Pacific Northwest NATIONAL LABORATORY

PNNL-31059

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Final Report

June 2021

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Abstract

The U.S. Department of Energy's (DOE's) Pacific Northwest National Laboratory (PNNL) has been tasked by DOE's Office of International Affairs to assess the use of water resources for power generation needs on Lake Gazivode/Ujmani in Kosovo, and provide recommendations for improved coordination and efficiency. Lake Gazivode/Ujmani is a 15-mile long man-made reservoir that straddles the Serbian-Kosovo border. Lake Gazivode/Ujmani is currently managed without a transboundary cooperation agreement. Kosovo is profoundly dependent on the lake's waters, which provide one-third of Kosovo's drinking water and cool two coal plants that provide 95 percent of Kosovo's energy production. After conducting a scoping visit to Pristina, Kosovo, Lake Gazivode/Ujmani, and Belgrade, Serbia, in October 2020, PNNL staff compiled hydrometeorological, water management operations, and power grid operations data. They analyzed the data and existing literature to provide third-party observations about and recommendations for the use of the lake. Their recommendations aim to promote regional water and energy security.

Summary

Lake Gazivode/Ujmani is a 15-mile long man-made reservoir that straddles the Serbian-Kosovo border. The lake was created by the construction of the Gazivode/Ujmani Dam on the Ibar/Ibër River between 1979 and 1985 (when the whole region was part of Yugoslavia. Lake Gazivode/Ujmani is currently managed without a transboundary cooperation agreement.

Pacific Northwest National Laboratory (PNNL) has been tasked by the U.S. Department of Energy (DOE) Office of International Affairs to (1) evaluate opportunities for Serbia and Kosovo to coordinate their use of water resources at Lake Gazivode/Ujmani, and (2) provide recommendations for improved coordination and efficiency. The overall approach to the evaluation consisted of conducting a scoping visit in October 2020, during which PNNL staff provided technical support to a U.S. delegation and met with the Kosovo Water Council, Kosovo transmission system and market operator KOSTT, and hydro-economic enterprise Ibër-Lepenc/Ibar-Lepenac in Pristina, Kosovo. The team also visited Lake Gazivode/Ujmani and the dam operator (Ibër-Lepenc/Ibar-Lepenac, followed by Serbian Office for Kosovo, Public Water Management Company Srbijavode, Serbia transmission system and market operator EMS (Elektromreza Serbije) and Serbia power utility EPS (ElektroPrivreda Serbije), in Belgrade, Serbia. PNNL staff followed up the visit with a request addressed to both nations for hydrometeorological, water management operations, and electricity operations, and grid operations data. The data were acquired in late December 2020. A review of recent World Bank reports about Kosovo water security and a preliminary analysis of the data led to the following observations and recommendations:

<u>Observations</u>

1. Kosovo relies on a complex water system to meet its domestic, industrial, agricultural, and energy water demands and support socioeconomic development in this water-scarce region. The water system consists of the man-made Lake Gazivode/Ujmani and its dam, Pridvorica/Pridvoricë Dam which regulates releases from Gazivode/Ujmani Dam, and the Ibër-Lepenc/Ibar-Lepenac Canal. The joint operations of the Gazivode/Ujmani System and the gravity-driven Ibër-Lepenc/Ibar-Lepenac Canal supply drinking water to the cities of Mitrovica/ë North and Mitrovicë/a South, Vushtrri/Vučitrn, Gllogovc/Glogovac, Obiliq/Obilić, and Pristina; support agriculture and mining operations; and provide cooling water to coal-based thermoelectric plants Kosovo A and B.
2. The three pillars of regional water security are (1) institutions and information systems; (2) financial and human resources, specifically investors and education; and (3) infrastructure, specifically maintenance and operations. A main message inferred from World Bank reports is that water insecurity is not solely based on water scarcity (i.e., insufficient natural water supply to meet demand). World Bank reports about water security in Kosovo noted concerns related to young institutions, lack of investors, and the need for repair and improvement of the existing water infrastructure—the canal in particular. The prospect of climate change and uncertain socioeconomic growth plans in the region further stress water security.
3. Our assessment specifically focuses on water and electricity security in the region. We observe that the regional water insecurity propagates regional energy insecurity. More than 97 percent of Kosovo electricity generation relies on the release of water from Lake Gazivode/Ujmani, including more than 95 percent of electricity generation that is derived from coal-based thermoelectric plants that rely on cooling water supplied by the canal from the lake and 1–2 percent that is derived from dam hydropower. As such, the coal-based thermoelectric power plants also rely on the proper operation of the canal, because their

intakes are downstream of key junctions where canals divert water to the cities of Pristina and Gllogovc/Glogovac. Finally, the operations of both the Gazivode/Ujmani System and the Ibër-Lepenc/Ibar-Lepenac Canal are financially supported by the revenues derived from conventional hydropower generation at Gazivode/Ujmani Dam. Currently, the Lake Gazivode/Ujmani has a storage capacity close to the mean annual inflow, and hydropower generation is directly connected to the water releases from the dam. The existing information and computation systems currently prevent the scheduling of hydropower generation in a way that maximizes revenues. We further note that, overall, water releases are driven by seasonal water supply needs, leading to more hydropower in summer when the electricity demand is the lowest. The outdated information and computation systems used in the thermoelectric power plants' operations also lead to a lack of coordination with hydropower generation and a stronger imbalance between regional electricity generation and regional demand in winter.

4. We found that Gazivode/Ujmani Dam releases seem to be driven by spring water storage targets and summer water demand. From the data provided, we could not identify consistent practices for the distribution of Gazivode/Ujmani System releases to canal diversions and the Ibar/Ibër River natural bed. Overall, 20–36 percent of the Ibar/Ibër River annual flow is diverted into the Ibër-Lepenc/Ibar-Lepenac Canal. Withdrawals are typically larger in summer, and the interannual variation is as large as the seasonal variation. There is also low correlation between the actual mean annual flow and the annual withdrawals. The interannual uncertainty and low predictability of withdrawals contribute to the low reliability of the water supply from the lake and canal.

5. The energy industry is planning a profound transformation in the region. Kosovo A Power Station has been in service since 1962 and is well past the end of its expected life. Some alternatives, such as replacing coal-based thermoelectric plants with combined-cycle natural gas power plants, might conserve the existing tight connection between energy and water security. Other alternatives, such as migrating to more wind and solar power generation and relying on external markets, might lead to a disconnection between water and energy security. Recommendations about how to improve the efficiency and coordination of Gazivode/Ujmani System and Ibër-Lepenc/Ibar-Lepenac Canal operations might vary, depending on the directions considered on the electricity side.

Recommendations

Recommendations for how to enhance water and electricity security in the region and associated opportunities are listed below.

1. Upgrade the water infrastructure.

   Implement World Bank recommendations for the repair, maintenance, and upgrade of the Ibër-Lepenc/Ibar-Lepenac Canal, including the Mihaliq/Mijalić Reservoir, to enhance the reliability of the water supply system and the region's water security.

2. Implement Supervisory Control and Data Acquisition (SCADA) system at Gazivode/Ujmani hydropower plant to enhance power plant revenues and further support load balancing.

   Using SCADA systems, upgrade the water and electricity infrastructures at the Gazivode/Ujmani System. Connecting the acquired data and controls to KOSTT energy management system (EMS) would provide additional abilities for KOSTT to balance the load and manage regional electricity prices. For Gazivode/Ujmani hydropower plant, the connection to the resulting power system model data and electricity demand forecasts would also enhance revenues by scheduling hydropower operations when prices are high.

Operating agreements are needed. The SCADA data can be also used to inform power system planning models and would help identify infrastructure investment needs that could provide more economic grid operation services, such as ramping capabilities and cycling to add the flexibility needed to integrate renewable energies.

3. Implement a river commission and valuation of river services.

   Explore the formation of an Ibar/Ibër River commission or committee that would support regional stakeholders and coordinate river operations. A river commission would support discussion between parties about the water resource management opportunities, including actions by either side that would directly affect water supply and river services for the other party.

   To anticipate the potential structure for such a commission, we reviewed nine European transboundary river agreements and structures of river commissions, including parties to any agreements and uses covered by the agreements. The review focused only on the technical benefits offered by river commissions. None of the reviewed European agreements covers the regional challenges of the Ibar/Ibër River where hydropower revenues sustain the water and electricity security of part of the river basin. We propose that Serbia and Kosovo consider the technical coordination developed under the U.S.-Canada Columbia River Treaty between water supply, flood control, and power agencies, and the modeling and institutional needs to support such a commission for the Ibar/Ibër River. The modeling and analytical needs include a coordinated and joint effort to value the monetized and non-monetized river services provided by the dam and address the cost and value of evolving upstream and downstream needs.

4. Improve the predictability of the water supply.

   The Gazivode/Ujmani System appears to play a role similar to that of Grand Coulee Dam on the Columbia River in the Pacific Northwest in the United States in terms of its contribution to storage services for seasonal water supply, and hydropower and flood control services—all based on a combination of seasonal and short-term inflow forecasts. We propose that Serbia and Kosovo explore the value of seasonal and short-term flow forecasts, which are forecast products available from the European Commission in the Balkans region, in order to enhance Gazivode/Ujmani System operations planning. Such enhanced efficiency would inform river commission negotiations for operations under interannual variability in water supply (very dry and very wet years), which would further inform discussions between stakeholders. The impact of climate change on water supply also needs to be considered, in conjunction with its impact on water demand and electricity demand compounded with the impact of socioeconomic development and energy sector transitions.

Studies of long-term electricity resource adequacy and reliability in the region are challenged by the uncertainty in socioeconomic development, including potential energy and industrial transformations. Stronger water and energy security supported by our recommendations is expected to trigger investor engagement and support less uncertain projections of socioeconomic development in the region.

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Acronyms and Abbreviations

DOE	U.S. Department of Energy
EU	European Union
HPP	Hydropower Plant
PNNL	Pacific Northwest National Laboratory
SCADA	Supervisory Control and Data Acquisition
TPP	Thermoelectric Power Plant
UNECE	United Nations Economic Commission for Europe

Contents

Figures

Tables

1.0 Introduction

Lake Gazivode/Ujmani is a 15-mile long man-made reservoir that straddles the Serbian-Kosovo border. The lake was created by the construction of the Gazivode/Ujmani Dam on the Ibar/Ibër River between 1979 and 1985 (when the whole region was part of Yugoslavia). Lake Gazivode/Ujmani is currently managed without a transboundary cooperation agreement. Pacific Northwest National Laboratory (PNNL) has been tasked by the U.S. Department of Energy (DOE) Office of International Affairs to (1) evaluate opportunities for Serbia and Kosovo to coordinate their use of water resources at Lake Gazivode/Ujmani, and (2) provide recommendations for improved coordination and efficiency.

Because Gazivode/Ujmani Dam is powered, opportunities for coordination are investigated within both the water and electricity systems. Figure 1 provides an overview of the water and electricity systems in and connecting with Kosovo. Gazivode/Ujmani Dam is located at the northern tip of Kosovo, and the impounded lake extends across Serbia and Kosovo. The lake storage relies on the inflow from the Ibar/Ibër River for filling. The headwaters of the Ibar/Ibër River are located in the country of Montenegro, and the river flows into Serbia and the lake itself. There currently are no major settlements or industrial or touristic activities upstream of the lake, so inflows are considered natural at this time, which has implications for the lake's inflow predictability and choice of benchmarks for valuing river services. The natural river flows through northern Kosovo without any major river confluence until it reaches the cities of Mitrovica/ë North and Mitrovicë/a South. Just downstream of the cities of Mitrovica/ë North and Mitrovicë/a South is a major confluence with the Sitnicë/Sitnica River. The headwaters of the Sitnicë/Sitnica River are in southern Kosovo and the river defines the river valley in which the cities of Mitrovica/ë North and Mitrovicë/a South, Vushtrri/Vučitrn, Gllogovc/Glogovac, Obiliq/Obilić, and Pristina are located. After the confluence, the Ibar/Ibër River flows through northwestern Kosovo, supplying the city of Leposavić/Leposaviq, and crosses to Serbia again. In Serbia, the Ibar/Ibër River grows from its confluence with the rivers of Raška and Studenica, and where it joins the West Morava River and then the Danube.

Kosovo relies on a complex water system to meet its domestic, industrial, agricultural, and energy water demands and supports socioeconomic development in this water-scarce region. The water system consists of the man-made Lake Gazivode/Ujmani, Gazivode/Ujmani Dam, and Pridvorica/Pridvoricë Dam, which regulates releases from Gazivode/Ujmani Dam into the Ibër-Lepenc/Ibar-Lepenac Canal. The joint operations of the Gazivode/Ujmani Reservoir System and the gravity driven Ibër-Lepenc/Ibar-Lepenac Canal supply drinking water to the cities of Mitrovica/ë North and Mitrovicë/a South, Vushtrri/Vučitrn, Gllogovc/Glogovac, Obiliq/Obilić, and Pristina; support agriculture and mining operations; and provide cooling water to coal-based thermoelectric plants Kosovo A and B. The hydro-economic Ibër-Lepenc/Ibar-Lepenac enterprise, a joint stock company completely owned by the government of Kosovo, operates and maintains the complex hydrosystem consisting of Gazivode/Ujmani Dam, Pridvorica/Pridvoricë Dam, and Ibër-Lepenc/Ibar-Lepenac Canal.

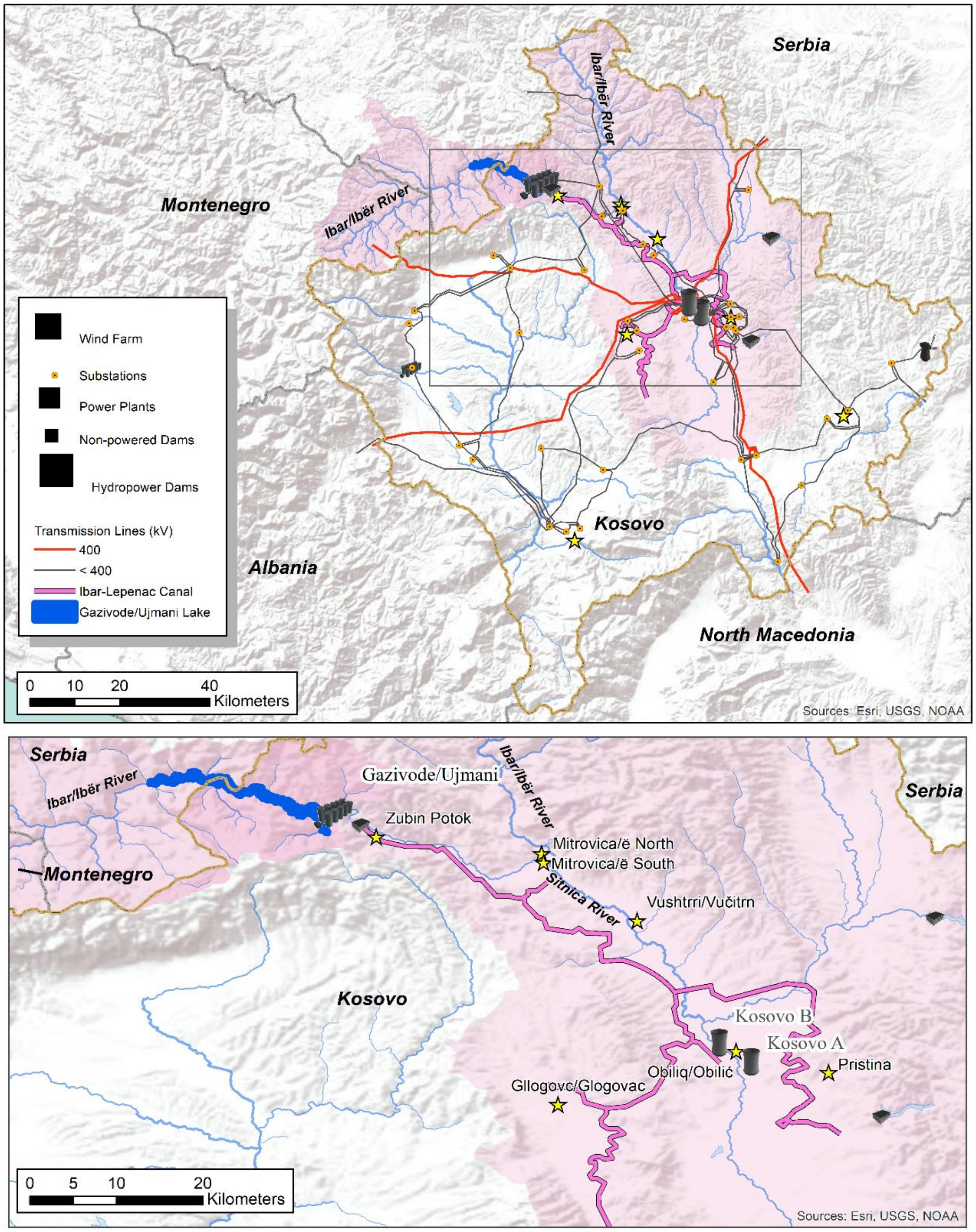

Figure 1. Kosovo water and electricity infrastructure. The inset represents the Gazivode/Ujmani hydrosystem that supplies the cities of Mitrovica/ë North and Mitrovicë/a South, Vushtrri/Vučitrn, Obiliq/Obilić, Gllogovc/Glogovac, and Pristina with freshwater through the Ibër-Lepenc/Ibar-Lepenac Canal. The colored area represents the Ibar/Ibër River basin area draining into Kosovo, and within Kosovo, before flowing into Serbia. (Map Credit: Jerry Tagestad and Corrine DeCiampa – PNNL. Data Credits: Data were digitized on screen from resources at https://kostt.com and http://www.iber-lepenc.org; Background map ESRI 2021.)

According to the recent World Bank Water Security Outlook for Kosovo (World Bank Group 2018), water security is at stake because of exposure to droughts, water uses, and the state of infrastructure. The security is projected to be even further at risk under climate change and population growth conditions. A number of recommendations were provided by the World Bank report, especially related to the protection of the infrastructure. The Kosovo energy sector is also in transition due to aging infrastructure and multiple pathways forward relative to new technologies such as renewable energies and natural gas, and regional goals in energy autonomy and greenhouse gas emissions. The objectives of this report are to lay out the complex dependencies between the water and energy sectors in the region in order to inform future coordination of the management of the lake resources by Serbia and Kosovo.

To achieve this goal, the technical approach consisted of (1) gathering data, meeting stakeholders, and reviewing existing reports; (2) reviewing water resources management strategies and identifying the water-electricity dependencies; and (3) reviewing transboundary agreements in other regions to understand how water-electricity dependencies are represented by institutions. Based on these three steps, we provide recommendations for technical and coordination activities that promote water and energy security in the region.

2.0 Preparing for a Water–Energy Analysis

PNNL staff provided technical support to a U.S. delegation during a scoping visit in October 2020. PNNL staff met with the Kosovo Water Council, Kosovo transmission system and market operator KOSTT, and hydro-economic enterprise Ibër-Lepenc/Ibar-Lepenac in Pristina, Kosovo. The team also visited thermoelectric plants Kosovo A and Kosovo B, Lake Gazivode/Ujmani and the dam operators (Ibër-Lepenc/Ibar-Lepenac) (Appendix A), followed by Serbia's Office for Kosovo, Public Water Management Company Srbijavode, Serbia transmission system and market operator EMS (Elektromreza Serbije) and Serbia power utility EPS (ElektroPrivreda Serbije), in Belgrade, Serbia. PNNL staff followed up the visit with a request addressed to both nations for hydrometeorological, water management operations, electricity operations, and grid operations data. The data were acquired in late December 2020 and are described in more detail in Appendix B. Table 1 provides a summary of the available data that we leveraged to look at water and electricity operations in this report and are available for future studies.

Table 1. Summary of hydrometeorological, water management, and power operations in Kosovo and Serbia in association with the Gazivode/Ujmani System. (For data details, please refer to Appendix B.)

Data	Source	Format and Documentation
Meteorological data – Kosovo	Hydro-Economic Enterprise Ibër-Lepenc/Ibar-Lepenac, Kosovo; Hydrometeorological Institute of Kosovo, Kosovo; The Republic Hydrometeorological Institute, Serbia	Meteorological station observations at 15 stations across Serbia and Kosovo, mostly at daily time steps, with availability ranging from 1961 to 2020.
Hydrological data – Ibar/Ibër River	Hydrometeorological Institute of Kosovo; Hydro-Economic Enterprise Ibër Lepenc/Ibar-Lepenac, Kosovo; The Republic Hydrometeorological Institute, Serbia; PoE "Ibar" Zubin Potok, Kosovo; The Environmental Protection Agency, Serbia; The Regional Water Supply Gazivode.	River gauge measurements of flow rate or water level at 4 gauges upstream or downstream of the Gazivode/Ujmani Dam, mostly at daily time steps, with availability ranging from 1934 to 2020. There are additional flow data on river gauges that are not on the Ibar/Ibër River. Also, there are some water quality measurements from 3 sites in 2017, 2018, and 2020.
Water management and hydropower operations – Lake Gazivode/Ujmani System	Hydro-Economic Enterprise Ibër-Lepenc/Ibar-Lepenac, Kosovo; PoE "Ibar" Zubin Potok, Kosovo;	Dam characteristics, daily reservoir water level from 2000 to 2020, daily hydropower generation from 2011 to 2020, and canal release at 10-day intervals from 2010 to 2020.
Electricity generation at Kosovo power plants (hydropower, thermoelectric, wind) and power flow data across Kosovo	KOSTT, Kosovo; Elektromreža Srbije A.D, Serbia; PoE "Ibar" Zubin Potok, Kosovo.	Daily electricity generation from different sources, along with demand, from 2018 to 2020. Hourly import/export power flow with external entities in 2019 and 2020.

3.0 Water Security

The concept of water security is complex and includes a number of definitions (Doeffinger et al. 2020). The World Bank defines pillars of water security as (1) institutions and information systems, (2) finances and education, and (3) infrastructure and management. Water security has been addressed by a series of reports from the World Bank, notably the 2012 Water Security for Kosovo report (Baudry and Denigot 2012) and the most recent 2018 Water Security Outlook for Kosovo (World Bank Group 2018).

The 2012 Water Security Report describes the hydrology of the region, including surface and groundwater resources, existing water users and demand, and it provides future projections of water uses under a range of socioeconomic scenarios. The report finds that water security in Kosovo is vulnerable for a number of reasons. The overall variability of the water supply coupled with the lack of storage (outside of Lake Gazivode/Ujmani) may result in a shortage of water supply in the future, considering projected socioeconomic development and the effects of climate change. Overall, the existing water infrastructure is vulnerable to natural hazards, such as landslides and flooding, and is not well maintained or modernized. Finally, due to lack of regulations, the risk of pollution of surface water and drinking water is high, presenting sanitary and health concerns.

We noted a water–energy assessment in the 2012 report (Baudry and Denigot 2012) describing the reliance of Kosovo A and B on water supply from the canal, which presents an energy security risk that could be mitigated by development of additional water storage to reduce the vulnerability caused by water shortage or canal delivery problems. At the time of that report, plans were under way for a new lignite thermoelectric power plant that would increase pressure on the water demand (0.25 cms for Kosovo A, 0.4 cms for Kosovo B). The analysis recognizes the dependencies of water security and regional electricity generation due to this reliance of the power plants on water supply from the canal, but the report does not further investigate energy security per se.

The 2018 Water Security Outlook for Kosovo is a series of more focused reports that follow the 2012 assessment. The reports contain separate sections on the Kosovo context, water resources, water security, and management challenges. A key finding of the report about the Ibër-Lepenc/Ibar-Lepenac Canal – Lake Gazivode/Ujmani water balance is that the Kosovo water storage capacity is underdeveloped; it has only 300 m^3 of storage per person. Most of this storage is located in Lake Gazivode/Ujmani, which is shared with Serbia. The water from Lake Gazivode/Ujmani also supplies the water for cooling Kosovo's two power plants, which produce nearly all of the power in the country. This limited, unmaintained, and inefficiently managed water storage, combined with its location, tightly links water security with energy security and national security in Kosovo. The World Bank recommends development of an additional water storage reservoir to help reduce some of this vulnerability by adding redundancy (World Bank 2015).

The 2018 outlook report provides a more structured approach to achieving water security than the 2012 assessment; it looks beyond water availability and users to focus on management practices, including institutions that support river services. According to the report, Kosovo has good policy and legal frameworks in place to manage the water resources, but has been challenged by operationalization and implementation of the framework. Part of these implementation challenges stem from a lack of financial support for infrastructure operations, because revenues from hydropower are not sufficient to support the maintenance, repair, and modernization of the dam or the canal. As a result, the Ibër-Lepenc/Ibar-Lepenac Canal is in need of repair to fix leakage and vulnerability to pollution, as recommended by the World Bank (2015).

4.0 Water–Energy Interdependencies

The previous section provided a review of existing studies of the stressed water resources of Kosovo and Kosovo water security relying on Lake Gazivode/Ujmani for storage and Ibër-Lepenc/Ibar-Lepenac Canal for water delivery. A dependency between the water and energy security was introduced because Kosovo's two thermoelectric power plants currently rely on Ibër-Lepenc/Ibar-Lepenac Canal water delivery for cooling purposes. In this section, we take a closer look at the linkages between Gazivode/Ujmani system operations and the electricity operations in the region.

Mean annual inflow into Gazivode/Ujmani Lake is 13.1 cms (Prelez station), ranging respectively from 7.9 cms to 19.2 cms for a very dry and very wet year (adjusted Ribarićе station). With little settlement upstream of the lake, the inflow is mostly in a natural state and projected to be affected in volume only by climate change under no land use change, land cover change, or other human activities. The reservoir can store 375 million m3, implying that the reservoir can store 90 percent of the mean annual inflow. Water levels can vary between 630 and 692.7 m above sea level, although in practice the storage is maintained between 676 and 690 m. The mountainous climate limits evaporation from the lake, which tops 0.2 m in August during a normal year (Baudry and Denigot 2012). Releases from the dam include a 1.8 cms environmental flow leaving from the shaft and reversing into the natural river bed and joining the Pridvorica/Pridvoricë regulating dam (Figure 2). The other releases are through the penstock into the hydropower plant Gazivode/Ujmani, which has two 17.5 MW turbines. As an annual average, 10.5 cms goes through the turbine (not the penstock capacity) for an overall 12.3 cms release from the dam. Pridvorica/Pridvoricë Dam regulates the hourly hydropower operations for a stable daily release of 9 cms into the natural Ibar/Ibër River bed, and 3.3 cms into the Ibër-Lepenc/Ibar-Lepenac Canal. The canal delivers water to Mitrovica/ë North and Mitrovicë/a South (0.53 cms), Pristina (0.06 cms), irrigated agriculture fields, industrial activities (NewCo Feronikeli – 0.11 cms), and Kosovo A (0.14 cms) and Kosovo B (0.4 cms). The spillway has been used only once in 2016. The canal has an overall capacity of 12 cms due to its current state.

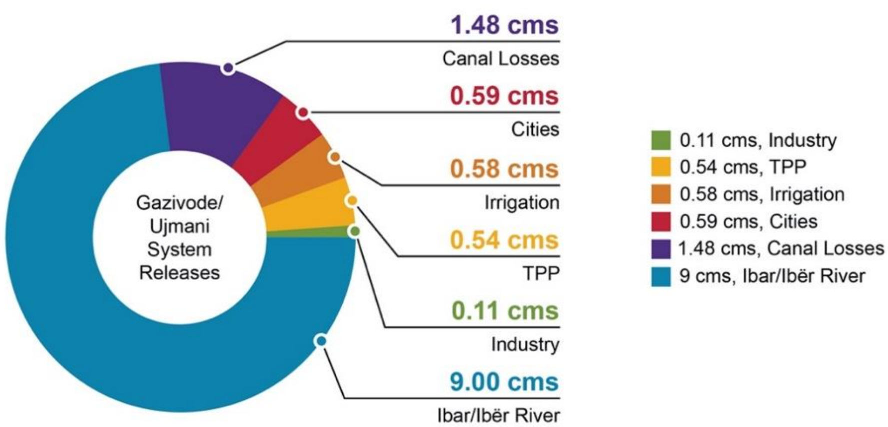

Figure 2. Distribution of Gazivode/Ujmani System releases by user (Water demand source: Baudry and Denigot 2012; canal and river overall distribution source: Ibër-Lepenc/Ibar-Lepenac and Serbia).

The bulk electricity system of Kosovo consists of two thermoelectric power plants, Kosovo A and B, a wind power plant, and a number of hydropower plants with Gazivode/Ujmani having the largest capacity (Figure 1). The generation operations are coordinated to meet the regional electricity demand within security constraints at eight substations. The substations and power plants are connected by two 110 kV lines and two 220 kV lines, and the whole system is connected with neighboring regions by four 400 kV lines. Figure 3 provides an overview of the annual water-electricity dependencies. Note that the water estimates are slightly different than in the water security assessment and Figure 2, because the period is reduced to 2018-2019, which corresponds to the availability of the bulk power system operations data. Over those 2 years, at an annual scale, 72 percent of the Gazivode/Ujmani System releases are directed into the natural river bed and 28 percent are directed into the Ibër-Lepenc/Ibar-Lepenac Canal; 11.2 cms was used to support hydropower operations, generating 101,000 MWh, which corresponds to 2 percent of the demand. Thermoelectric plants Kosovo A and Kosovo B consumed 0.54 cms delivered by the canal, and generated 5,335,000 MWh, i.e., 90 percent of the regional electricity demand. The other wind and power plants operations provide another 2 percent of the demand but do not rely on Gazivode/Ujmani water system operations. Given that the storage and water delivery operations are financially supported by hydropower revenues, but Gazivode/Ujmani Dam hydropower is not a major component of the electricity system, we further investigate (1) the overall water management of the Gazivode/Ujmani reservoir, and (2) the contribution of Gazivode/Ujmani hydropower to Kosovo bulk power system operations at finer temporal scales.

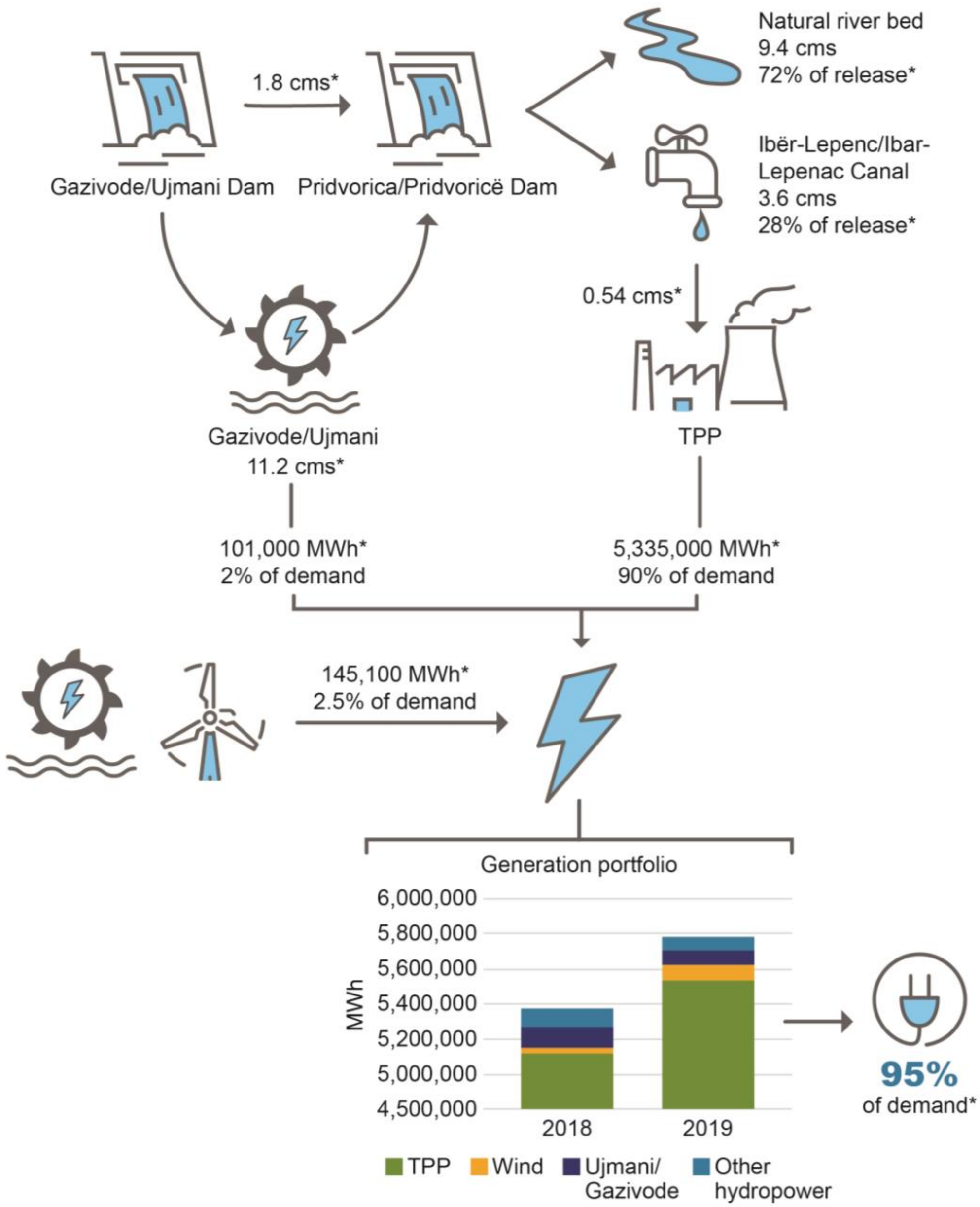

Figure 3. Water and energy dependencies. (* Based on 2018-2019 data only.)

4.1 Lake Gazivode/Ujmani Management and Predictability of Operations

Clear operating rules are key to evaluating water management strategies; they typically reflect priorities between river services and provide a benchmark for valuing river services and promoting the exploration of alternate operations as water needs evolve. No clear rules were provided but operators reported operating for storage and water delivery for the Ibër-Lepenc/Ibar-Lepenac Canal, and maintaining the energy value of the water release, i.e., hydropower generation. As further shown in this section, the reservoir levels are maintained high (above 85 percent of maximum storage capacity) through May-June when water demand increases by 50 percent to meet irrigation demand. During the irrigation season, water management appears to be driven by release targets. No storage target could be identified during shoulder seasons (November– February). Most importantly, we found that the annual and monthly diversions through the Ibër-Lepenc/Ibar-Lepenac Canal are not predictable and are neither a function of the reservoir storage level, nor of the overall water year conditions. The operators mentioned that demands, e.g., canal releases, are communicated on a monthly basis by the users. This unpredictability in the diversions—and/or the demands—is either providing little resilience and few planning opportunities for their uses or providing fewer opportunities for reservoir operators to enhance the energy value of the water release. Below we show the data analysis that supports these observations.

4.1.1 Storage and Release Targets

Without having access to the explicit operating rules, we use monthly water storage variations, storage change, and electricity generation as proxies for dam releases, over the 2012–2019 period to infer whether storage targets, or release targets, or combinations thereof, are used to guide the Gazivode/Ujmani System operations. We note that on average, the full storage capacity can store 90 percent of the mean annual inflow, implying that reservoir operations likely focus on alleviating drought conditions rather than on providing seasonal flood control, which was also confirmed by the operators themselves during the visit. Figure 4a shows the daily time series of storage levels over the 2006–2020 period, indicating that operations maintain a high reservoir level between 676 and 690 m above sea level. Figure 4b. displays the monthly reservoir level from which to infer seasonal patterns and storage targets. We observe that the highest level typically occurs in June, and most of the time the level is between 687 and 690 m, then gradually decreases as the irrigation season evolves. There is, however, a large variability in winter storage, ranging from 676 to 688 m between November and February. Figure 4c provides insight into the monthly changes in lake level. Given the variability of reservoir levels and no conclusive storage targets but full storage in June, the change in storage is an indication of release targets rather than storage targets. Figure 4c also shows large variability between November and May-June. However, the figure shows that the decrease in reservoir level between July and November is engineered to be relatively constant, possibly addressing downstream water demands; deviations only occurred in 2014 and 2016, two very wet years during which the levels were not drawn, and in 2019, not a particularly dry year, during which the storage was drawn in September.

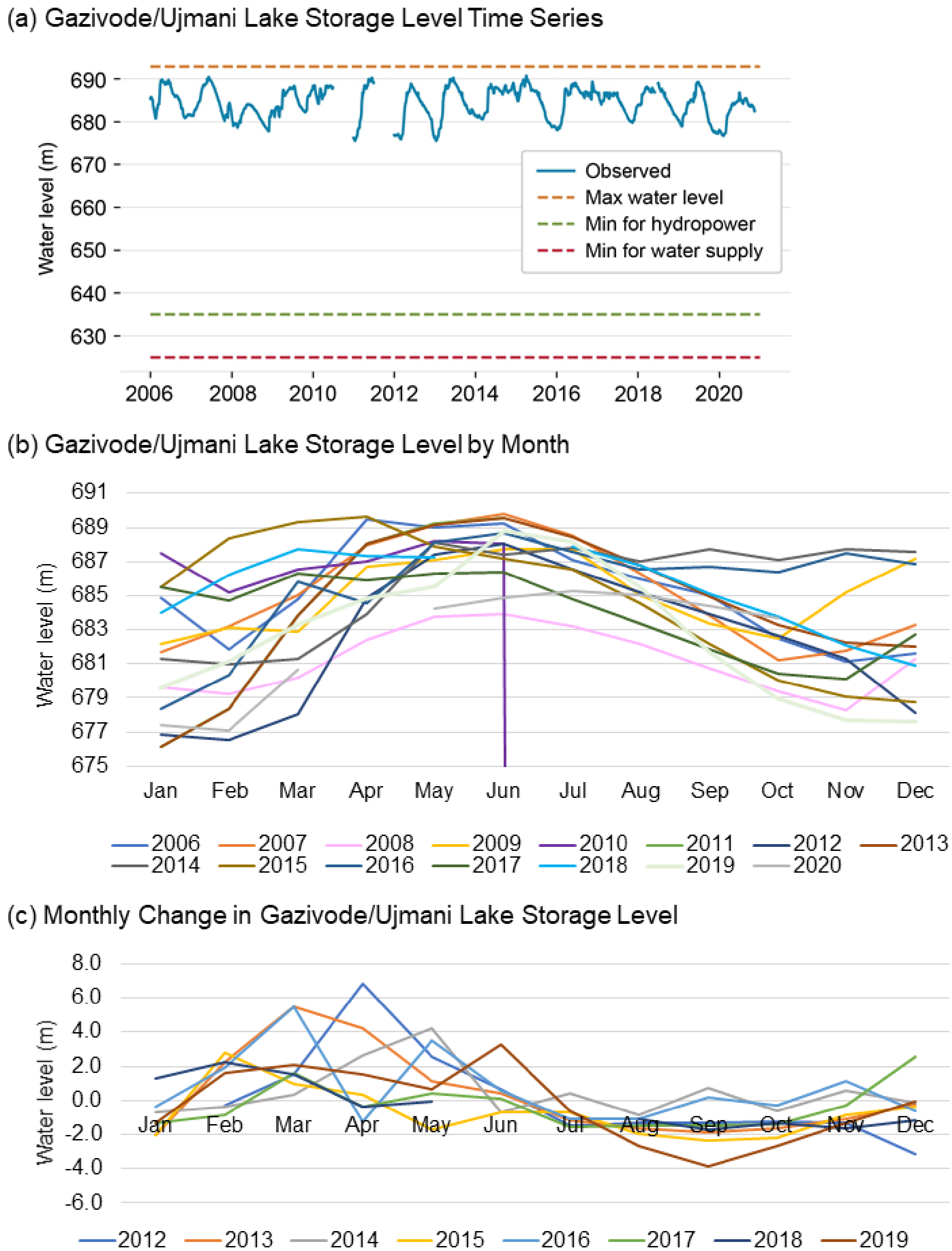

Figure 4. (a) Daily time series of the Lake Gazivode/Ujmani storage level in meters above sea level; (b) monthly storage levels showing that the only storage target is an attempt for full storage in June but none at the end of the irrigation season; and (c) monthly changes in lake levels showing that the July–October operations are release-target driven. (Source: Ibër-Lepenc/Ibar-Lepenac)

4.1.2 Diversions into the Ibër-Lepenc/Ibar-Lepenac Canal

We now look at the reservoir releases into the Ibër-Lepenc/Ibar-Lepenac Canal and the natural riverbed. The canal has an original capacity of 22 cms at Pridvorica/Pridvoricë Dam and 6.5 cms at its end. The current capacity is reduced to 12 cms due to the current state of the infrastructure. Figure 5–Figure 7 aim to help determine any release targets in the canal and overall. Figure 5 shows the interannual variability in monthly releases into the canal. Figure 6 shows the 2010–2020 monthly releases into the canal as a function of the Lake Gazivode/Ujmani level. And Figure 7 shows the 2010–2019 overall water allocation of the Gazivode/Ujmani System releases into the canal and the natural riverbed. We note that the releases into the Ibër-Lepenc/Ibar-Lepenac Canal are on average 3.3 cms, although here as well we see an interannual variability (2.8–3.8 cms) as large as seasonal variations, 1.8–5 cms being the most extreme and typical variability being in the 2.6–4.3 cms range. Consistent with the slowly but consistently decreasing reservoir levels from July to September, we note that the diversions in the canal tend to be around 4.5 cms in the summertime, and then vary between 2 and 4 cms in winter and shoulder seasons. Overall, between 20 and 36 percent of the annual release is diverted into the canal. We note an overall lack of correlation between the annual total release from the dam, the storage level in the lake, and the distribution between the river and the canal diversion.

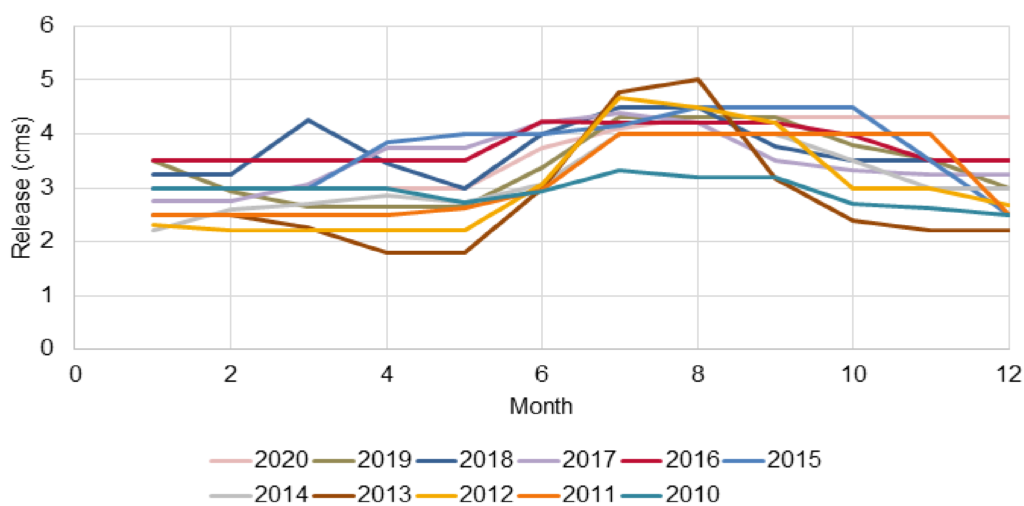

Figure 5. 2010–2020 mean monthly release into the Ibër-Lepenc/Ibar-Lepenac Canal showing the interannual variability in summer and non-summer releases. (Source: Ibër-Lepenc)

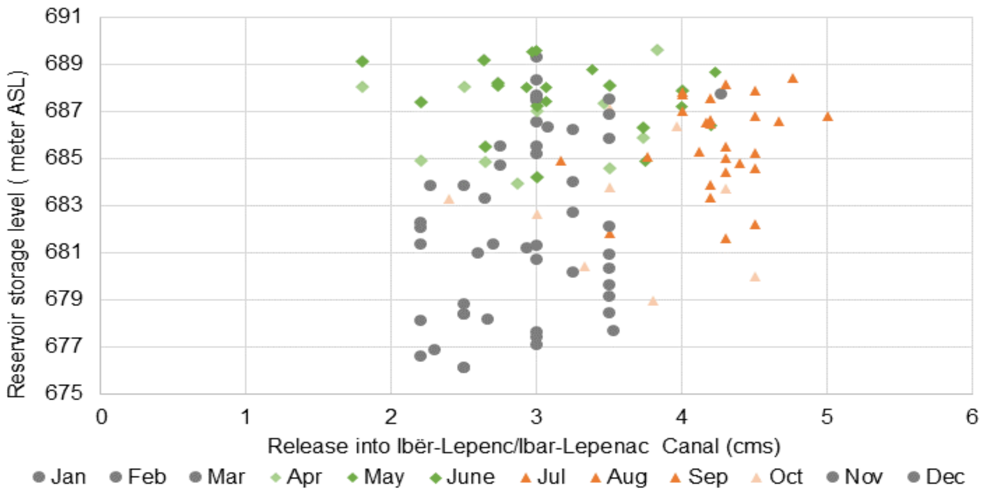

Figure 6. 2010–2020 monthly release into the Ibër-Lepenc/Ibar-Lepenac Canal as a function of the Lake Gazivode/Ujmani level showing the summer and non-summer release patterns independent of storage levels. (Source: Ibër-Lepenc/Ibar-Lepenac)

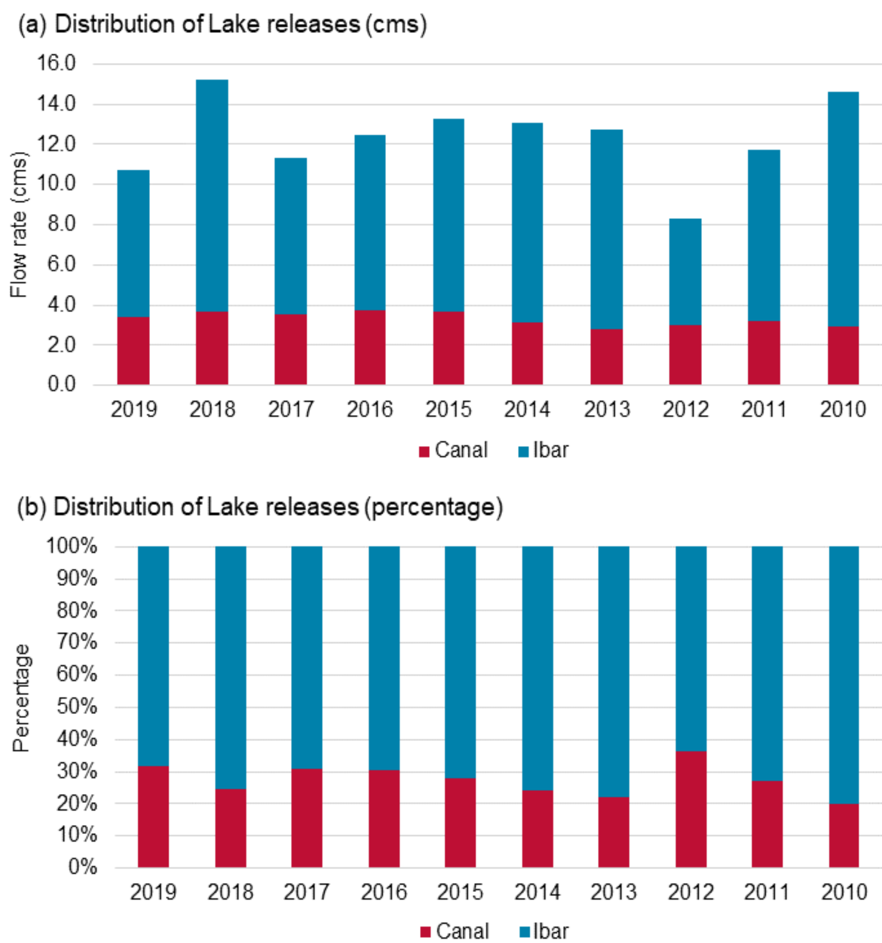

Figure 7. 2010–2019 annual water allocation of Gazivode/Ujmani System releases into the Ibar/Ibër River natural bed and the Ibër-Lepenc/Ibar-Lepenac Canal showing the low correlation with annual release. (Source: Ibër-Lepenc/Ibar-Lepenac and Serbia)

4.1.3 Synthesis

Lake Gazivode/Ujmani water level is maintained at a high level, between 85 to 100 percent of the maximum lake level, with a drop in 2016 to 40 percent that might be a data error. Because the reservoir can store 90 percent of the mean annual flow, with an interannual variation of 80 to 100 percent, it is surprising that the monthly reservoir levels have such interannual variability. According to the operators, no seasonal flow forecast is used to plan for carry-over storage targets, i.e., storage level in the fall to maintain reservoir level and ensure filling at 100 percent in the spring. No medium-range flow forecasts are used either for managing reservoir storage and releases when the reservoir is full in the May-June period (communication with operator). Hence, we can infer that the buffer between the mean monthly maximum storage and the spillway provides this operational flexibility when storage is high. Diversions into the Ibër-Lepenc/Ibar-Lepenac Canal appear to be difficult to predict; a summer goal of about 4.5 cms varies in duration and volume. The predictability of the annual and monthly delivery through the Ibër-Lepenc/Ibar-Lepenac Canal is low and is neither a function of the reservoir storage level, nor of the overall water year conditions. Potential coordination for water quality purposes at the confluence of the Ibar/Ibër and Sitnicë/Sitnica Rivers was not evaluated.

4.2 Gazivode/Ujmani Hydropower Operations and Contribution to Bulk Power System Operations

Hydropower operations of Gazivode/Ujmani System provide limited contributions to meeting the Kosovo electricity demand, while providing revenues critical to maintaining the storage and water delivery to maintain over 92 percent of the Kosovo overall generation and to meet 90 percent of the demand. Currently, 95 percent of the Kosovo electricity generation relies on the overall Gazivode/Ujmani System operations. In this section, we review the hydropower operations and their operational value to the grid, which typically translates into revenues.

4.2.1 Hydropower Generation Operations

Previously, we noted that the water level of Lake Gazivode/Ujmani is maintained at above 85 percent of maximum level at all times, which is characteristic of hydropower operations but not characteristic of water supply operations where water supply services constitute 25 percent of the mean annual flow. In this case, maintaining the lake level is possible because of the large storage capacity of the reservoir and an overall water demand that has a limited seasonality; only irrigation demand is seasonal and it represents only 50 percent of the overall demand in summer. Projections to increase the irrigation acreage might affect the system's ability to maintain storage levels, which can also be alleviated by maintenance and repair of the canal that experiences a 45 percent loss through leakage. In this section, we review the hydropower operations and their operational value to the grid, which typically translates into revenues. This analysis is based on 2 years of data, specifically for 2018 and 2019.

As reported by the operators, the hydropower plants' turbines run at maximum operational capacity daily, for about 2 hours at a time, in the morning and in the afternoon. The units are manually operated and are offline, i.e., not spinning, outside of those generation times. The higher the storage level, the higher the generating capacity, which means in this type of operation that less water is required to generate the same amount of electricity at a lower lake level. Figure 8 shows the 2011–2019 monthly generation as a function of the lake level. Generation in April-May-June shows the largest interannual variability with monthly generation ranging from 5,000 to 20,000 MWh. Outside of the irrigation season (October–March) is when reservoir level variations are the highest but the monthly generation is maintained at around 5,000 MWh. Those monthly operations seem to reflect a tradeoff between water delivery and the energy value of the releases.

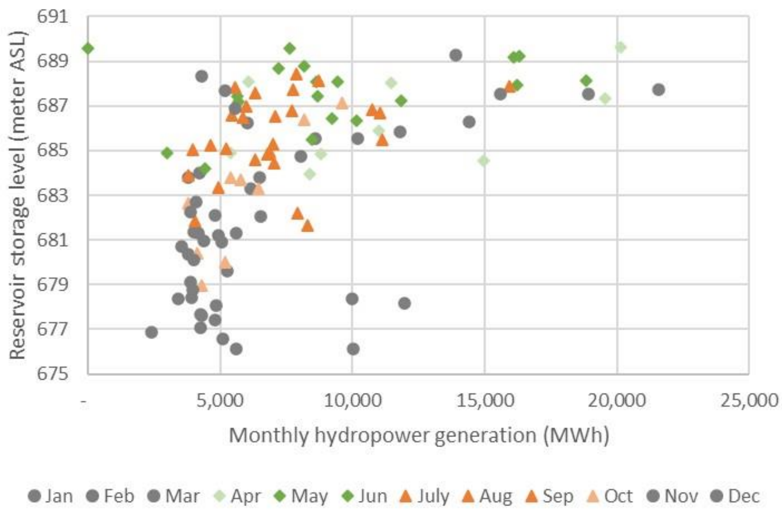

Figure 8. 2010–2019 monthly hydropower generation (MWh) at Gazivode/Ujmani hydropower plant, as a function of Lake Gazivode/Ujmani water level (meters above sea level).

4.2.2 Contribution to Grid Operations

Hydropower operations can provide a range of services to grid operations, from energy generation to meet overall electricity demand to varying its generation (ramping) to match subhourly electricity demand variations and facilitate wind integration, to providing capacity reserve in case of sudden disruptions. Independent hydropower producers, as in this case, tend to schedule their operations to maximize revenues. When water is limited, such as in the Gazivode/Ujmani System that can generate at operational capacity for only about 4 hours a day, the strategy is typically to generate when the energy prices are the highest. No Supervisory Control and Data Acquisition (SCADA) system is implemented, and operations are all manual. As a first overview of Gazivode/Ujmani hydropower plant operations, Figure 9 shows the hourly generation and Kosovo electricity demand for the 2018-2019 period. The demand displays a seasonal pattern with higher values in wintertime and lower demand in summer, plateauing from July to October. At a seasonal time scale, Gazivode/Ujmani hydropower generation, which is two orders of magnitude less than the electricity demand, does not display such a seasonal pattern and actually is lowest in wintertime when demand is highest.

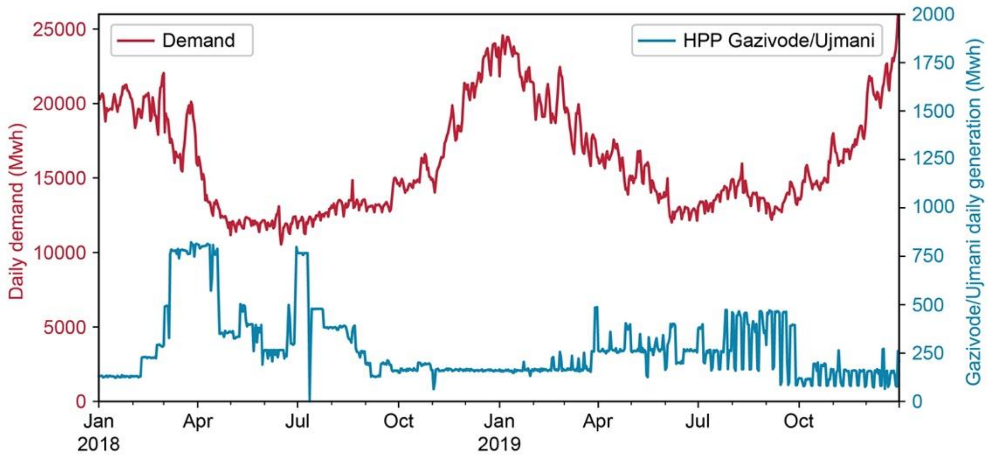

Figure 9. 2018-2019 Kosovo daily demand time series (red), and Ujmani daily hydropower generation time series (blue).

The hourly profile provides a better representation of the contribution of Gazivode/Ujmani hydropower plant operations. Figure 10 shows the mean annual hourly profile of Kosovo electricity demand; Kosovo A and B generation; combined Kosovo A, B, and Gazivode/Ujmani generation; and total generation, including wind and other hydropower. While overall Kosovo electricity generation meets 95 percent of the electricity demand, the hourly profile shows that total generation substantially exceeds the electricity demand, from an hourly minimum of 38 percent to an hourly maximum of 287 percent over the 2018-2019 period. This imbalance is mostly attributed to the constant hourly generation profile from the thermoelectric power plants. Kosovo A does not operate with a SCADA system, but Kosovo B does (Appendix A). We also note that Gazivode/Ujmani hydropower contributes to decreasing the imbalance by producing electricity only during hours when the thermoelectric power plants production does not meet the electricity demand.

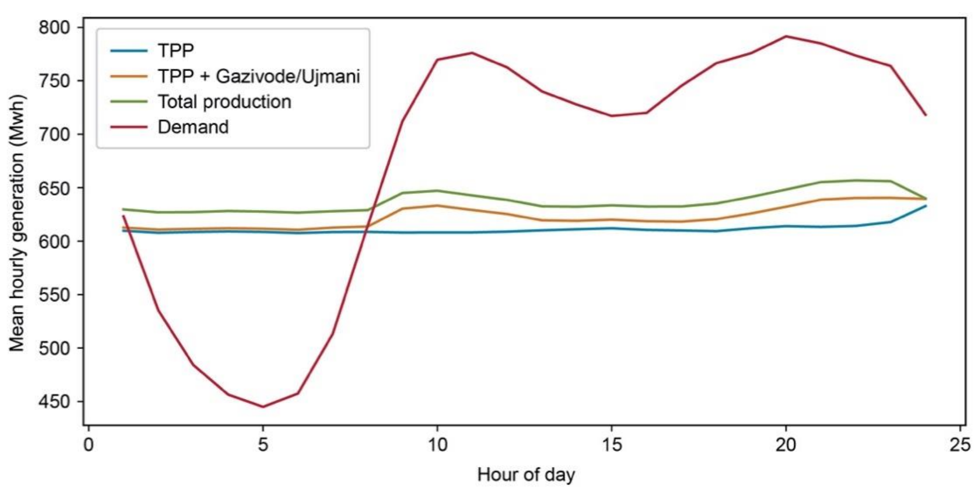

Figure 10. Mean hourly generation aggregated across 2018 and 2019 from thermo power plants (TPP) only, thermo power plants and Gazivode/Ujmani hydropower generation, Kosovo total generation, and Kosovo total demand.

Figure 11 shows heat maps of Gazivode/Ujmani hourly hydropower generation, along with Kosovo electricity demand and Kosovo A and B combined generation to grasp seasonal variations in daily hourly profiles. It appears that Gazivode/Ujmani hydropower operations were able to contribute to balancing the hourly electricity demand and atypical events in the spring of 2018 and summer and fall of 2019. The seasonal variations in hourly load profile in hydropower generation at Gazivode/Ujmani hydropower plant and Kosovo electricity demand reveal a challenge in scheduling the 2–4 hours daily generation at the time demand sharply rises or decreases, supporting the need for a SCADA system and connection to the Energy Management Systems (EMS) and market to enhance not just the energy value of the dam releases but also their economic value.

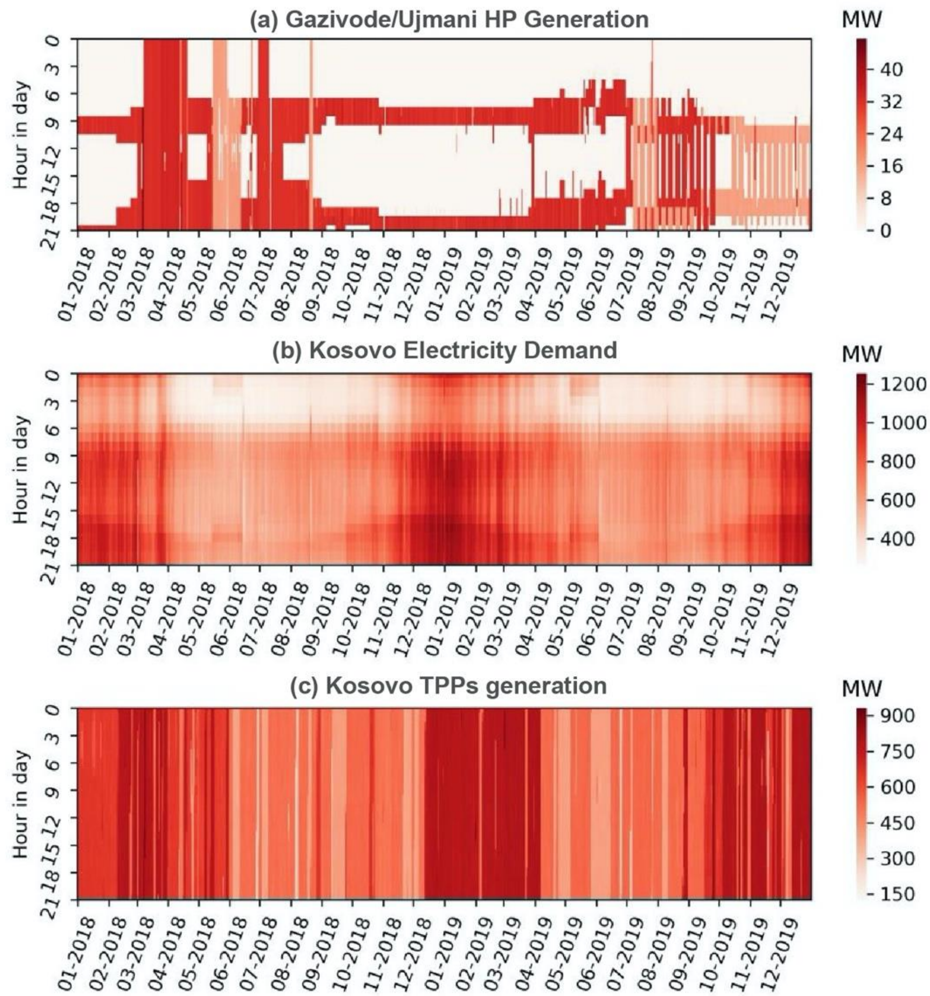

Figure 11. (a) Hourly Gazivode/Ujmani hydropower generation in 2018 and 2019, and (b) hourly Kosovo total electricity demand in 2018 and 2019. (Data source: KOSTT).

4.2.3 Synthesis

With hydropower operations running simply at maximum operational capacity, or being offline, the only potential revenues are from generation. A more technical evaluation of the infrastructure would be needed to explore the investments needed to provide additional services to the grid, such as ramping and reserve services, which would depend on their market value. Under current operations, there is a direct relationship between releases, storage level, and hydropower generation. Any change in consumptive use over Lake Gazivode/Ujmani contributing drainage area or retention structure that would result in lower lake levels, would affect the generation and thus the revenues, further affecting the operations and maintenance of the entire Gazivode/Ujmani Ibër-Lepenc/Ibar-Lepenac Canal hydrosystem.

5.0 Transboundary Coordination

Transboundary lakes and rivers are common, but the level of international coordination of the management of the resources is often unique. In the case of Lake Gazivode/Ujmani management, we note the tight link between the current water security outlook for Kosovo and energy security. Throughout the report, we first look at the water security as a basis for transboundary coordination, and then expose the connections with the energy sector to provide more insight into the value of certain water management operations. We approach this valuation from an energy production perspective and only allude to the monetary value of both river and energy services.

We now review European water laws and case studies from nine European transboundary river agreements, looking for similar water–energy complexity and how it influences transboundary coordination, specifically how it influences the structures of river commissions.

5.1 European Water Laws for Transboundary River Basins

Transboundary water law throughout Europe and the United Nations member states is governed by a series of nonbinding treaties and customary laws that have been signed or agreed to by numerous countries. The first treaty, known as the Helsinki Rules on the Uses of the Waters of International Rivers (ILA 1966),for later treaties, including the 1997 Convention on Non-Navigational Uses of International Watercourses (UN Watercourses Convention, UN 1997), the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (UNECE Water Convention, UNECE 1992), the Berlin Rules on Water Resources (ILA 2004), and the European Union Water Framework Directive (EU 2000, Salman 2007).

The UN Watercourses Convention was adopted in 1997 but did not enter into force until 2014. A total of 40 entities have signed, approved, accepted, acceded to, or ratified the treaty.[1] Article 4 provides that all watercourse states can participate in agreements that apply to the entire international watercourse, and if expected to be significantly affected, are entitled to participate in consultation and negotiations. Article 5 includes the provision that international watercourses should be used in an "equitable and reasonable" manner to attain optimal and sustainable utilization of benefits as set forth in the Helsinki Rules. Article 7 states that those using an international watercourse shall take all appropriate measures to prevent "significant harm" to other watercourse users. If harm is caused, the party responsible shall eliminate or mitigate the harm, and discuss compensation. Article 8 requires cooperation between watercourse states in "good faith," with regular exchange of data and information (Article 9). Article 10 states that no use has priority over other uses, except for consideration of vital human needs. The UN Watercourses Convention provides a general framework and allows countries or states to determine the specifics for their watercourses in cooperation with their neighbors.

The UNECE Water Convention was adopted in Helsinki in 1992, in force in 1996, and opened globally to all UN member states to sign in 2016. A total of 44 entities have signed, ratified, acceded to, or approved the treaty,[2] including the European Union (EU). This convention is considered fully compatible with the 1997 UN Watercourses Convention, and several states are party to both, because they are very similar. The Water Convention comprises three principles:

[1] A full list of countries that are party to the UN Watercourses Convention is available at https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-12&chapter=27&lang=en
[2] A full list of countries that are party to the UNECE Water Convention is available at https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-5&chapter=27&clang=_en

the "no harm rule" to prevent transboundary impacts (including pollution, conservation, and restoration), the equitable and reasonable utilization principle, and the principle of cooperation (UNECE 2015a, b). This convention requires watercourse states to enter into agreements or treaties in alignment with these principles across international boundaries, and obligates the formation of joint management bodies, while the UN Watercourses Convention merely recommends these steps be taken (Rieu-Clarke 2008). The Water Convention also supports the implementation of the 2030 Agenda for Sustainable Development (UN 2015), notably Target 6.5 – "implement integrated water resources management at all levels, including through transboundary cooperation as appropriate" (UN 2018).

The EU Water Framework Directive was established in 2000 and provides a framework for environmental protection of all freshwater and coastal waters throughout its territory. A key point of the Water Framework Directive is management on a river basin or catchment scale, in order to create or maintain "good water status" (Baranyai 2016). This naturally points to transboundary cooperation (van Rijswick et al. 2010). The Water Framework Directive includes several procedural requirements for coordinated management of these international river basins, including formation of River Basin Management Plans (Skoulikaris and Zafirakou 2019) and other tools for compliance (Keessen et al. 2018).

The UN Watercourses Convention and the UNECE Water Convention form the basis of present day international water law, in conjunction with numerous regional and small-scale agreements. Throughout these agreements, the principles of equitable and reasonable utilization, no significant harm, cooperation, information exchange, notification, consultation, and peaceful settlement of disputes are common (Rahaman 2009, Kliot et al. 2001). The next section describes a few key examples of joint management of transboundary rivers that could inform our case.

5.2 Case Studies of Cooperative Transboundary River Management in Europe

There are 310 delineated international river basins globally (McCracken and Wolf 2019), and many of them already have in place some form of joint management commissioning body or treaty between entities (UNEP and OSU 2002). Where these agreements are in place, nearly all of them provide for creation of a joint body or commission to manage the basin (UNECE 2018), as stipulated by the Water Convention (UNECE 1992). The tasks to be implemented by these joint bodies are described in Article 9(2) of the Water Convention, including pollution control, monitoring of water quality and quantity, information sharing, facilitation of consultation on planned projects or installations, and participation in environmental impact assessments. Table 2 below synthesizes the agreements and structures of nine river commissions throughout Europe, including parties to any agreements and uses covered by the agreements. We note that of the nine examples, only two cases (Meuse and Sava Rivers) represent similar coordination interests in water allocation and hydropower, along with flood control and water quality, which would also likely further enhance the coordination. To provide additional insight, we extended the review of transboundary agreements outside of Europe, this time focusing on agreements that include water supply or water allocation along with hydropower interests.

Table 3 describes the few additional examples outside of Europe. Though none of these examples of river commissions fully encapsulate the challenges unique to the Ibar/Ibër River and the connection to both water and energy securities of one of the entities involved, this review provides key insights into the range of possibilities for the structure of a river commission. We also note that the Columbia River Treaty and its development provide an interesting case for the governments of Kosovo and Serbia to explore because of the coordination of storage to enhance flood control, water supply, and hydropower services, that influence the management of Grand Coulee Dam in the United States (Stern 2020). Consequently, we provide some more detail in the recommendation section about Grand Coulee Dam management in the context of the Columbia River Treaty.

Table 2. Case studies of cooperative transboundary river management in Europe.

River Basin	Entities Involved	Management Agreements	Institutions	Uses Considered in the Agreement
Danube	17 European states and the European Commission, United Nations Development Program, United Nations Environment Program, World Bank	Danube River Protection Convention (ICPDR 1994), Danube River Basin Management Plan (IPCDR 2009) and 2015 Update (ICPDR 2015)	International Commission for the Protection of the Danube River[a]	Navigation, pollution control
Elbe	Czech Republic, Germany (Austria and Poland as observers)	International Commission for the Protection of the River Elbe 1990 (ICPE 1990)	ICPE, Coordination Group, Working Groups	Drinking water, irrigation, ecosystem restoration, pollution control
Ems	Germany, the Netherlands	Ems International Management Plan: 2015-2021 (SGD Eems 2015)	SGD Eems[b], Ems River Basin Community[c]	Border control, navigation, ecological protection
Meuse	France, Luxembourg, Germany, Belgium, the Netherlands	Meuse Convention (International Agreement on the River Meuse 2002), Meuse Agreement (FAO 1994a)	International Commission for the Protection of the Meuse[d]	Pollution control, water allocation, flood control, hydropower
Nestos/ Mesa	Greece, Bulgaria	1995 Agreement for the waters of the Nestos River (Greek National Legislation 1996), though it was never implemented (Kampragou et al. 2007)	None	Water allocation (percentage-based), water quality, pollution control
Oder	Germany, Poland, Czech Republic, European Community	Convention on the International Commission for the Protection of the Oder (1996)	International Commission for the Protection of the Odra River against Pollution[e]	Pollution control, drinking water, agriculture, flood control, navigation

River Basin	Entities Involved	Management Agreements	Institutions	Uses Considered in the Agreement
Sava	Bosnia and Herzegovina, Croatia, Slovenia, Serbia	Framework Agreement on the Sava River Basin (FASRB 2002)	International Sava River Basin Commission[f]	Navigation, hydropower, flood control, water quality and quantity
Scheldt	France, Belgium, the Netherlands	Scheldt Convention (International Agreement on the River Scheldt 2002), 1994 Scheldt Agreement (FAO 1994b)	International Scheldt Commission[g], Flemish-Dutch Scheldt Commission[h]	Pollution control, port access, navigation, salinity, flood control
Rhine	Germany, France, Luxembourg, The Netherlands, Switzerland	1998 Rhine Convention (Convention on the Protection of the Rhine 1998)	International Commission for the Protection of the Rhine[i]	Water quality, environmental protection, pollution control, drinking water, flood control

(a) https://www.icprd.org/main
(b) https://www.ems-eems.nl/
(c) https://www.ems.eems.de/
(d) http://www.meuse-maas.be/
(e) http://www.mkoo.pl
(f) http://www.savacommission.org/
(g) http://www.isc-cie.com/
(h) https://www.vnsc.eu/
(i) https://www.iksr.org/en

Table 3. Additional examples of cooperative transboundary river management outside of Europe.

River Basin	Entities Involved	Management Agreements	Institutions	Uses Considered in the Agreement
Mahakali	India, Nepal	Mahakali Treaty (1996)_	Mahakali River Commission, though it was never implemented (Bagale and Adhikari 2020)	Water sharing for power generation, irrigation use, flood control
Mekong	Thailand, Laos, Vietnam, Cambodia (China and Myanmar included as observers only)	1995 Mekong Agreement (Mekong River Commission 1995)	Mekong River Commission[a]	Hydropower, flood control, fishing, irrigation, navigation, salinity control, water supply
Senegal	Mauritania, Mali, Senegal, Guinea	Convention Establishing the Organization for the Development of the Senegal River (1972)	Senegal River Authority[b]	Navigation, irrigation, hydropower, ports
Columbia	United States, Canada	Columbia River Treaty (1961), in renegotiations for modernization beginning in May 2018	Implemented by BC Hydro[c], U.S. Army Corps of Engineers[d], and Bonneville Power Administration[e]	Flood control, hydropower, ecosystem benefits

(a) http://www.mrcmekong.org/
(b) http://www.omvs.org/
(c) https://www.bchydro.com/
(d) https://www.nwd.usace.army.mil/CRWM/Columbia-River-Treaty/
(e) https://www.bpa.gov/Projects/Initiatives/Pages/Columbia-River-Treaty.aspx

6.0 Recommendations

Recommendations for how to enhance water and electricity security in the region dependent on Gazivode/Ujmani System and Ibër-Lepenc/Ibar-Lepenac Canal operations are described in the following sections. Implementation of these recommendations, if pursued, would require additional funding.

6.1 Upgrade the Water Infrastructure

We support the infrastructure repair and modernization recommendations made by the World Bank (2015), including development of additional water storage and improvements to the canal lining and aqueducts. The additional storage would provide resilience to the overall hydrosystem in case of any disruptions on either the canal or the Gazivode/Ujmani System operations and infrastructure. The repairs of the canal would also reduce the currently substantial water losses (45 percent of water delivery), thereby providing more opportunities to other water uses, and enhancing the energy and economic value of the hydropower operations.

More specifically, these recommendations propose construction of a new reservoir in Mihaliq/Mijalić that would have a capacity of about 1,100,000 m^3 to buffer the water supply for power plant cooling and allow for maintenance work on the canal. They also include the addition of a lining of 12 cm reinforced concrete on top of the damaged sections in the upstream half of the canal as part of rehabilitation and modernization. Additional renovation is recommended in aqueducts, to fix leaking expansion joints, remove debris and algae, fill holes, and fix other damage and leakage. Along with these infrastructure improvements, further measures are proposed to protect the water resource from pollution, including turbid water, waste deposits, sedimentation, and vegetation. The recommended work includes construction of additional bridges and walkways, access roads, covering slabs, fencing, run-off protection, retaining walls, trash racks, and vegetation treatment. Each of these recommendations is described more fully in the *Feasibility Study for the Protection of Ibar-Lepenac Canal* report (World Bank 2015).

6.2 Implement SCADA Systems to Enhance Power Plant Revenues and Improve Load Balancing

We recommend using SCADA systems to upgrade the water and electricity infrastructure at the Gazivode/Ujmani System. Connecting the acquired data and controls to KOSTT energy management system (EMS) would provide additional abilities for KOSTT to balance the load and manage regional electricity prices. For Gazivode/Ujmani hydropower plant, the connection to the resulting power system model data and electricity demand forecasts would also enhance revenues by scheduling hydropower operations when prices are high. Operating agreements are needed. The SCADA data can be also used to inform power system planning models and would help identify infrastructure investment needs that could provide more economic grid operation services, such as ramping capabilities and cycling to add the flexibility needed to integrate renewable energies.

6.3 Implement a River Commission and Valuation of River Services

An established water management plan and operating rules, including joint operations with the Ibër-Lepenc/Ibar-Lepenac Canal, that would benchmark the energy and economic value of Gazivode/Ujmani system operations and other uses such as water supply and water quality management, is necessary for the exploration of transboundary coordinated opportunities.

We further recommend the formation of an Ibar/Ibër River commission or committee that would support regional stakeholders and coordinate river operations. To anticipate the potential structure for such a commission, we reviewed international water laws and case studies of nine European transboundary river agreements and structures of river commissions. The review focused on the technical objectives addressed by a commission. None of the reviewed agreements cover the regional challenges of the Ibar/Ibër RiverIbar/Ibër River, where hydropower revenues sustain the water and electricity security of part of the river basin. We describe the complex coordination between U.S. and Canada water supply, flood control, and power agencies engaged in the U.S.-Canada Columbia River Treaty to illustrate the modeling and institutional needs to support such a commission for the Ibar/Ibër River. The modeling and analytical needs include a coordinated and joint effort to value the monetized and non-monetized river services provided by the dam and address the cost and value of evolving upstream and downstream needs.

The Columbia River Basin is a transboundary river basin in the Pacific Northwest of America, in Canada and the United States. The headwaters of the Columbia River main stem are located in Canada, and in the United States, with a confluence of headwaters in Canada below which the Columbia River flows into the United States. The socioeconomic development in the mid-1900s was minimal in the Canadian region while in the United States the irrigation project was being extended. Grand Coulee Dam, the main U.S. storage in the basin, provides flood control to growing cities along the river, hydropower, and water supply. Coordination was explored to enhance storage in Canada, which would provide additional flood protection and hydropower benefits. The 1961 Columbia River Treaty[1] (hereafter Treaty) was implemented by Canadian and U.S. entities. The Canadian entity is BC Hydro, and the U.S. entities are Bonneville Power Administration and the U.S. Army Corps of Engineers (Northwestern Division). The organization of the Treaty is shown in Appendix C. The objectives of the Treaty are adequate flood risk management, a reliable and economical power supply, and more recently, protection of ecosystem-based function. The Treaty led to the construction of four dams (Keenleyside/Arrow, Duncan, Mica, Libby; Figure 12) to create 15.5 million acre-feet of water storage for flood control, hydropower, and other downstream benefits. As the recipient of these benefits, the United States agreed to pay Canada in cash and hydropower benefits (known as the “Canadian Entitlement”).

[1] The Columbia Treaty. 1961. Available at https://engage.gov.bc.ca/app/uploads/sites/6/2012/04/Columbia-RiverTreaty-Protocol-and-Documents.pdf

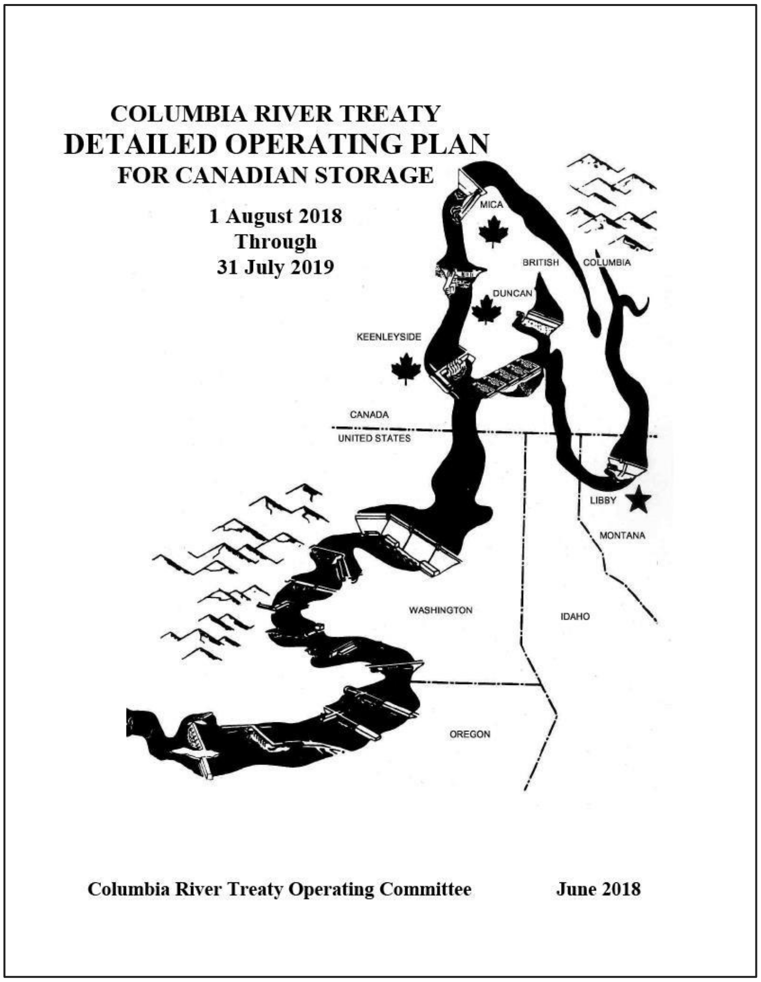

Figure 12. Dams coordinated through the Columbia River Treaty. (Source: US Army Corps of Engineers, https://usace.contentdm.oclc.org/digital/api/collection/p266001coll1/id/7979/download)

The U.S. entity reviewed the Treaty and delivered a recommendation for its modernization in 2013.[1] This update to the Treaty would include an ecosystem-based function in negotiations (including base stream flows), Columbia Basin Tribes resource protection, redefinition of the compensation package for Canada related to flood storage, incorporation of climate change impacts, and membership updates. British Columbia initiated their own Treaty review process and published the B.C. Decision[2] in 2013, recommending continuance of the Treaty while seeking improvements within the existing Treaty framework. These recommendations focus heavily on appropriate compensation to Canada for benefits provided, as well as exclusion of salmon management from any Treaty considerations and incorporation of climate change impacts into management and planning. Negotiations between the United States and Canada began in May 2018. The stated goal of both parties is to maximize benefits received by the United States and Canada.

[1] U.S. Entity Regional Recommendation for the Future of the Columbia River Treaty after 2024. 2013. Available at https://www.bpa.gov/Projects/Initiatives/crt/CRT-Regional-Recommendation-eFINAL.pdf

[2] Columbia River Treaty Review: B.C. Decision. 2013. Available at https://engage.gov.bc.ca/app/uploads/sites/6/2012/03/BC_Decision_on_Columbia_River_Treaty.pdf

The benefits are evaluated using a combination of climate, hydrology, water management, and power system models, along with economic evaluation of hydropower operations in a transitioning energy sector. The outcome of the negotiation affects the timing and volume of water flowing into Grand Coulee Dam, and the ability of the dam and downstream much smaller dams to maintain or enhance flood control and hydropower benefits, as well as maintaining water supply and addressing environmental considerations.

Grand Coulee Dam is operated by the Bureau of Reclamation, in accordance with storage targets also referred to as rule curves, with a set of rules derived for varying water conditions as projected by snow measurement and seasonal flow forecasts. The rule curves are re-evaluated as part of the Treaty renegotiation because different upstream river management would affect activities in the United States.

Despite fundamental differences in the water and energy systems in the Columbia and Ibar/Ibër Rivers, and upstream and downstream interactions between countries, a common technical challenge for coordination involves the operations of large storage reservoirs operated for hydropower and water supply in both situations. Table 4 summarizes side by side some physical and operational characteristics of both the Grand Coulee and Gazivode/Ujmani Dams. Despite similar operational objectives (water supply and delivery), Grand Coulee reservoir can only store 1/10th of the mean annual flow, resulting in a main seasonal water management strategy focused on flood control and based on storage targets. Both reservoirs, however, aim for full storage for the beginning of the irrigation season and maintain the reservoir at high levels for sustained hydropower capacity. Storage and hydropower capacity decrease during summer months. Similar to the Lake Gazivode/Ujmani System, revenues from hydropower support the water storage and delivery operations while hydropower operations do not have priority over storage operations. While outside of the transboundary coordination exploration, the economic value of hydropower within the region’s energy transition is essential to maintaining the water security of Kosovo if no other funds can support the operation and maintenance of the Gazivode/Ujmani System and Ibër-Lepenc/Ibar-Lepenac Canal.

Table 4. Physical and operational characteristics of the Grand Coulee and Lake Gazivode/Ujmani Dams.

	Lake Gazivode/Ujmani, Dam and Hydropower Plant	Grand Coulee Reservoir, Dam and Hydropower Plant
Reservoir Capacity	375 Mm^3	11,795 Mm^3
Ability to store inflow (inflow/capacity ratio) with interannual variations	1.10	10.38
Water uses	Water storage and delivery, hydropower	Flood control, water storage and delivery (Columbia Basin Project), hydropower, recreation, fisheries
Water supply (% of reservoir and % of annual inflow)	28% of reservoir capacity 25% of inflow	34% of reservoir capacity 3.3% of inflow
Hydropower plant capacity	33.35 MW	6,809 MW
Hydropower annual generation	101,000 MWh	20,240,000 MWh
Hydropower operations	Baseload during peak hours.	Baseload, peaking
Hours of operations at full capacity (just a benchmark estimate because capacity decreases with lower storage levels)	2592	2973
Water management	Appears to be driven by water supply release targets in summer and hydropower generation otherwise (storage targets)	Rule curves based on seasonal flow forecasts

6.4 Improve the Predictability of the Water Supply

Assuming that the infrastructure repair and modernization recommendations are followed along with the implementation of SCADA systems in all power plants, there are a couple of additional ways to further enhance the overall value (water supply, energy, and economic value of the release) of the Gazivode/Ujmani System operations. We recommend working with stakeholders to establish seasonal water demand projections to be communicated on an agreed-upon date or lead time that supports the optimization of the dam operations. We also recommend the evaluation of seasonal and medium-range flow forecasts. For a reservoir of such storage capacity, storage targets for the end of the irrigation season tend to have major impact on the operations and would help maintain the lake level for generation in wintertime. It would also provide guidance and transparency for the distribution of the system release into the canal and the natural riverbed. Seasonal flow forecasts have also been shown to support the optimization of reservoir operations, in this case to support the planning of operations during the spring season. Finally, medium-range flow forecasts are useful when reservoir levels are high, in order to further fill the reservoir to enhance the energy value of dam releases. Given the current operations, having to generate during day hours to capture the flood volume would also lead to increased revenues. While we are aware of the availability of those forecasts, their accuracy in this region has not been evaluated yet. Data derived from additional river gauges and snow measurement stations in the upstream watershed would provide immediate benefits to the dam operations.

Climate change is currently the major unknown affecting the inflow into the lake given the existing low level of socioeconomic development, and is a threat to transboundary water management worldwide (Zeitoun et al. 2013). Table 5 below shows the projected precipitation and temperature at the city of Mitrovica/ë North and Mitrovicë/a South (World Bank Group 2018). The highest uncertainty is in the overall amount of precipitation and its timing. The area draining into the Lake Gazivode/Ujmani has a more mountainous climate than Mitrovica/ë North and Mitrovicë/a South (Ivanović et al. 2016). The reservoir storage is such that the precipitation volume—rain or snow—would be captured. However, less snow but more rain would affect the summer inflow, and thus decrease the energy value of the inflow, but not necessarily its economic value. The 2011 World Bank report evaluated the impact of climate change and socioeconomic development scenarios on the Kosovo water demands and the ability of the overall water infrastructure to meet the water demands. Under climate change conditions, the likelihood of severe summer drought is expected to increase significantly (World Bank Group 2018), which would exacerbate Kosovo's existing water stress. The compounded impacts of climate change on the water supply into Lake Gazivode/Ujmani, on Kosovo electricity demand, and on water uses could be significant, especially when further compounded with projected socioeconomic development in the region and with the energy sector transitions.

Table 5. Projected temperatures and precipitation for Mitrovica/ë North and Mitrovicë/a South. Change is calculated using the bias-corrected RCP 8.5 projection 2011–2040 mean compared to the observed 1981–2010 mean.

Month	Obs Mean Temp. (°C)	Change (BC RCP 8.5 - obs) (°C)	Obs Minimum Temp. (°C)	Change (BC RCP 8.5 - obs) (°C)	Obs Maximum Temp. (°C)	Change (BC RCP 8.5 - obs) (°C)	Obs Precipitation Amount (mm)	Change ([BC RCP 8.5 –obs]/ obs)
January	-0.5	2.2	-3.7	2.5	4	1.9	33.1	-20%
February	1.4	1.3	-2.7	1.5	7	0.8	34.38	26%
March	5.7	2	1.2	1.2	12.1	2.2	36.8	-38%
April	10.1	0.9	1.7	3.8	17	0.4	50.9	4%
May	15.5	0.6	8.7	1.1	22.9	0	46.9	70%
June	19	0.6	11.9	0.8	26.3	0.1	55	-1%
July	20.9	1.1	13.7	1.2	28.7	0.8	50.2	-13%
August	20.3	0.2	13.4	0.3	28.9	-0.3	39.4	40%
Sept.	15.7	1.1	9.5	1.3	23.8	1.2	50.8	5%
October	11	0.9	5.1	1.3	18.3	0.8	38.7	9%
Nov.	5	1.8	1.1	1.9	10.5	1.4	60.5	0%
Dec.	1	2	-2.1	2.3	5	1.8	46.7	13%
Year	**10.4**	**1.3**	**5.1**	**1.4**	**17.1**	**0.9**	**543.2**	**8%**

6.5 Synthesis

The long-term electricity resource adequacy and reliability studies in the region are challenged by the uncertainty in socioeconomic development, including potential energy and industrial transformations. Stronger water and energy security supported by our recommendations is expected to trigger investor engagement and support less uncertain projections of socioeconomic development in the region.

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Appendix A

Visits at the Gazivode/Ujmani System and Kosovo Thermoelectric Plants

Figure A.1. October 2020 visit at the Gazivode/Ujmani System and Kosovo thermoelectric plants Kosovo A and B, which are supplied with cooling water using freshwater releases from the Gazivode/Ujmani System through the Ibër-Lepenc/Ibar-Lepenac Canal.

Appendix B

Gazivode/Ujmani System Data

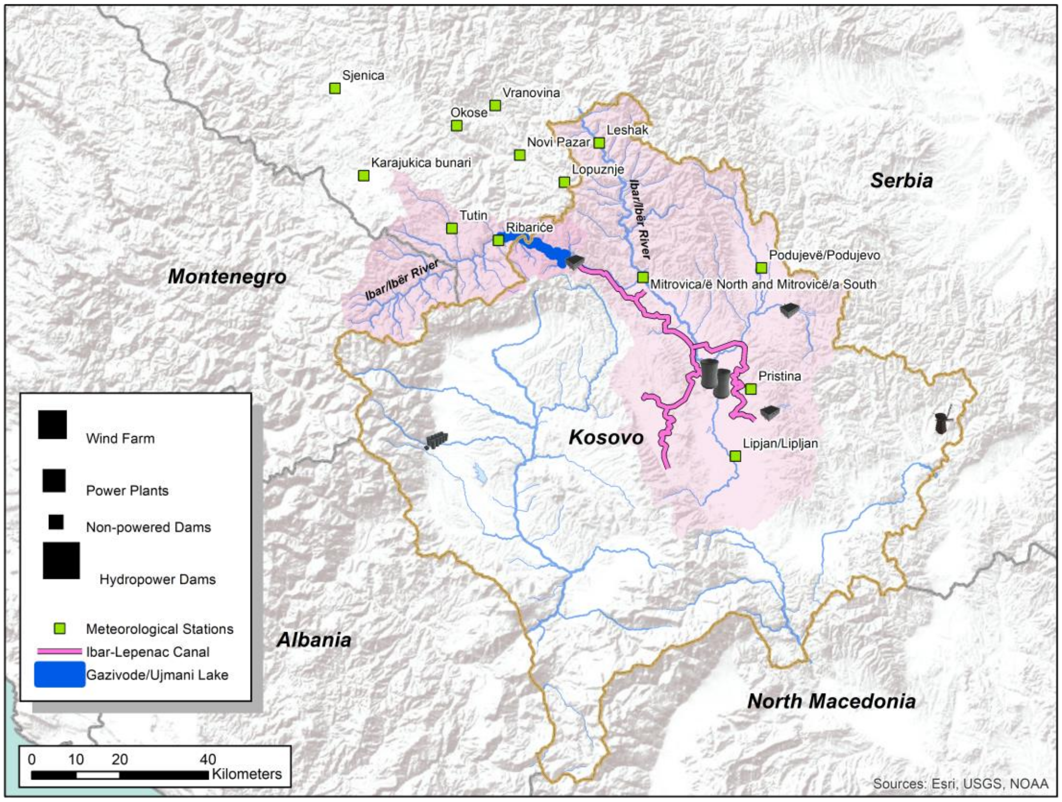

Figure B.1. Meteorological station map.

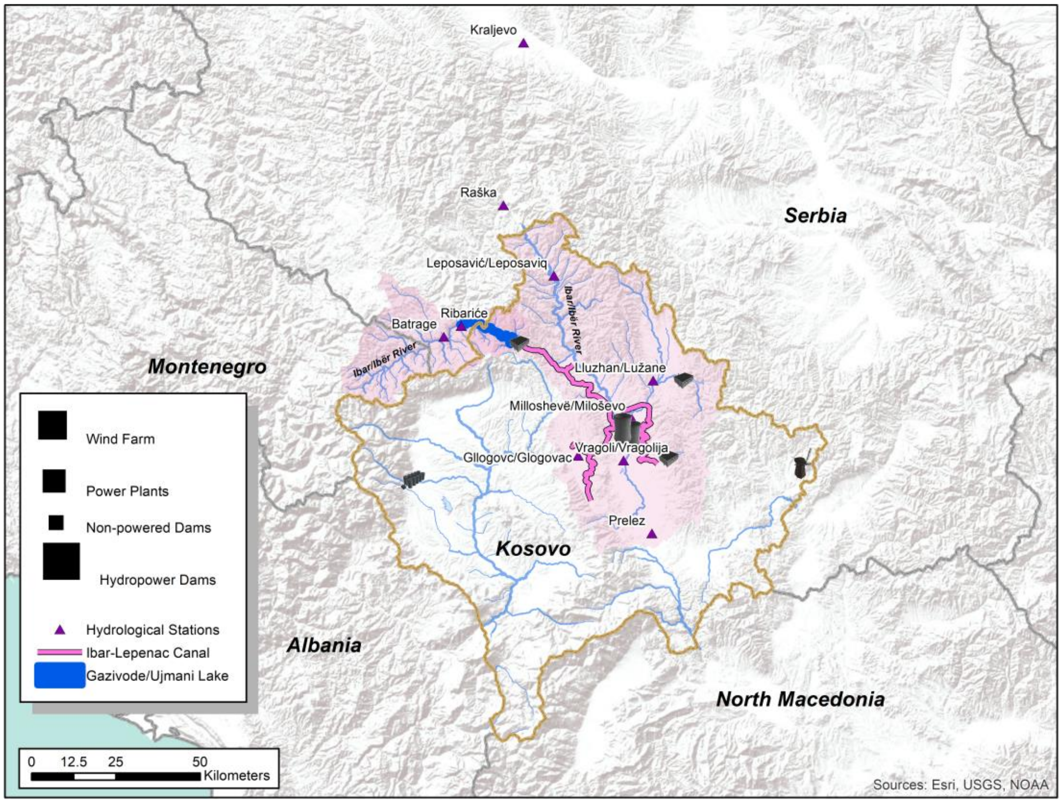

Figure B.2. Hydrological station map.

Table B.1. Meteorological data.

Data	Source	Format and Documentation
Meteorological station measurements	Hydro-Economic Enterprise Ibër-Lepenc, Kosovo	Meteorological data_Prishtinë 2001-2013.doc • Monthly temperature, relative humidity, precipitation, and wind, 2001-2013
Meteorological station measurements	Hydrometeorological Institute of Kosovo	Pellgu_Ibrit_Reshjet.xls • Daily precipitation at 5 stations Lešak/Leshak/Leposavić/Leposaviq 7/1/2017-9/30/2020 Lipjan/Lipljan 1/1/2016-9/30/2020 Podujevë/Podujevo/Shajkovc/Šajkovac1/1/2006-9/30/2020 Podujevë/Podujevo/Batllavë/Batlava 1/1/2016-1/31/2020 Podujevë/Podujevo/Zakut 1/1/2006-9/30/2020

Data	Source	Format and Documentation
Meteorological station measurements	Hydrometeorological Institute of Kosovo	Te_dhenat_Meteorologjike_Mitrovicë (2).xlsx • Mitrovicë daily precipitation, temperature, and relative humidity, 1/1/2016-9/30/2020 Te_dhenat_meteorologjike_Prishtine.xlsx • Pristina daily precipitation, temperature, and relative humidity, 1/1/2006-9/30/2020
Meteorological station measurements	The Republic Hydrometeorological Institute, Serbia	Climatological_Data_Ibar River Basin.xlsx • Daily Precipitation, temperature, relative humidity, and solar radiation from 8 stations with varying availability ranging from 1961 to 2019: • Lopuznje, Okose, Vranovina, Ribariće, Karajukica bunari, Novi Pazar, Tutin, Sjenica
Climate change assessment	The Republic Hydrometeorological Institute, Serbia	Gazivode_CC part.docx • Monthly climate model projection of temperature and precipitation for the RCP8.5 (2011–2040) along with observed monthly climatology. Data cover 4 sites, including Mitrovica/ë North and Mitrovicë/a South.

Table B.2. Hydrological data.

Data	Source	Format and Documentation
River gauge measurements	Hydrometeorological Institute of Kosovo	Te_dhenat_Hidrologjike_Pellgu_Ibrit (1).xls • Daily water level at 3 gauges on Ibar/Ibër River, incomplete recording over the specified time periods below: Leposavić/Leposaviq, 1/1/1939-12/31/2019 Prelez,1/1/1954-12/31/2018 Ribariće, 1/1/1950-12/31/1973 • Daily flow rate at 3 gauges, incomplete recording over the specified time periods below: Leposavić/Leposaviq, 1/1/1960-12/31/1998 Prelez, 1/1/1960-12/31/1994 Ribariće, 1/1/1968-12/31/1973

Data	Source	Format and Documentation
River gauge measurements	Hydrometeorological Institute of Kosovo	Pellgu_Ibrit_Hidrologjike.xls • Daily Water levels at 5 gauges: Vragoli/Vragolija 7/18/1909-9/30/2020 Nedakovc/Nedakovac 9/3/1953-9/30/2020 Gllogovc/Glogovac 7/10/1957-5/7/2017 Milloshevë/Miloševo 8/16/1950-8/17/2020 Lluzhan/Lužane 10/1/1953-8/17/2020 • Daily flow rate at 4 gauges: Nedakovc/Nedakovac1/1/1963-12/31/1998 Gllogovc/Glogovac 1/1/1981-3/31/1998 Milloshevë/Miloševo 1/1/1980-8/17/1998 Lluzhan/Lužane 1/1/1980-12/31/2019
River gauge measurements	Hydro-Economic Enterprise Ibër-Lepenc, Kosovo	L.Iber S.Ribariç.xls • Daily water level and flow rate measurements at Ribariće, incomplete records for 1950-1973 Lumi Ibër stacioni Prelez.xls • Daily water level and flow rate measurements at Prelez, incomplete records over 1969-2007 Lumi Ibër Stacioni Leposaqeviq.xls • Daily water level and flow rate measurements at Leposavić/Leposaviq, incomplete records over 1934-1997 7 other Excel spreadsheets that contain flow and water level measurements at river gauges that are not on Ibar/Ibër River. River Drenica.xls Lumi Ilap Stacionii Luzhanë.xls Lumi Sitnica Stacioni Nadakovc.xls Prishtevka-Prishtine.xls L.Drenica S.Drenic.xls L.Sitnica S.Duber dub.xls L.LLap S.Millosheve.xls
River gauge measurements	The Republic Hydrometeorological Institute, Serbia	Hydrological_Data_Ibar River_hydrological station_Batrage_H_Q.xlsx • Batrage daily flow rate with incomplete record from 5/15/1980 – 9/302020

Data	Source	Format and Documentation
River gauge measurements	PoE "Ibar" Zubin Potok	Godišnji protok ibra.xlsx • Annual flow rate back calculated from hydropower production, 2010-2020
Water quality measurements	The Environmental Protection Agency, Serbia The Regional Water Supply Gazivode	Copy of XI0000093.xlsx • Monthly water quality measurement in 2018 at 3 sites: Batrage, Kraljevo, and Raška Copy of XI0000094.xlsx • Monthly water quality measurement in 2017 at 3 sites: Batrage, Kraljevo, and Raška izvestaj Regionalni vodovod Gazivode.pdf • Report of the Regional Water Supply Gazivode/Ujmani, with some water quality measurement in 2020 at water intake of the Gazivode/Ujmani Dam.

Table B.3. Hydropower and water management.

Data	Source	Format and Documentation
Dam characteristics and operations	Hydro-Economic Enterprise Ibër-Lepenc, Kosovo	IL_data_2020.xlsx • Dam characteristics • Daily generation, 2011-2020 • Daily reservoir water level, 2006-2020
Dam operations	Hydro-Economic Enterprise Ibër-Lepenc, Kosovo	Janar-Dhjetor 2000 - 2010.xls Janar-Dhjetor 2012.xls Janar-Qershor 2013.xls • Daily reservoir water level, 2000-2013 Prodhimi i en.elektrike 2006-2010.xls • Monthly generation, 2006-2010
Dam operations	PoE "Ibar" Zubin Potok, Kosovo	Kota jezera Gazivode.xlsx • Elevation of Lake Gazivode/Ujmani 2014-2020
Canal flow rate	PoE "Ibar" Zubin Potok, Kosovo	Godišnji protok kanala.xlsx • Canal flow rate provided in 10-day frequency from 2010 to 2020

Table B.4. Electricity generation and power flow data.

Data	Source	Format and Documentation
Electricity demand and production	KOSTT, Kosovo	KOSTT DATA 2018-2019.xlsx • Hourly demand and generation from different sources, 2018-2019
Electricity demand and production	Elektromreža Srbije A.D, Serbia PoE “Ibar” Zubin Potok, Kosovo	accounting dataobračunski podaci po DV i TS Valač/Vallaq 01122020.xlsx • 2019-2020 Hourly electricity needs for northern Kosovo 2019 and 2020 daily electricity Production of Gazivode/Ujmani Dam, consumption, and need to supply • Data of each day is saved as an Excel spreadsheet
Electricity production	PoE “Ibar” Zubin Potok, Kosovo	dijagram proizvodnje aktivne i reaktivne energije u 2019.xlsx, • Monthly Gazivode/Ujmani Dam hydropower generation in 2019 dijagram proizvodnje aktivne i reaktivne energije u 2020.xlsx, • Monthly Gazivode/Ujmani Dam hydropower generation in 2020
Regional power flows	Elektromreža Srbije A.D, Serbia	EMS and KOSTT Internal_External_2019_2020_without BRPs_za slanje.xlsx • Hourly import/export power flow with external entities in 2019 and 2020.

Appendix C

Organization Chart for the Columbia River Treaty

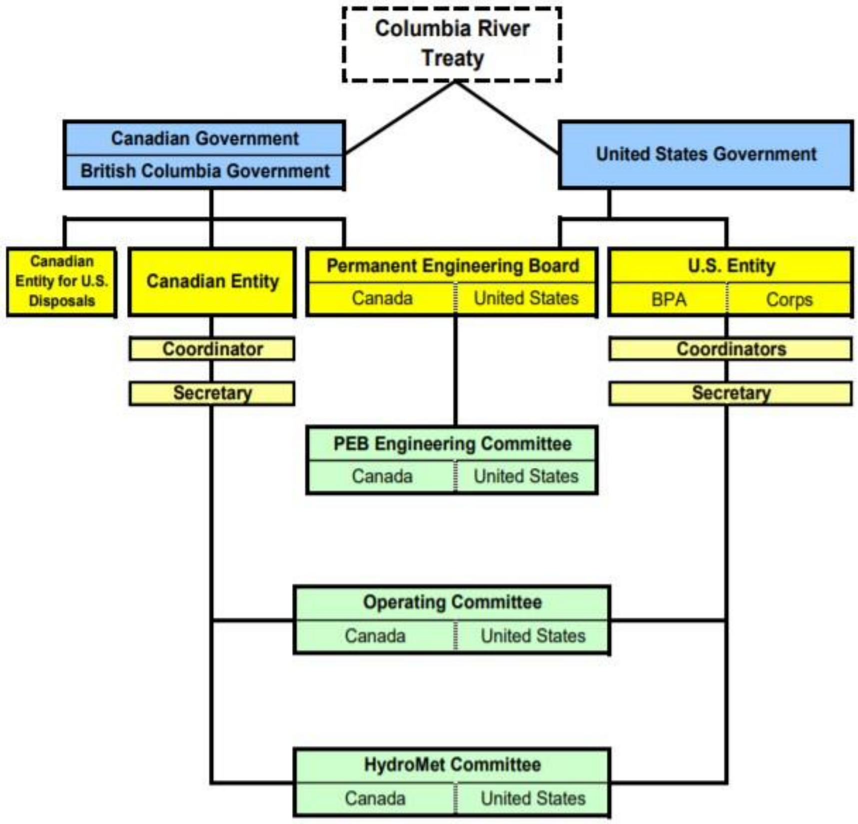

Figure C.1. Organization chart for the Columbia River Treaty. (Source: U.S. Army Corps of Engineers) The use of the Columbia River Treaty as an example does not imply any similarities in the political relationship nor suggest that political agreements between the U.S. and Canada under the treaty would work in exactly the same way as agreements between Kosovo and Serbia. The model is used for technical recommendations only.

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