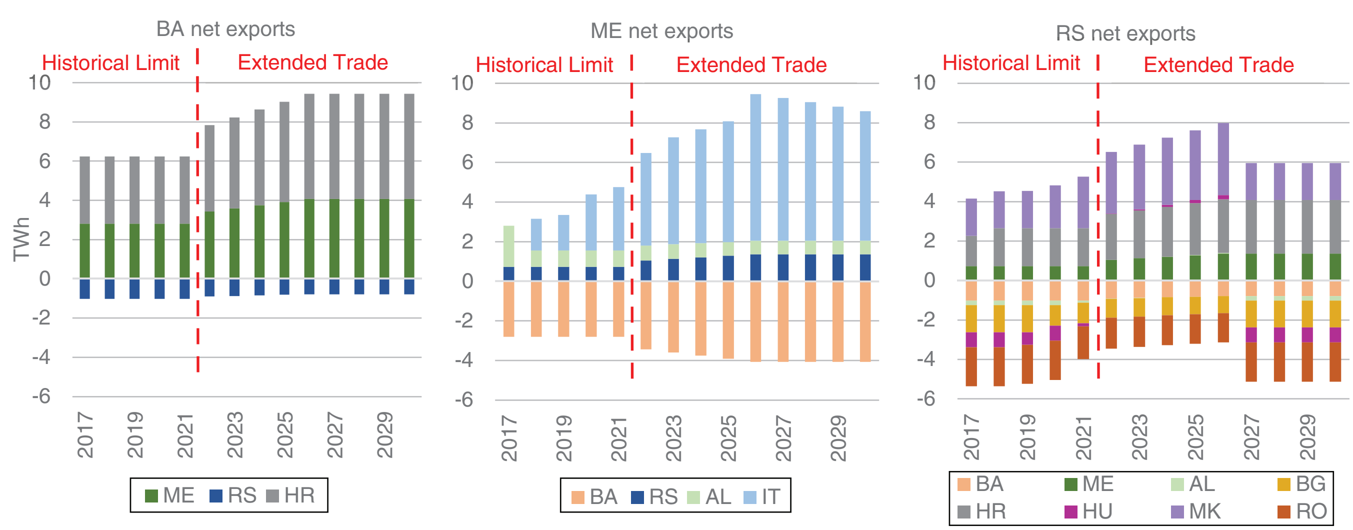

Figure 4: Trade profile for the three countries in the Drina Basin under the cooperative extended trade scenario (COP_TRD) [AL: Albania; BA: Bosnia and Herzegovina; BG: Bulgaria; HR: Croatia, HU: Hungary; IT: Italy; ME: Montenegro; MK: Macedonia; RO: Romania; RS: Republic of Serbia]

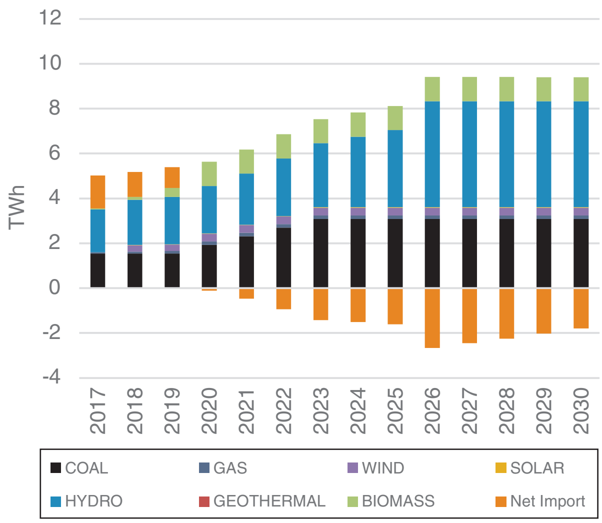

Figure 5: Electricity generation mix of Montenegro under the cooperative trade scenario (COP_TRD) from 2017 to 2030

Furthermore, this interconnection facilitates potential electricity flows from other countries to Montenegro and then to Italy. This is seen in Figure 4 as increased trade between the three countries. This outlook is in line with the National Renewable Energy Action Plan of Montenegro [49] as well as with Trans-Balkan corridor project [61]. The latter shall enhance the connectivity of internal networks of Montenegro, Serbia, and Bosnia and Herzegovina as well as their transnational interconnectivity. It is worth mentioning that, under the assumed conditions of this study, Montenegro has the opportunity to shift from a net electricity importer to a net exporter after 2020 (see Figure 5). This is conditional to increasing the generation from inexpensive hydro and coal and the exploitation of biomass and wind potential - as noted in the NREAP.

3.3. Impact of energy efficiency measures on hydropower and thermal generation on the national level and in the Drina river basin

The implementation of energy efficiency measures and the consequent reduction in final electricity demand result in reduced thermal (mainly coal) power generation in the three countries. The overall decline in thermal production in the three countries becomes clearer from 2021 onwards (see red dashed line in Figure 6) when electricity savings become more significant, to reach the level of 7 TWh by 2025 and 8 TWh by 2030 as shown in Figure 6. The decommissioning of 'Kostolac' coal power plant in 2027 causes a steep decrease in thermal production in both *COP_REF* and *COP_EE* scenario.

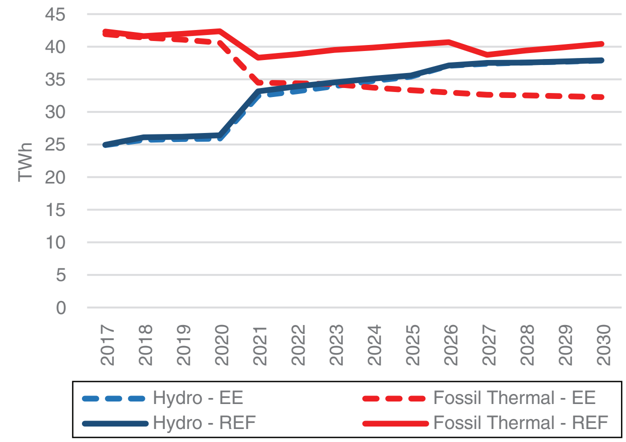

Figure 6: Electricity generation in the energy efficiency and reference scenarios for the three countries of DRB (*in TWh*) from 2017 to 2030

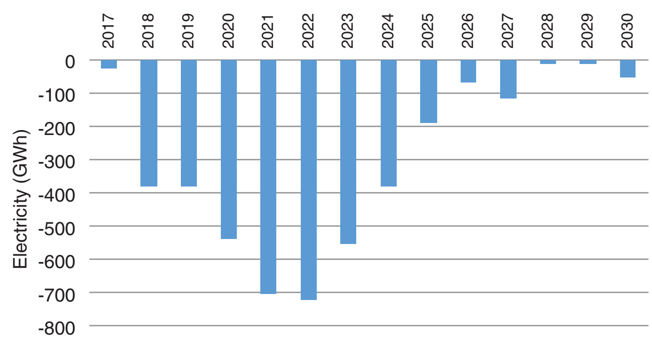

Figure 7: Absolute difference in hydro production in the three countries between Cooperative Energy Efficiency *(COP_EE)* and Cooperative Reference *(COP_REF)* scenarios

The reduced demand will also slightly decrease the pressure on hydropower plants, which will decrease their generation by about 700 GWh in 2021 and 2022. In other words, the reduced demand will delay investments in new hydro projects, especially in Bosnia and Herzegovina. From 2023 on, hydropower will increase again to generate up to its maximum possible capacity in both scenarios, offsetting thermal production and allowing meeting the national electricity demand as shown in Figure 7.

Zooming into the DRB, the profile of electricity generation between the two scenarios looks different from the profile on the three-country level. As shown in Figure 8, the contribution of hydro generation inside DRB is higher than thermal generation in both scenarios. The implementation of the energy efficiency measures is expected to have a small impact on reducing the stress on both sources of electricity. In the case of hydro, only slight decrease will be achieved between 2020 and 2022;

however, this reduced demand is enough to delay the investments in the first phase of middle Drina HPP (Dubravica, Tegare and Rogacica) from 2020 in the *(COP_REF)* scenario to 2022 in the *(COP_EE)* scenario.

In the case of thermal generation, the savings will appear later between 2027 and 2030. The decom missioning of 'Kostolac' coal power plant in 2027 will cause a drop in thermal production outside DRB, which will increase the thermal generation inside DRB to compensate for this drop and meet the high electricity

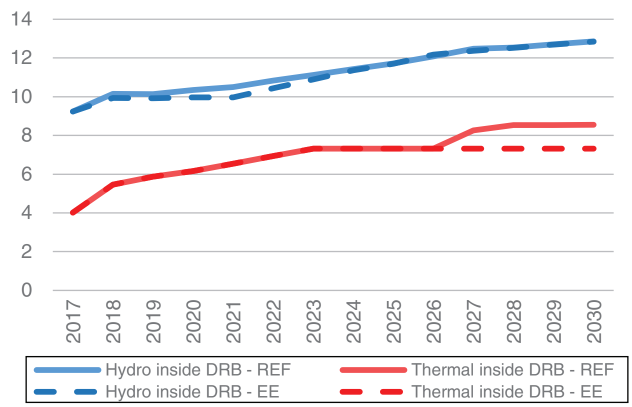

Figure 8: Electricity generation between the energy efficiency and reference scenarios inside the DRB (in TWh) from 2017 to 2030

demand of the *(COP_REF)* scenario. However, in the *(COP_EE)* scenario the decommissioning of 'Kostolac' will not drive higher thermal generation from the DRB due to low electricity demand in this scenario.

Coal-fuelled electricity generation is the main source of emissions from electricity sector; therefore any decline in coal-fired generation is obviously followed by a decline in CO_2 emissions in the region. This contributes to achieving the NDCs[xii], which aim at reducing GHG emission by 2030 (compared to 1990 level) by 2% , 9.8% and 30% for Bosnia and Herzegovina, Serbia and Montenegro respectively [63]. Figure 9 shows a comparison between the generation of electricity from different sources (thermal, hydro and other non-hydro renewables) under the cooperative reference scenario *(COP_REF)* and the cooperative with energy efficiency measures scenario *(COP_EE)*. It also shows the total CO_2 emissions (in million tons) of all three countries from 2017 to 2030. As shown in graph (b), CO_2 emissions drop from 38 Mt in 2017 to about 28 Mt in 2030, which corresponds to mitigation of about 21% of total CO_2 emissions across the three countries in 2015. Comparing the two scenarios, it can be noticed that the implementation of the energy efficiency action plans is expected to reduce the emissions from about 35 Mt by 2030 in the *(COP_REF)* scenario to about 28 Mt by 2030 in the (COP_EE) scenario.

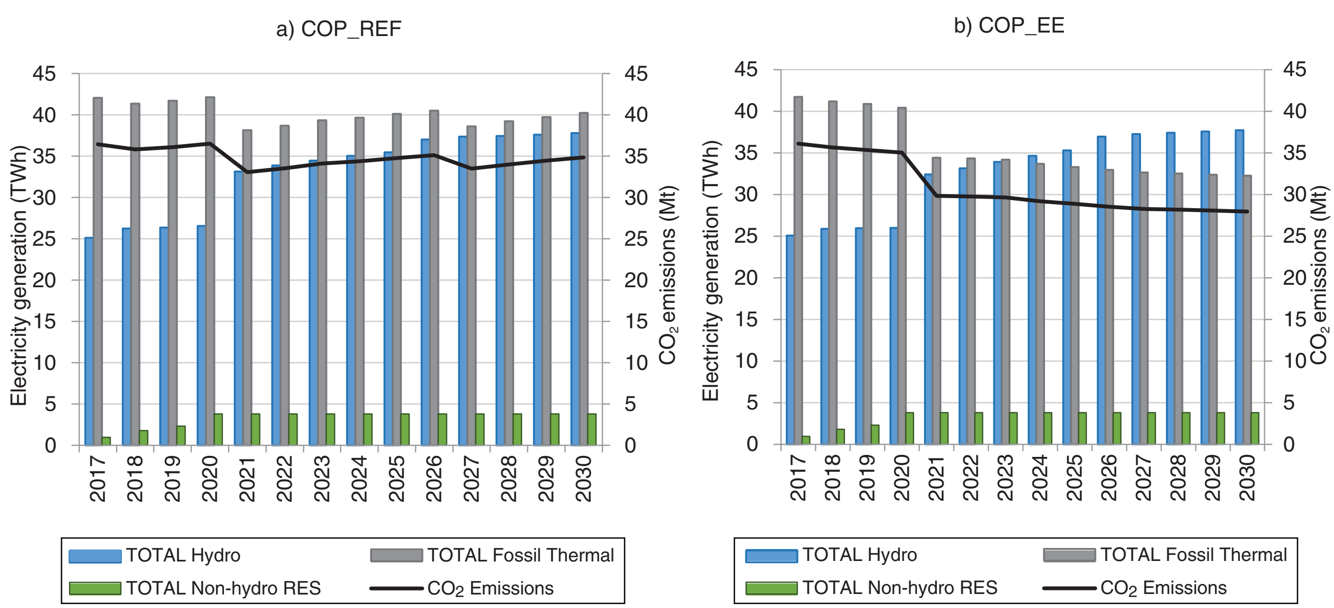

Figure 9: Comparison between a) cooperative reference scenario *(COP_REF)* and b) cooperative with energy efficiency measures scenario *(COP_EE)* in term of CO2 emissions and electricity generation from thermal, hydro and Non-hydro renewables. Results aggregated for the three countries in the Drina basin

4. Conclusions

The electricity generation in the Drina Basin depends heavily on water management and flow regulation. The study focused on the potential benefits deriving from increased transboundary collaboration in the operation of hydropower plants, increased interconnections between the countries and energy efficiency measures to reduce the electricity demand.

As a first outcome, the analysis demonstrates that improved cooperation in hydropower plants operation along the Drina river basin could lead to increasing the annual production of hydropower plants downstream without affecting the output of those upstream. This signifies that the benefits and possible formalisation of coordination would merit investigation. In addition to improving the legislative framework to support the coordinated operation, the development of information exchange, involving possibly the establishment of information systems between power plants along the river basin and across national boundaries would seem beneficial.

As a second outcome, if the coordination were to be agreed upon and formalised, the benefits of cooperation could be multiplied by development plans and investments in the electricity transmission network. The analysis shows how the increased hydroelectric production could unlock the potential for international trade, within and outside the three riparian countries. However, in the local policy context, the trade-offs related to further development of hydropower would need to be weighed against other objectives such as protection of ecosystems (environmental flows), flood risk management and other water uses notably agriculture whose water requirements are predicted to increase although the current use is low.

Finally, the analysis of the impact of energy efficiency measures in the end-use sectors shows interesting insights. The energy efficiency measures reduce the pressure on primary resources for energy supply (here mostly hydro and coal), while the improved cooperation in hydropower plants operation further improves their production, overall resulting in potentially increased availability of water for non-energy uses (e.g. agriculture). These benefits add to reduced GHGs emissions, which help the countries reach the NDCs. We note that sustainable energy (SDG7), GHG mitigation (SDG13) and policy coherence targets required for a global partnership (SDG 17) can be quantitatively analysed by developing a more integrated modelling framework.

The aim of this study to gain insights using hypothetical scenarios – rather than predict outcomes. The future is shaped by many uncertainties. Several factors affect the outcomes of this modelling effort – that are difficult to estimate. For example, the analysis shows it may be cost-optimal for the three countries to expand their electricity trade. However, this assumes that there is an efficient market shaped by well-crafted policy. In reality this might not be the case. For instance, there can be uncertainty associated with the future development of electricity prices. This could, in turn, be exacerbated if the three countries are exposed to the regional market due to increased transmission integration with other neighbours. Further, large exogenous price fluctuations (and local distortions) may arise from connection to a much larger market in Italy. Another source of uncertainty in the analysis is related to future expansion plans for hydro and other non-hydro renewables. Potential development of new dams and hydropower plants on the Drina River or its tributary may increase the uncertainty of water availability along the river, especially downstream. This would have energy gains but may result in economic and environmental impacts or affect other water users (i.e. agriculture) and such trade-offs should be weighed sensibly and consultatively on the national and transboundary levels. . The deployment of intermittent non-hydro renewables like solar and wind will require changes in the electric power grid [64], which will affect the operation of hydro and coal power plants to accommodate these changes. Those may have significant impact as HPPs may be used to supply balancing services to the grid – as they can often be rapidly turned on and off. Finally, predictable water flows on the Drina river and its tributaries were maintained as throughout the years modelled.

This aspect can be enhanced by having a variating volatile monthly water flow scheme. Such enhancement would allow to better assess the resilience of the system against volatile future weather and an on average drying climate and drought/flood peaks due to climate change.

These conclusions have supported an ongoing dialogue on Water and Energy nexus challenges, which brought together representatives of national governmental institutions and utilities of both energy and water sectors as well as the civil society in the three riparian countries. In the broader participatory assessment process, they also provided a starting point for identification jointly of actions to improve sustainable management of energy and water resource in the Drina river basin such as enhanced data sharing and cooperative operation strategies.

Improvements in the modelling framework and its database could further support the dialogues. Currently, the models of the energy system and of the hydrological system are both represented in OSeMOSYS, with the aim of providing a straightforward tool for scenario analysis and decision-making. However, more detailed indications for the hourly scheduling of the hydropower plants could be obtained by soft linking the energy system model created in OSeMOSYS with a hydrological system model designed in an ad-hoc tool and/or hourly dispatch model. The model considers environmental flow in all scenarios; however, it would be interesting to investigate the impact of power plants discharge temperature in the river. Furthermore, additional data from local institutions and electricity utility companies, particularly regarding site-specific technology costs and water availability data, will allow the current data gaps to be filled and the resolution of the results to increase.

Disclaimer

The views expressed in this article are those of the authors and do not necessarily represent the views of the United Nations or its Member States.

References

[1] Huisman, P., de Jong, J., & Wieriks, K. (2000). Transboundary cooperation in shared river basins: experiences from the Rhine, Meuse and North Sea. http://dx.doi.org/10.1016/S1366-7017(99)00023-9

[2] Wouters, P. (2013). *International law: facilitating transboundary water cooperation.* Stockholm: Global Water Partnership. Retrieved from http://www.gwp.org/globalassets/global/toolbox/publications/background-papers/17-international-law-facilitating-transboundary-water-cooperation-2013-english.pdf

[3] UN water. (n.d.). Transboundary Waters. Retrieved from http://www.unwater.org/water-facts/transboundary-waters/

[4] UNECE, United Nations Economic Commission for Europe. (n.d.). About the UNECE Water Convention. Retrieved August 10, 2017, from http://www.unece.org/env/water/text/text.html

[5] IAEA, International Atomic Energy Agency. (2009). Annex VI: seeking sustainable climate land energy and water (CLEW) strategies. Retrieved from https://www.iaea.org/About/Policy/GC/GC53/GC53InfDocuments/English/gc53inf-3-att6_en.pdf

[6] Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., … Yumkella, K. K. (2011). Considering the energy, water and food nexus: Towards an integrated modelling approach. Energy Policy, 39(12), 7896–7906. http://dx.doi.org/10.1016/j.enpol.2011.09.039

[7] Meadows, D. H., & Club of Rome (Eds.). (1972). *The Limits to growth: a report for the Club of Rome's project on the predicament of mankind.* New York: Universe Books. Retrieved from http://collections.dartmouth.edu/published-derivatives/meadows/pdf/meadows_ltg-001.pdf

[8] Grenon, M., & Lapillonne, B. (1976). The *WELMM approach to energy strategies and options.* Retrieved from http://pure.iiasa.ac.at/526/1/RR-76-019.pdf

[9] Rogner, H. H. (2009). *Climate, Land, Energy and Water Strategies.* IAEA. Retrieved from https://www.iaea.org/OurWork/ST/NE/Pess/csd17/csd17clew_2009_holger.pdf

[10] The Water, Energy & Food Security Resource Platform. (2011). Bonn2011 Conference. Nexus - *The Water, Energy & Food* Security Resource Platform. Retrieved from https://www.water-energy-food.org/about/bonn2011-conference/

[11] Hoff, H. (2011). *Understanding the Nexus. Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus*. Stockholm: Stockholm Environment Institute. Retrieved from http://wef-conference.gwsp.org/fileadmin/documents_news/understanding_the_nexus.pdf

[12] Howells, M., Hermann, S., Welsch, M., Bazilian, M., Segerström, R., Alfstad, T., … Ramma, I. (2013). Integrated analysis of climate change, land-use, energy and water strategies. *Nature Climate Change,* 3(7), 621–626. http://dx.doi.org/10.1038/nclimate1789

[13] Benson, D., Gain, A., & Rouillard, J. (2015). Water governance in a comparative perspective: From IWRM to a 'nexus' approach? *Water Alternatives,* 8(1). Retrieved from http://search.proquest.com/openview/a23c4e50ba1d4ebd937eb271ad0068a7/1?pq-origsite=gscholar&cbl=1136336

[14] GWP, Global Water Partnership. (2011). What is IWRM? *Global Water Partnership*. Retrieved August 10, 2017, from http://www.gwp.org/en/GWP-CEE/about/why/what-is-iwrm/

[15] UNESCO, *United Nations Educational, Scientific and Cultural Organization* (2014). The United Nations World Water Development Report. Paris: UNESCO. Retrieved from http://unesdoc.unesco.org/images/0022/002257/225741E.pdf

[16] de Strasser, L., Lipponen, A., Howells, M., Stec, S., & Bréthaut, C. (2016). A Methodology to Assess the Water Energy Food Ecosystems Nexus in Transboundary River Basins. *Water,* 8(2), 59. http://dx.doi.org/10.3390/w8020059

[17] USAID, US Aid for International Development. (NA). *Best Practices Guide: Integrated Resource Planning For Electricity.* Washington, DC - USA. Retrieved from http://pdf.usaid.gov/pdf_docs/Pnacq960.pdf

[18] UN General Assembly. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development* (No. A/RES/70/1). New York. Retrieved from http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

[19] UNFCCC, United Nations Framework Convention on Climate Change. (2014). The Paris Agreement - main page. Retrieved

January 8, 2018, from http://unfccc.int/paris_agreement/items/9485.php

[20] UNECE, United Nations Economic Commission for Europe. (2015). *Reconciling resource uses in transboundary basins: assessment of the water-food-energy-ecosystems nexus.* Geneva, Switzerland: United Nations Publications. Retrieved from http://www.unece.org/fileadmin/DAM/env/water/publications/WAT_Nexus/ece_mp.wat_46_eng.pdf

[21] Ramos, E., Howells, M., Mentis, D., & Lipponen, A. (Forthcoming). A Nexus study of the Sava River Basin.

[22] UNECE, United Nations Economic Commission for Europe. (Forthcoming). *Methodology for assessing the Water-Food-Energy-Ecosystems Nexus in transboundary basins and experiences from its application: Synthesis.* New York and Geneva.

[23] ISRBC, INTERNATIONAL SAVA RIVER BASIN COMMISSION. (2009). *Sava River Basin Analysis Report.* Zagreb. Retrieved from http://www.savacommission.org/dms/docs/dokumenti/documents_publications/publications/other_publications/sava_river_basin_analysis_report_high_res.pdf

[24] WBIF. (2015). Support to Water Resources Management in the Drina River Basin. Inception Report. Retrieved August 9, 2017, from http://www.wb-drinaproject.com/index.php/en/

[25] Matiç, B. B., & Simiç, Z. (2016). Comparison of Pre and Post Development Low Flow Conditions for Drina River. *Procedia Engineering, 162,* 284–292. http://dx.doi.org/10.1016/j.proeng.2016.11.061

[26] UNECE, United Nations Economic Commission for Europe. (2017). *Assessment of the water-food-energyecosystems nexus and benefits of transboundary cooperation in the Drina River Basin.* New York and Geneva. Retrieved from http://www.unece.org/fileadmin/DAM/env/water/publications/WAT_Nexus/ECE_MP.WAT_NONE_9/Drina-EN-for_Web_final.pdf

[27] UNECE, United Nations Economic Commission for Europe. (2016). S*tudy finds transboundary cooperation key to water and energy security in the Drina Basin.* Participatory workshop, Belgrade. Retrieved from http://www.unece.org/info/media/news/environment/2016/study-finds-transboundary-cooperation-key-to-water-and-energy-security-in-the-drina-basin/doc.html

[28] GEF SFCC. (2015). Technical assistance for the preparation of the West Balkans Drina River Basin Management Project. Environmental and social management framework. Retrieved August 8, 2017, from http://projects.worldbank.org/P145048?lang=en

[29] WB, World Bank. (2014). *Drina Flood Protection Project. Project Information Document (PID) Appraisal Stage* (No. PID 2584). Retrieved from http://documents.worldbank.org/curated/en/357511468035473553/pdf/PID-Appraisal-Print-P143844-02-12-2014-1392242559850.pdf

[30] EU. (1978). Council Directive 78/659/EEC of 18 July 1978 on the quality of fresh waters needing protection or improvement in order to support fish life. Official Journal of the European Union. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31978L0659&from=EN

[31] EU. (2006). DIRECTIVE 2006/44/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 September 2006 on the quality of fresh waters needing protection or improvement in order to support fish life. Official Journal of the European Union. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006L0044&from=en

[32] Gjorgiev, B., & Sansavini, G. (2018). Electrical power generation under policy constrained water-energy nexus. *Applied Energy, 210,* 568–579. http://dx.doi.org/10.1016/j.apenergy.2017.09.011

[33] Gjorgiev, B., & Sansavini, G. (2017). Water-energy nexus: Impact on electrical energy conversion and mitigation by smart water resources management. *Energy Conversion and Management, 148,* 1114–1126. http://dx.doi.org/10.1016/j.enconman.2017.06.053

[34] EnC, Energy Community. (2013). The Energy Community – Legal Framework, 3rd Edition. Retrieved from http://heyzine.com/flipbooks?hash=98d62d207ed7c9179209a50d-ca19ec21b8055695.pdf

[35] EnC, Energy Community. (2016, September). Creating a Regional electricity Market in the Western Balkans: From Paris to Rome. WB6 Monitoring Report. Retrieved from https://www.energy-community.org/portal/page/portal/ENC_HOME/DOCS/4346408/3E2FD222C83F0FE8E053C92FA8C032A8.pdf

[36] Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., … Roehrl, A. (2011). OSeMOSYS: The Open Source Energy Modeling System. *Energy Policy,* 39(10), 5850–5870. http://dx.doi.org/10.1016/j.enpol.2011.06.033

[37] UNECE, United Nations Economic Commission for Europe. (2016). *Reconciling resource uses in transboundary basins: assessment of the water-food-energy-ecosystems nexus in the Sava River Basin*. New York and Geneva: United Nations Publications. Retrieved from https://www.unece.org/fileadmin/DAM/env/water/publications/GUIDELINES/2017/nexus_in_Sava_River_Basin/Nexus-SavaRiverBasin_ECE-MP.WAT-NONE-3_WEB_final_corrected_for_gDoc.pdf

[38] de Moura, G. N. P., Legey, L. F. L., & Howells, M. (2018). A Brazilian perspective of power systems integration using OSeMOSYS SAMBA – South America Model Base – and the bargaining power of neighbouring countries: A cooperative games approach. *Energy Policy, 115,* 470–485. http://dx.doi.org/10.1016/j.enpol.2018.01.045

[39] Cervigni, R., Liden, M. J. R., Neumann, J. L., & Strzepek, K. M. (2015). *Enhancing the climate resilience of Africa's infra-*

structure?: the power and water sectors (No. 96040) (pp. 1–219). The World Bank. Retrieved from http://documents.worldbank.org/curated/en/857671468179354431/Enhancing-the-climate-resilience-of-Africas-infrastructure-the-power-and-water-sectors

[40] Stevovic, S., Milovanovic, Z., & Stamatovic, M. (2015). Sustainable model of hydro power development—Drina river case study. *Renewable and Sustainable Energy Reviews, 50,* 363–371. http://dx.doi.org/10.1016/j.rser.2015.05.016

[41] Weber, H., & Prillwitz, F. (2003). Simulation models of the hydro power plants in Macedonia and Yugoslavia. In *2003 IEEE Bologna Power Tech Conference Proceedings,* (Vol. 3, p. 8 pp. Vol.3-). Presented at the 2003 IEEE Bologna Power Tech Conference Proceedings,. http://dx.doi.org/10.1109/PTC.2003.1304511

[42] Arsiç, M., Milivojeviç, V., Vuãkoviç, D., Stojanoviç, Z., & Vukosaviç, D. (2009). Modeling of flow in river and storage with hydropower plant, including the example of practical application in river Drina basin. *Journal of the Serbian Society for Computational Mechanics/Vol, 3*(1), 127–153. Retrieved from http://www.sscm.kg.ac.rs/jsscm/downloads/Vol3No1/Modeling_of_Flow_in_River_and_Storage_with_Hydropower_Plant_Including6.pdf

[43] Divac, D., Grujoviç, N., Milivojeviç, N., Stojanoviç, Z., & Simiç, Z. (2009). Hydro-information systems and management of hydropower resources in Serbia. Journal of Serbian Society for Computational Mechanics, 3(1), 1–37. Retrieved from http://www.sscm.kg.ac.rs/jsscm/downloads/Vol3No1/Hydro-Information_Systems_and_Management_of_Hydropower_Resources1.pdf

[44] Stojanoviç, Z., Vukosaviç, D., Divac, D., Milivojeviç, N., & Vuãkoviç, D. (2009). Hydropower Plants Cascade–Modeling of Short and Long-Term Management. *Journal of the Serbian Society for Computational Mechanics/Vol, 3*(1), 210–227. Retrieved from https://www.researchgate.net/profile/Nikola_Milivojevic/publication/267410837_Hydropower_Plants_Cascade_-_Modeling_of_Short_and_Long-Term_Management/links/54857e560cf24356db60f438.pdf

Welsch, M., Howells, M., Bazilian, M., DeCarolis, J. F., Hermann, S., & Rogner, H. H. (2012). Modelling elements of Smart Grids – Enhancing the OSeMOSYS (Open Source Energy Modelling System) code. Energy, 46(1), 337–350. http://dx.doi.org/10.1016/j.energy.2012.08.017

[45] Ramos, E. P. (2015). *Energy systems analysis of transboundary river basins in a nexus approach: the Sava river basin study case.* Universidade de Aveiro. Retrieved from https://ria.ua.pt/bitstream/10773/15833/1/An%C3%A1lise%20integrada%20de%20sistemas%20energ%C3%A9ticos%20de%20bacias%20hidrogr%C3%A1ficas%20transfronteiri%C3%A7as_caso%20de%20estudo%20da%20Bacia%20do%20Rio%20Sava.pdf

[46] MFTER- BiH, Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina. (2016). National Renewable Energy Action Plan of Bosnia and Herzegovina. Retrieved from https://www.energy-community.org/dam/jcr:ef59bc5d-a6c3-48a8-9653-2a40e5721d58/NREAP_2016_BH.pdf.

[47] Government of Montenegro. (2014). National Renewable Energy Action Plan to 2020 of the Republic of Montenegro. Retrieved from http://www.mek.gov.me/ResourceManager/FileDownload.aspx?rId=194055&rType=2.

[48] MEDEP, M. of E., Development and Environmental Protection-REPUBLIC OF SERBIA. (2013). NATIONAL RENEWABLE ENERGY ACTION PLAN OF THE REPUBLIC OF SERBIA. Retrieved from http://www.mre.gov.rs/doc/efikasnost-izvori/NREAP%20OF%20REPUBLIC%20OF%20SERBIA%2028_June_2013.pdf?uri=CELEX:32009L0028

[49] ISRBC, INTERNATIONAL SAVA RIVER BASIN COMMISSI ON. (2015). Sava GIS Geoportal. Retrieved August 8, 2017, from http://www.savagis.org/map;jsessionid=3F-2D7AA751413B9F74A0C36332004D3A

[50] ISRBC, INTERNATIONAL SAVA RIVER BASIN COMMISSION. (2008). International Sava River Basin Commission. Retrieved August 8, 2017, from http://www.savacommission.org/index.php

[51] UNECE, United Nations Economic Commission for Europe. (2016, November). Second workshop on Assessing the Water-Food-Energy-Ecosystems Nexus and Benefits of Transboundary Cooperation in the Drina River Basin. Retrieved November 28, 2017, from http://www.unece.org/index.php?id=44591

[52] International Atomic Energy Agency (Ed.). (2006). Brazil: a country profile on sustainable energy development. Vienna: International Atomic Energy Agency.

[53] UNECE, United Nations Economic Commission for Europe. (2016, April). Workshop on Assessing the Water-Food-Energy-Ecosystems Nexus and Benefits of Transboundary Cooperation in the Drina River Basin. Retrieved October 5, 2017, from http://www.unece.org/index.php?id=42800

[54] Platts. (2015). World Electric Power Plants Databse. Retrieved November 29, 2017, from https://www.platts.com/products/world-electric-power-plants-database

[55] Global Energy Observatory. (n.d.). Information on Global Energy Systems and Infrastructure. Retrieved August 8, 2017, from http://globalenergyobservatory.org/

[56] ANDRITZ HYDRO. (n.d.). Bajina Bašta. Retrieved March 2, 2018, from https://www.andritz.com/hydro-en/hydronews/25/hy-25-18-bajinaBašta

[57] WB, World Bank. (2017). *SUPPORT TO WATER RESOURCES ANAGEMENT IN THE DRINA RIVER BASIN - DRINA RIVER*

BASIN ROOF REPORT. Retrieved from http://www.wb-drinaproject.com/pdf/Roof%20Report%20-%20English%20-%20Final.pdf

[58] Balkan Green Energy News. (2016, November). Intersectoral cooperation in the Drina river basin discussed in Belgrade. Retrieved from https://balkangreenenergynews.com/intersectoral-cooperation-drina-river-basin-discussed-belgrade/

[59] ENTSO-E, European Network of Transmission System Operators for Electricity (n.d.). Retrieved October 25, 2017, from https://www.entsoe.eu/Pages/default.aspx

[60] ENTSO-E, European Network of Transmission System Operators for Electricity (n.a). Project 146 - CSE8 Transbalkan Corridor. Retrieved from https://docstore.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202016/projects/P0146.pdf

[61] EPA. (2014). *Emission Factors for Greenhouse Gas Inventories.* Retrieved from https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

[62] UNFCCC, United Nations Framework Convention on Climate Change (n.d.). Paris Agreement - Status of Ratification. Retrieved October 25, 2017, from http://unfccc.int/paris_agreement/items/9444.php

[63] Buss, K., Wrobel, P., & Doetsch, C. (2016). Global distribution of grid connected electrical energy storage systems. *International Journal of Sustainable Energy Planning and Management, 9,* 31–56. http://dx.doi.org/dx.http://dx.doi.org/.org/10.5278/ijsepm.2016.9.4

[64] EnC, Energy Community. (2014, December). Assessments of the Energy Efficiency Action Plans of each Contracting Party. Retrieved from https://www.energy-community.org/portal/page/portal/ENCHOMEDOCS/3500148/0926ED3C92FA8C0E6A4.PDF

[65] EnC, Energy Community. (n.d.). Security-of-Supply Statement for Bosnia and Herzegovina, Montenegro and Serbia. Retrieved August 8, 2017, from https://www.energy-community.org/documents/reports.html

[66] Eurostat. (2007). Electricity prices for non-household consumers - bi-annual data (from 2007 onwards). Retrieved January 9, 2018, from http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=en

[67] ENTSO-E, European Network of Transmission System Operators for Electricity (2015). NTC Matrix. Retrieved July 19, 2016, from https://www.entsoe.eu/publications/market-reports/ntc-values/ntc-matrix/Pages/default.aspx

[68] ENTSO-E, European Network of Transmission System Operators for Electricity (2015). Forecasted Transfer Capacities - Year Ahead. *entsoe Transparency Platform.* Retrieved January 9, 2018, from https://transparency.entsoe.eu/transmission-domain/ntcYear/show

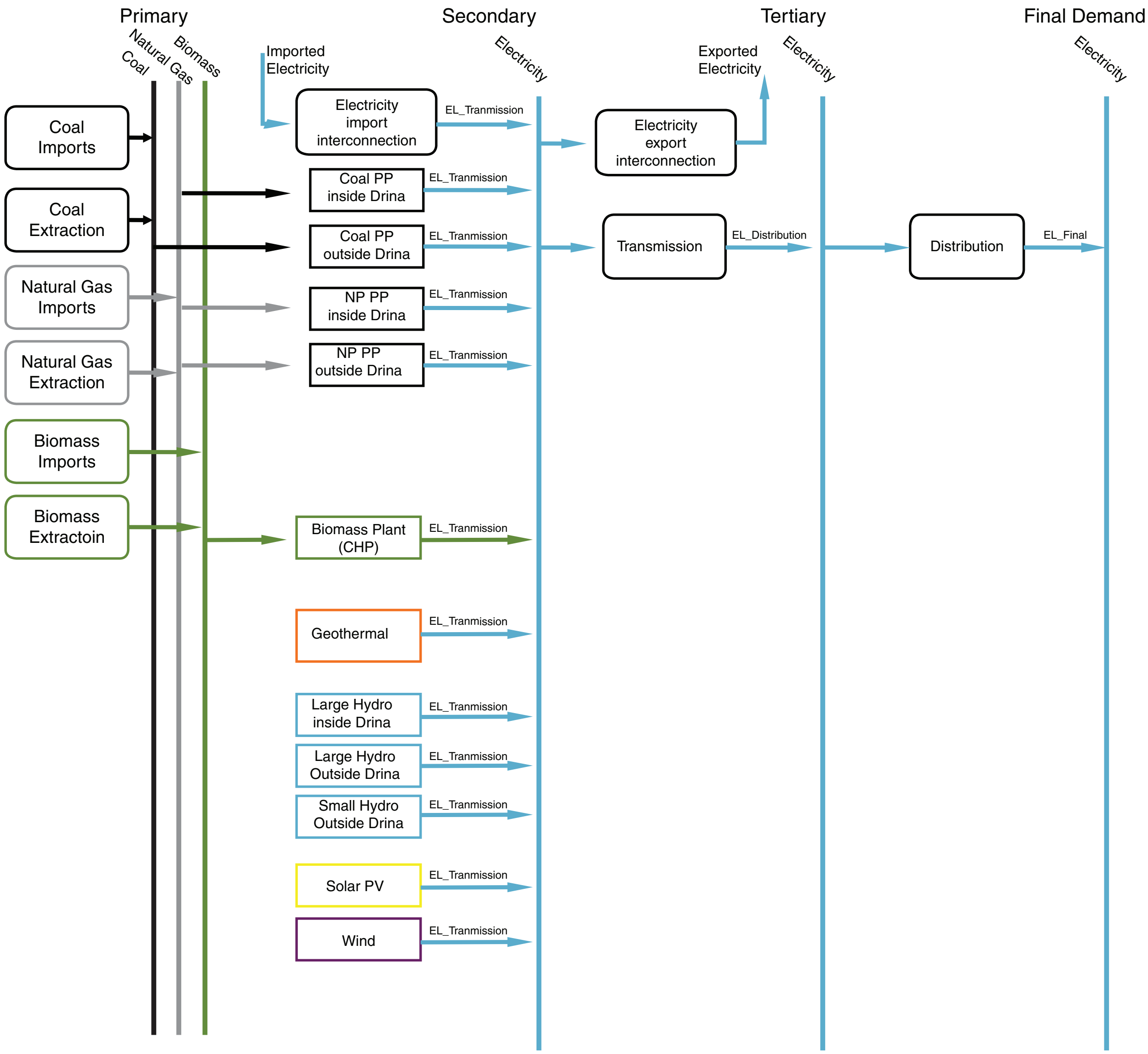

Figure A 1: A generic representation of the Reference Energy System (RES) for the electricity system in the Drina River Basin Water-Energy Model. [Note: Large hydropower plants are aggregated in this schematic representation for the sake of simplicity]

Appendic A

Key assumptions

The modelling assumptions are classified into three main categories:

a) global assumptions, that are constant throughout the modelling period for the whole system;
b) Electricity system assumptions, mainly related to the techno-economic characteristics of the technologies included in the electricity system of the model;
c) Hydrological system assumptions that demonstrate how the river system and the cascade of hydropower plants with storage are developed in OSeMOSYS.

Table A 1 lists the global assumptions used in all scenarios.

Electricity system assumptions:

- The electricity demand for each country is based on the National Renewable Energy Action Plans (NREAP) to 2020 [41,42,57], with

Table A 1: List of global assumptions used in the model

#	Parameter	Assumption
1	Monetary unit	2010 US$.
2	Real discount rate	5% for all technologies.
3	Time horizon	2010 to 2035.
4	Reporting horizon	2017 to 2030 to prevent the 'edge-effects' of the mathematical optimisation from affecting the analysis.
5	Temporal resolution	Yearly basis for the entire model period. Each yearis represented by 36 periods (Time Slices) as follows: 12 seasons (months); 1 day type; 3 daily demand levels (Day, Night and Peak).

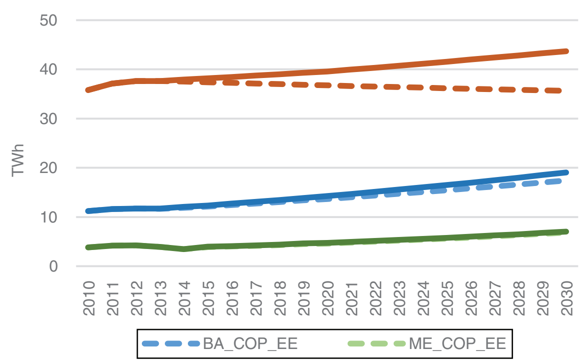

Figure A 2: Electricity demand projections for the countries in DRB from 2010 to 2035 for the two scenarios: Cooperative reference (COP_REF) and Cooperative with Energy Efficiency (COP_EE). [BA: Bosnia and Herzegovina; ME: Montenegro and RS: Republic of Serbia]

extrapolation for the period after that as shown in Figure A 2.

- In this analysis, site-specific techno-economic data for electricity generation technologies were not available; therefore, generic data from literature were used according to each technology type as shown in Table A 2.
- Transmission and distribution losses are defined on the national level based on historical data from literature with assumptions for future improved transmission and distribution system as shown in Table A 3 and Table A 4 [40,58].
- The renewable energy plans and targets are based on [41, 42,43]; all scenarios are developed to meet RE targets for hydro and non-hydro energy (mainly solar, wind and biomass) by 2020 (see Figure A 4), despite plans facing in some cases financing challenges.
- Conservative approach was followed with the penetration of non-hydro renewables beyond 2020. To address the uncertainty of the plans and unavailability of public data, the model was restricted to maintain the 2020 levels in the years after (unless specific dates were given for certain projects as shown in the list of projects Table A 8).
- For the electricity trade between countries: the model decides the price of electricity traded between the DRB countries based on the optimisation of the overall electricity system. For the countries outside DRB, that were not included in the model, prices were assumed for electricity imports and exports based on cost of electricity supplied to industries in each country as shown in Table A 6 [67]. This limitation of this analysis that should be taken in consideration in future work.

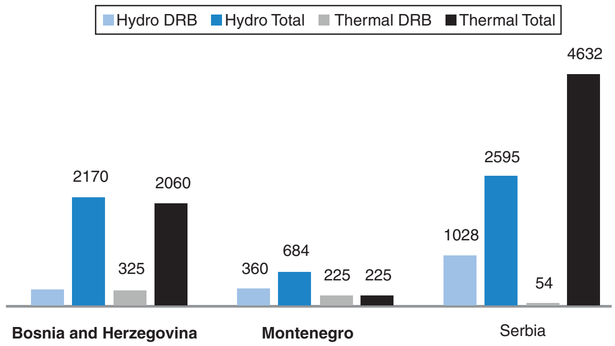

Figure A 3: Overview of installed capacity (MW) at national and Drina River basin level.

- All committed power plants are added to the model until 2016, other un-committed expansion projects (hydro, non- hydro renewables and thermal) are gradually allowed to be chosen by the model from 2017 to 2030. Since the model is an optimisation model, it chooses projects that meet the demand at the least overall system cost. All power plants considered in this analysis are presented in Table A 8.
- Emission factor data were obtained from [62].

Table A 2: Techno-economic parameters considered in the analysis

	Capital cost	Fixed cost	Variable cost	Life Time	Efficiency	Capacity factor
Technologies	(US$/kW)	(US$/kW)	($/MWh)	Years	%	%
Coal - Steam Cycle (ST)	2921	–	3.96	60	37%	85%
Fuel Oil - Gas Cycle (GT)	1488	–	4.16	25	35%	90%
Natural Gas - Combined Cycle (CC)	1238	–	0.80	30	48%	70–85%
Hydropower	2552	21	0.32	80	100%	Varies
Wind - on shore	2205	–	3.97	25	N/A	25%
Solar Photovoltaic	2100	–	5.58	25	N/A	15–48 %
Biomass	3039	–	5.56	30	38%	50%
Transmission lines	365	–	–	60	95.88–99.52 %*	–
Distribution lines	2433	–	–	60	88.55–98.48 %*	–

Table A 3: Transmission and distribution losses based on national historical data (2012–2014)

		2010	2011	2012	2013	2014	2015
Bosnia and Herzegovina	%	6.9	6.9	6.9	6.9	6.9	6.6
Montenegro	%	16.6	16.6	16.6	16.6	16.6	15.9
Serbia	%	14.7	14.7	14.7	14.3	14.3	13.8

Table A 4: Projections for transmission and distribution losses

Country		2016	2020	2025	2030
Bosnia and Herzegovina	%	6.4	5.5	4.3	3.2
Montenegro	%	15.2	12.5	9.0	5.6
Serbia	%	13.2	10.9	7.9	5.0

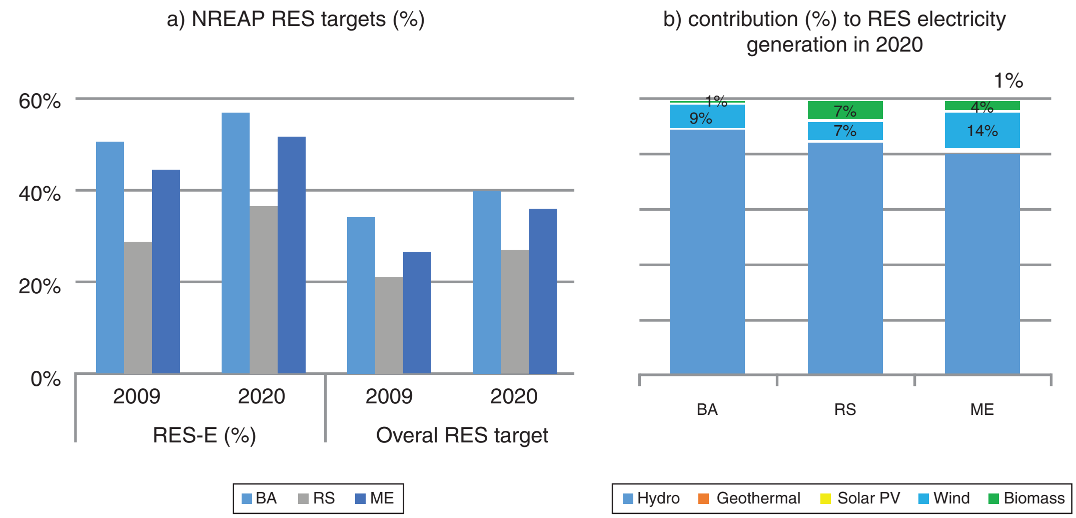

Figure A 4: Overview of the National Renewable Energy Action Plans (NREAPs) of the Drina River Basin countries: a) RES targets for the electricity sector and overall energy targets; b) expected contribution of RES (%) to electricity production in 2020

Table A 5: Net Transfer Capacities, in MW, for 2015 [60,61]

From	Bosnia and Herzegovina	Serbia	Montenegro	Croatia	Italy	Hungary	Romania	Bulgaria	FYROM	Albania
To										
Bosnia and Herzegovina		100	200	400						
Serbia	100		100	150		300	200	200	100	0
Montenegro	200	100								200
Croatia	400	100								
Italy										
Hungary		300								
Romania		150								
Bulgaria		100								
FYROM		100								
Albania			200							

Table A 6: Price of electricity in ($/MWh) for trade interconnections between countries [67]

	Bosnia and Herzegovina		Montenegro		Serbia	
	Import	Export	Import	Export	Import	Export
Albania			81.7	94.4	81.7	65.2
Bosnia and Herzegovina			Computed by the model[xiv]		Computed by the model	
Bulgaria					94.7	65.2
Croatia	81.7	81.7			81.7	81.7
Hungary					107.5	65.2
Italy			138.9	138.9		
Macedonia					53.9	65.2
Montenegro	Computed by the model				Computed by the model	
Romania					96.8	65.2
Serbia	Computed by the model		Computed by the model			

Table A 7: Gauging station data on the average and maximum annual discharge at different locations of the Drina river and its tributaries [51]

Station name	Location (along the Drina river or its tributary)	Avg. Discharge rate (m3/s) (2009–2014)	Max discharge rate (m3/s) (2009–2014)
Gorazde	Piva, Tara and Cehotina – Lower	190	1245
Cedovo	Uvac	5	48
Bijelo Polje	Lim	83	956
Prijepolje - mid lim	Lim - Middle	71	920
Priboj - Lower Lim	Lim - Lower	88	896
Bajina Bašta Station	Drina - Upper	311	1150
Radalij	Drina - Middle	389	4450

Table A 8: List of power infrastructure projects considered in the model for the three countries of DRB

Country	Plant Name	River	Type	Plant-Capacity (MW)	Fuel	Earliest year on
BA	USTRIPACA	Drina	Hydro	7		2015
BA	BISTRICA-B2A	Drina (Bistrica)	Hydro	8		2017
BA	DUB	Drina (Ratiknica)	Hydro	9		2016
BA	VRLETINA KOSA	Vrbas (Ugar)	Hydro	11		2018
BA	IVIK	Vrbas (Ugar)	Hydro	11		2018
BA	UGAR USCE	Vrbas (Ugar)	Hydro	12		2018
BA	JANJICI	Bosna	Hydro	13		2017
BA	KOVANICI	Bosna	Hydro	13		2019
BA	CIJEVNA-3	Vrbas	Hydro	14		2015
BA	VRANDUK	Bosna	Hydro	20		2018
BA	NERETVICE	Neretvika	Hydro	26		2017
BA	ULOG	Neretvika	Hydro	35		2015
BA	BILECA	Trebinsjica	Hydro	36		2020
BA	MRSOVO	Drina (Lim)	Hydro	37		2017
BA	PAUNCI	Drina	Hydro	37		2026
BA	SUTJESKA	Drina RB	Hydro	42		2017
BA	FOCA (SRBJINE)	Drina	Hydro	44		2018
BA	KABLIC	Bistrica (Adriatic Basin)	Hydro	52		2019
BA	NEVESINJE	Trebinsjica	Hydro	60		2020
BA	USTIKOLINA	Drina	Hydro	60		2018
BA	VRILO	·uica	Hydro	64		2014
BA	BUK BIJELA	Drina	Hydro	94		2018
BA	GORNJA DRINA	Drina	Hydro	115		2015
BA	DABAR	Trebinsjica	Hydro	159		2018
BA	DUBRAVICA	Middle Drina	Hydro	122		2020
BA	Tegare	Middle Drina	Hydro	124		2020
BA	Rogacica	Middle Drina	Hydro	140		2020
BA	KAKANJ CCGT	in SRB	Thermal	100	Gas	2020
BA	KONGORA	Outside DRB	Thermal	550	Coal	2017
BA	GRACANICA - Bugojno a nd mine	Outside DRB	Thermal	300	Coal	2021
BA	KAKANJ 8	in SRB	Thermal	300	Coal	2019
BA	TUZLA 7 - CHP	in SRB	Thermal	450	Coal	2018
BA	TUZLA-B2	in SRB	Thermal	450	Coal	2023
BA	ZENICA CHP GT 1	Bosna	Thermal	384	Gas	2015
BA	BANOVICI	Litva (Oscova,Spreca,Bosna)	Thermal	300	Coal	2017
BA	STANARI	Ostruznja	Thermal	300	Coal	2016
BA	KAMENGRAD	Sana (Una)	Thermal	215	Coal	2017

(Continued)

Table A 8: List of power infrastructure projects considered in the model for the three countries of DRB *(Continued)*

Country	Plant Name	River	Type	Plant Capacity (MW)	Fuel	Earliest year on
BA	UGLJEVIK-3 NO 1	Drina	Thermal	600	Coal	2018
BA	MESIHOVINA WIND WTG 1-22		Wind	55		2014
BA	TRUSINA		Wind	51		2016
BA	GRADINA BIH WTG 1-35		Wind	70		2014
BA	PAKLINE-LJUBUSA-KUPRES		Wind	408		2014
BA	BALJCI		Wind	48		2015
BA	JELOVACA		Wind	36		2015
BA	PODVELEZJE-2 WTG 1-15		Wind	48		2016
BA	WF Debelo Brdo		Wind	55		2016
BA	ORLOVACA		Wind	42		2016
BA	IVOVIK		Wind	84		2016
BA	MUCEVACA		Wind	60		2016
BA	VLASIC		Wind	50		2016
BA	GALICA		Wind	50		2016
BA	VELIKA VLAJNA WIND WTG		Wind	32		2017
BA	BOROVA GLAVA-1 WTG		Wind	52		ND - allowed after 2020
BA	POKLECANI WIND WTH		Wind	72		ND - allowed after 2020
BA	WF Kamena		Wind	42		ND - allowed after 2020
BA	WF MerdÏan Glava		Wind	72		ND - allowed after 2020
BA	WF Sveta Gora , Mali Grad Poljica		Wind	48		ND - allowed after 2020
BA	WF Mokronoge		Wind	70		ND - allowed after 2020
BA	WF Planinica		Wind	28		ND - allowed after 2020
BA	WF Velja Me?a		Wind	18		ND - allowed after 2020
BA	WF Ivan Sedlo		Wind	20		ND - allowed after 2020
BA	WF Srdani 30 MW		Wind	30		ND - allowed after 2020
BA	WF Crkvine		Wind	24		ND - allowed after 2020
ME	KOMARNICA	Piva	Hydro	172		2022
ME	HPP na Moraci	Moraca	Hydro	238		2021
ME	PERUCICA 8	Zeta	Hydro	59		2018
ME	PLJEVLJA 2	In the Drina Basin	Thermal	225	Coal	2020
ME	MOZUR WTG 1-23		Wind	46		2017
ME	KRNOVO WTG I		Wind	50		2017
ME	KRNOVO WTG II		Wind	22		2017
ME	OTHER I		Wind	8		2018
ME	OTHER II		Wind	26		2020
ME	OTHER III		Wind	17		2025
ME	OTHER IV		Wind	21		2030
RS	BRODAVERO-1,2	Lim	Hydro	58		2015
RS	BAJINA BA·TA (after revitalization in 2013)	Drina	Hydro	422		2013
RS	BISTRICA PSP	Lim	Hydro PSP	680		2020
RS	KOSTOLAC-B NO 3	Danube	Thermal	350	COAL	2019
RS	STAVALJ	Grabovica/Jablanica (Uvac, Drina)	Thermal	300	COAL	2017
RS	KOLUBARA-B NO 1	Kolubara (Sava)	Thermal	750	COAL	2017
RS	NIKOLA TESLA-B NO 3	Sava	Thermal	740	COAL	2017
RS	KOVIN CIBUK WTG		Wind	170		2014
RS	LA PICCOLINA VETRO-1 WTG 1&2		Wind	6		ND - allowed after 2020
RS	KULA WTG 1-3		Wind	9		ND - allowed after 2020
RS	RAM VELIKOVO-1 WTG		Wind	9		ND - allowed after 2020
RS	RAM VELIKOVO-2 WTG		Wind	9		ND - allowed after 2020

(Continued)

Table A 8: List of power infrastructure projects considered in the model for the three countries of DRB *(Continued)*

Country	Plant Name	River	Type	Plant Capacity (MW)	Fuel	Earliest year on
RS	BELO BLATO WTG		Wind	20		ND - allowed after 2020
RS	PANCEVO WTG		Wind	50		ND - allowed after 2020
RS	VRSAC PLANDISTE WTG		Wind	102		ND - allowed after 2020
RS	BELA ANTA WTG 1-60		Wind	120		ND - allowed after 2020
RS	LA PICCOLINA VETRO-2 WTG		Wind	120		ND - allowed after 2020
RS	KOVIN WELLBURY WTG 1-94		Wind	188		ND - allowed after 2020
RS	DOLOVO WTG		Wind	350		ND - allowed after 2020
RS	VRANJE SOLAR PV		Solar PV	10		ND - allowed after 2020
BA	STANARI	Ostruznja	Thermal	300	Coal	2016
BA	KAMENGRAD	Sana (Una)	Thermal	215	Coal	2017
BA	UGLJEVIK-3 NO 1	Drina	Thermal	600	Coal	2018
BA	MESIHOVINA WIND WTG 1-22		Wind	55		2014
BA	TRUSINA		Wind	51		2016
BA	GRADINA BIH WTG 1-35		Wind	70		2014
BA	PAKLINE-LJUBUSA-KUPRES		Wind	408		2014
BA	BALJCI		Wind	48		2015
BA	JELOVACA		Wind	36		2015
BA	PODVELEZJE-2 WTG 1-15		Wind	48		2016
BA	WF Debelo Brdo		Wind	55		2016
BA	ORLOVACA		Wind	42		2016
BA	IVOVIK		Wind	84		2016
BA	MUCEVACA		Wind	60		2016
BA	VLASIC		Wind	50		2016
BA	GALICA		Wind	50		2016
BA	VELIKA VLAJNA WIND WTG		Wind	32		2017
BA	BOROVA GLAVA-1 WTG		Wind	52		ND - allowed after 2020
BA	POKLECANI WIND WTH		Wind	72		ND - allowed after 2020
BA	WF Kamena		Wind	42		ND - allowed after 2020
BA	WF MerdÏan Glava		Wind	72		ND - allowed after 2020
BA	WF Sveta Gora , Mali Grad Poljica		Wind	48		ND - allowed after 2020
BA	WF Mokronoge		Wind	70		ND - allowed after 2020
BA	WF Planinica		Wind	28		ND - allowed after 2020
BA	WF Velja Međa		Wind	18		ND - allowed after 2020
BA	WF Ivan Sedlo		Wind	20		ND - allowed after 2020
BA	WF Srdani 30 MW		Wind	30		ND - allowed after 2020
BA	WF Crkvine		Wind	24		ND - allowed after 2020
ME	KOMARNICA	Piva	Hydro	172		2022
ME	HPP na Moraci	Moraca	Hydro	238		2021
ME	PERUCICA 8	Zeta	Hydro	59		2018
ME	PLJEVLJA 2	In the Drina Basin	Thermal	225	Coal	2020
ME	MOZUR WTG 1-23		Wind	46		2017
ME	KRNOVO WTG I		Wind	50		2017
ME	KRNOVO WTG II		Wind	22		2017
ME	OTHER I		Wind	8		2018
ME	OTHER II		Wind	26		2020
ME	OTHER III		Wind	17		2025
ME	OTHER IV		Wind	21		2030
RS	BRODAVERO-1,2	Lim	Hydro	58		2015
RS	BAJINA BAŠTA (after revitalization in 2013)	Drina	Hydro	422		2013
RS	BISTRICA PSP	Lim	Hydro PSP	680		2020
RS	KOSTOLAC-B NO 3	Danube	Thermal	350	COAL	2019

(Continued)

Table A 8: List of power infrastructure projects considered in the model for the three countries of DRB *(Continued)*

Country	Plant Name	River	Type	Plant Capacity (MW)	Fuel	Earliest year on
RS	STAVALJ	Grabovica/Jablanica (Uvac, Drina)	Thermal	300	COAL	2017
RS	KOLUBARA-B NO 1	Kolubara (Sava)	Thermal	750	COAL	2017
RS	NIKOLA TESLA-B NO 3	Sava	Thermal	740	COAL	2017
RS	KOVIN CIBUK WTG		Wind	170		2014
RS	LA PICCOLINA VETRO-1 WTG 1&2		Wind	6		ND - allowed after 2020
RS	KULA WTG 1-3		Wind	9		ND - allowed after 2020
RS	RAM VELIKOVO-1 WTG		Wind	9		ND - allowed after 2020
RS	RAM VELIKOVO-2 WTG		Wind	9		ND - allowed after 2020
RS	BELO BLATO WTG		Wind	20		ND - allowed after 2020
RS	PANCEVO WTG		Wind	50		ND - allowed after 2020
RS	VRSAC PLANDISTE WTG		Wind	102		ND - allowed after 2020
RS	BELA ANTA WTG 1-60		Wind	120		ND - allowed after 2020
RS	LA PICCOLINA VETRO-2 WTG		Wind	120		ND - allowed after 2020
RS	KOVIN WELLBURY WTG 1-94		Wind	188		ND - allowed after 2020
RS	DOLOVO WTG		Wind	350		ND - allowed after 2020
RS	VRANJE SOLAR PV		Solar PV	10		ND - allowed after 2020

- ND = No Data

Table A 9: Minimum environmental flow level at different segments of the Drina River and its tributaries

Country	Hydrological station	RS-BiH reg.	FBiH reg.		Serbia reg.	MNE reg.										
		All the year	May to Oct (a)	Nov to Ap r(b)	All the year	Jan	Feb	Mar	Apr	May	Jun	Jul	Sep	Oct	Nov	Dec
RS-BiH	Upper Drina (Baštasi)	21.7	14.3	21.5	14.3											
RS-BiH	Upper Drina (Foca Most)	28.2	19.3	28.9	19.3											
SRB/RS-BiH	Middle Drina (Bajina Bašta)	54.5	33.4	50.2	33.4											
SRB/RS-BiH	Lower Drina (Radalj)	57.2	36.5	54.7	36.5											
SRB/RS-BiH	Lower Drina (Badavinci)	-	37.4	56.5	37.4											
MNE	Upper Lim (Plav)					3.6	3.6	3.6	3.6	8.2	3.6	3.6	3.6	3.6	3.6	3.6
MNE	Upper Lim (Bijelo Polje)					10.4	10.4	10.4	25.2	10.4	10.4	10.4	10.4	10.4	10.4	10.4
SRB	Middle Lim (Brodavero)	10.5			6.9											
SRB	Middle Lim (Priboj)	18.2	9.2	13.8	9.2											
MNE	Upper Cehotina (Pljevlja)					1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
MNE	Middle Cehotina (Gradac)					2.1	2.1	2.1	4.3	2.1	2.1	2.1	2.1	2.1	2.1	2.1
RS-BiH	Lower Cehotina (Vikoc)	2.5														
RS-BiH	Middle Sutjeska (Igoce)	1.9														
RS-BiH	Middle Bistrica (Oplazici)	1.4														
SRB	Upper Jadar (Zavlaka)				0.31											
SRB	Lower Jadar (Lesnica)				0.83											
SRB	Middle Uvac (Radijevici)				0.82											
MNE	Upper Piva (Duski most)					1.8	1.8	1.8	5.8	6.0	1.8	1.8	1.8	1.8	4.8	1.8
MNE	Lowe Piva (Scepan Polje)					12.7	12.7	12.7	29.2	30.2	12.7	12.7	12.7	12.7	12.7	12.7
MNE	Upper Tara (Crna Poljana)					2.33	1.1	3.17	5.01	3.05	1.1	1.1	1.1	1.1	2.96	3.73
MNE	Lower Tara (Scepan Polje)					13.7	13.7	13.7	28.8	32.2	13.7	13.7	13.7	13.7	13.7	13.7

[i]IWRM can be defined as *'a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems'* [14]

[ii]Target 6.5: "By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate"

[iii]Number may vary between sources, e.g. WBIF reports a total basin area of 19,680 km^2 *[24].*

[iv]This depends on the importance of the power plants in the overall mix and how much their generation contributes to the demand.

[v]Based on consultations with local experts [53], the Dead Storage (Minimum reservoir level) is assumed to correspond to 10% of the reservoir total capacity.

[vi]Different sources have different estimates of the total installed capacity in the Drina basin, i.e. [44] states that the total hydro capacity in Drina basin is 1932 MW. It also states that Bajina Bašta pump storage has 600 MW turbine capacity and 580 MW pumping capacity.

[vii]The reservoir is located in the Beli Rzav River catchment area but the PSHPP powerhouse is located next to the 'Bajina Bašta' HPP powerhouse.

[viii]Only re-distribution occurs between different months within every year.

[ix]Based on discussion with stakeholders during the nexus dialogues [53] and comparing the historical annual variation of electricity trade in each country between (2008 – 2014) [60].

[x]The energy efficiency measures considered in the EEAP assumes no changes in hydrological conditions.

[xi]The total planned capacity is 386MW but will be installed on different phases starting by 25MW in phase 1 (see Table A 8).

[xii]Although the submitted NDC does not specify clear targets for the power sector, the intended measures indicates significant contribution of this sector.

[xiii]This is the unconditional emission reduction target of Bosnia and Herzegovina. The conditional target aims at 3% emission reduction by 2030 compared to the baseline (BAU) scenario.

[xiv]Since the electricity systems of the Drina River Basin countries are modelled in this analysis, the prices of electricity traded between the three countries are decided by the model based on the optimisation of the overall system.