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WATER PARTNERSHIP PROGRAM

Water & Climate Adaptation Plan for the Sava River Basin

ANNEX 3 - Guidance Note on Adaptation to Climate Change for– Hydropower

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GUIDANCE NOTE ON ADAPTATION TO CLIMATE CHANGE FOR THE SAVA RIVER BASIN – HYDROPOWER

1 Introduction

This report provides guidance note for decision making on the adaptation needs related to hydropower in the Sava River Basin (SRB). This guidance note is one of the components of the Water and Climate Adaptation Plan (WATCAP) being prepared by the Consultant for the International Sava River Basin Commission (ISRBC) under World Bank funding.[1] It builds on the main WATCAP report (World Bank, 2013b), the report on the development of future climate scenarios (Vujadinovic and Vukovic, 2013) and on the report on development of the hydrologic model for the Sava River basin (World Bank, 2013a). Thus, the guidance note is designed to provide fundamental and flexible instruction on how to conduct impact and vulnerability assessments in the energy sector, specifically for hydropower facilities along with identification opportunities and entry points for integration of climate change mitigation and adaptation measures into the hydropower energy (HPE) sector processes.

An eminent example upon which this guidance note on the hydropower sector is based is The Integrated Water and Energy Nexus Study (IWENS) for the Vrbas Basin, a tributary of the Sava River (see Figure 1), that represents a snapshot of the complex and integrated use, development and management of water resources, in order to meet the water needs of multiple users and their future harmonization as well as adapting to climate change.[2]

Figure 1: Location of Vrbas River Basin within Sava River Basin

[1] COWI AS of Norway were contracted by the World Bank to undertake the development of the hydrologic model – World Bank Contract No - 7162102
[2] COWI (2012) Update of the Water Resources Management Basis for the Vrbas River Basin, project report for the World Bank.

In order to provide proper information about climate change impact on the hydropower sector various analysis were performed with useful results that define an adaptation strategy direction. Similarly, though less extensive analysis is done for the purpose of completing this Adaptation Guidance note and also by giving an example for conducting a more profound and detailed analysis in the future.

2 Climate change impact on Hydropower – Vulnerability Screening

Climate change (CC) impact on the hydropower sector is mainly seen in the effects on power generation potential. Hydropower production would either be positively or adversely affected, depending on the CC effects and how are they managed. Change of three climate parameters as a consequence of CC should be analysed, namely: precipitation, temperatures and evaporation/evapotranspiration (ET). These three parameters are all important components of the hydrological cycle that affects river discharge, which in turn is a major input to power generation calculation.
Consequently, major projected climate change impacts on the HPE sector are:

- Decreased or increased HP generation potential due to more or less precipitation and consequently more or less river runoff;
- Reduced or increased energy demand for heating or cooling, with regard to CC by means of higher or lower air temperatures;
- A decrease or increase of installed flow for facilities changing HPP effectiveness;
- Flooding and landslides damage or complete destruction of HP structures (e.g. dams, transmission and distribution networks) that may create conflict with downstream communities, increase social vulnerability e.g. through involuntary resettlement; and
- Energy security and economic development activities will be compromised and production costs will increase.

Major vulnerability of hydropower plants and systems to CC lies in change of key parameters for power production, because they are directly linked to climate parameters. Key parameters whose change would largely affect hydropower production are:

- River discharge or mean flow and on specific dam profiles: a significant change would affect production in the same direction;
- Duration curves or a fluctuation of discharge in one time period (i.e. year, season,…) for the dam profile: a change would affect the change in total volume used for production and in the same manner production by itself;
- Evaporation/ET would affect volume of available water for production.

Some characteristics of hydropower facilities affect their vulnerability to climate change. For instance, electricity generation capacity relative change would be decreased or increased in a bigger or a smaller scale depending on the type of facility, size of the reservoir, etc. The vulnerability of different hydropower characteristics to CC are given in Table 1.
Using the pattern shown in Table 1, it is possible to define adaptation strategies depending on a specific situation.

Table 1: Hydropower climate change vulnerability according to HPP characteristic

Climate parameter	Climate parameter change	HPP type			Reservoir storage area: volume ratio		Reservoir size	
		Reservoir type	Run-of-river	Pumped storage	High	Low	Large	Small
Evapo-ra-tion/ET	Increase							

Climate parameter	Climate parameter change	HPP type			Reservoir storage area: volume ratio		Reservoir size	
		Reservoir type	Run-of-river	Pumped storage	High	Low	Large	Small
	Decrease							
River runoff	Increase			N/A				
	Decrease							
Temporal variability	Flood							
	Drought							
	Seasonal offset							

Legend: bigger decrease / smaller decrease / bigger increase / smaller increase

3 Scenarios for climate change in Sava River Basin

Climate change analysis in Sava River Basin starts with simulations of the future hydrologic regime using a hydrological model for the SRB developed in HEC-HMS. The future climate scenarios are taken from five Global Climate Models (GCM)/Regional Climate Models (RCM) simulations under the A1B Special Report on Emissions Scenario (SRES)/Intergovernmental Panel on Climate Change (IPCC) scenario and are later in text denoted as climate models -CM1 through CM5. With each climate model (CM) daily flows are simulated for three 30-year periods:

1. 1961-1990 (past or baseline climate scenario),
2. 2011-2040 (near future climate scenario), and
3. 2041-2070 (distant future climate scenario).

According to work undertaken under this WATCAP study climate change in the Sava River Basin implies:[3]

- Temperature increase about 1°C in the near future and 2.3°C in the distant future,
- Change of mean annual precipitation ranges between -6% to +4% across the Basin, but seasonal change takes values between -12% to +14% in the near future and as much as -32% to +19% in the distant future, as a mean value for all stations on the Basin. For some parts of the SRB difference is as high as ±30% in near and ±40% in the distant future;
- Seasonal variability as described by the 5 used climate models (i.e. CM1 to CM5) is not the same for all. Predictions of two climate model for the near future and three for the distant future indicate an increasing precipitation trend will occur in the winter and a decreasing trend in the summer season.

[3] COWI, 2013: Water & Climate Adaptation Plan for the Sava River Basin: Completion of the WATCAP with the construction of a hydrologic model.

Taking the information from Table 1 and the overall climate scenario results for the Sava River Basin area overall, the following conclusions can be drawn:

- With increasing evaporation/ET, due to temperature increase in the future, a bigger decrease of hydropower production is expected to occur on reservoir type and pumped storage type dams with a high storage area/volume ratio and small reservoirs. Other types of HPP would show smaller effects, but still experience a decrease of hydropower generation;
- A decrease in river runoff would affect power generation with a reduction on all facilities but in particular with run-of-river schemes in the SRB because they are highly and solely dependent on river runoff; and
- Floods in the fall/winter and droughts in the spring/summer would mostly affect run-of-river HPPs and HPP with small reservoirs. With this climate change parameter an overall power generation decrease is expected.

From all of the above it can be concluded that, in the future it would be customary to have lower power generation from the hydropower sector on the Sava River Basin from bigger or smaller schemes, depending on the region and the HPP facility. The magnitude of the change has been reviewed by conducting further analysis through case studies that are described below.

4 Case studies - Expected magnitude of climate change impact on Hydropower Sector in Sava River Basin

In the Sava River Basin there are 20 hydropower plants (HPP) with installed capacity larger than 10 MW (*see Chapter 2.4.5 of this Report)*). Four HPPs were selected as case studies for analysis of CC impact on energy production. The choice of HPP is made based upon the energy production magnitude and the share in average total energy production in the SRB or in other words upon their significance in the hydropower sector in SRB area. In addition, data needed for analysis were directly available from the developed Sava River Basin HEC-HMS Model since for each plant location of those four plants there is hydrological station included in model. All four HPPs are reservoir type dams.

Table 2: HPPs in the Sava River Basin used as Case Study

Country	HPP	River	Reservoir volume (mil m^3)	Reservoir storage area: volume ratio	Installed capacity [MW]- ref. year 2005	Installed discharge (m^3/s)	Average yearly production (ref. 2005-2007) [GWh/year]	Share* in average total energy production in SRB [%]	Share** in total installed capacity in SRB [%]
Slovenia	Blanca	Sava	9.95	0.13	43	500	144	2.2	1.8
Bosnia and Herzegovina	Bočac	Vrbas	52.1	0.045	110	240	308	4.8	4.5
Serbia	Zvornik	Drina	89.0	0.146	96	620	515	8	3.9
	Bajina Bašta	Drina	340	0.036	360	644	1691	26	14.7
Total Sava River Basin (reference year 2005)					**609 of 2449 in total**		**2658/6445 total**	**41**	**24.9**

Source: Adapted from the "Sava River Basin management Plan", Draft version, 2013.
*this refers to share of specific HPP's yearly average energy production in total yearly average energy production (from hydropower sector) in whole SRB
**this refers to share of installed capacity of the specific HPP in total installed capacity (from hydropower sector) in SRB

Simulated daily flows for the above mentioned three 30-years periods and five climate models scenarios are used to calculate the daily production for selected HPPs, with the following assumptions and generalizations:

- Efficiency coefficient value for generator is taken to be the same for all HPPs, η_{gen}=0.95;
- Efficiency coefficients for turbines that are used in the four chosen HPPs are:

Francis	0.92
Kaplan	0.9

- Useable head for energy production and for each dam is taken as a constant for each day's production calculation,
- All dams are close to dam type and no flow and head losses in the tunnel or penstock are taken into account.

Depending on the available daily flow, the flow through the turbines is calculated as:
If $Q_{river} \leq Q_{installed}$ then $Q_{turbines} = Q_{river}$
If $Q_{river} > Q_{installed}$ then $Q_{turbines} = Q_{installed}$.

Energy production is calculated using the formula:

$$E = \eta_{gen} \cdot \eta_{turb} \cdot 9.81 \cdot Q_{turb} \cdot H \cdot \Delta t \text{ [kWh]}$$

η_{gen} -coefficient of generator efficiency [-]

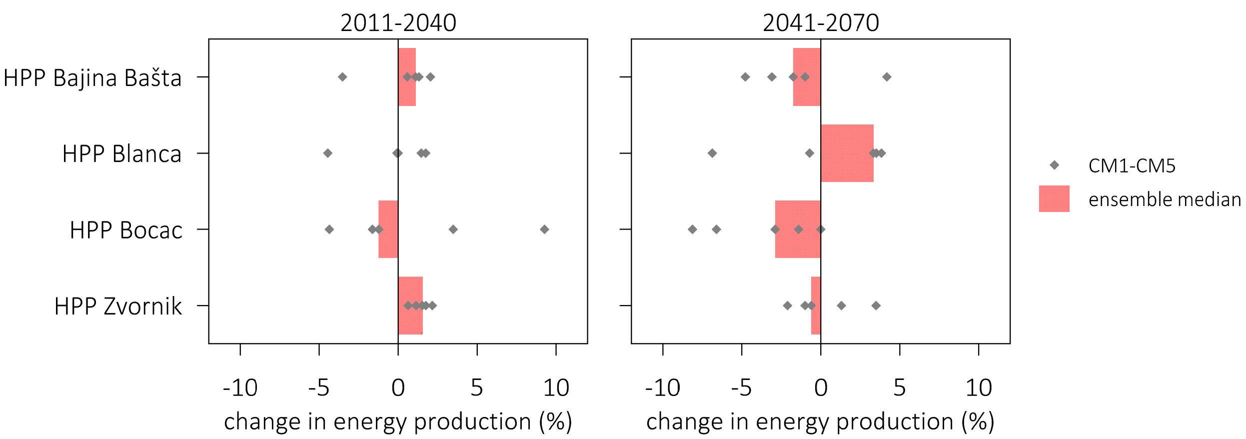
η_{turb} -coefficient of utilization of turbines [-]

Q_{turb} -flow through turbines [m^3/s]

H -dam head, difference between upstream of the dam water level (in reservoir) and downstream water level [m]

Δt -time period for which energy is calculated, 1day=24h

From the above the daily and yearly productions are calculated. The resulting averages for each 30-year period's energy production for both near and distant future scenarios are compared in relation to the baseline scenario (period 1961-1990). The results are given in Figure 2.



Source: Figure produced by COWI

Figure 2: Relative change in the annual energy production under A1B emission scenario for five climate model chains CM1-CM5 in near future (left) and distant future (right)

The results for all HPPs in the near future show a small expected change in the average annual energy production, with rather small variation between the scenarios except for HPP Bočac. Based on the ensemble median values (as a more robust estimate than the ensemble mean, which might be under influence of extreme values in short samples like this one), an increase in the range of 1-1.5% is expected at two HPPs on the Drina River (Bajina Bašta and Zvornik), and a small decrese is expected at HPP Bočac. HPP Blanca in Slovenia results in 0% change. Greater variation for HPP Bočac gives a power production decrease of 4% with CM4 and an increase of 9% with CM5, thus indicating a higher uncertainty related to the Vrbas basin hydrologic simulations and consequently to the derived energy production.

For the distant future the variation between the scenarios is greater, which is expected with the simulation period being further away from the observation period. The energy production is expected to change more markedly in this period, between -8% (HPP Bočac) and +4% (HPP Bajina Bašta), although the order of the magnitude of these changes is still in the range of the modelling and measurement uncertainties. The trend at two HPPs on the Drina River (Bajina Bašta and Zvornik) is reversed and their annual energy production is expected to decrease slightly by 1-2%. The decreasing trend for HPP Bočac continues in this period as well, while the energy production at HPP Blanca is expected to increase.

In addition to the results shown in Figure 2, seasonal energy production variability is analysed for HPP Bajina Bašta. These results are portrayed in Figure 3. The near future results show greater energy production in the winter and fall seasons, while in the spring a decrease in energy production is expected. Interestingly, the energy production in the summer season is not expected to change significantly. The distant future results show greater decrease in the spring and summer seasons (by 4% and 10% on average, respectively), whilst in the winter and fall energy production is expected to increase by 11% and 5%, respectively, on average.

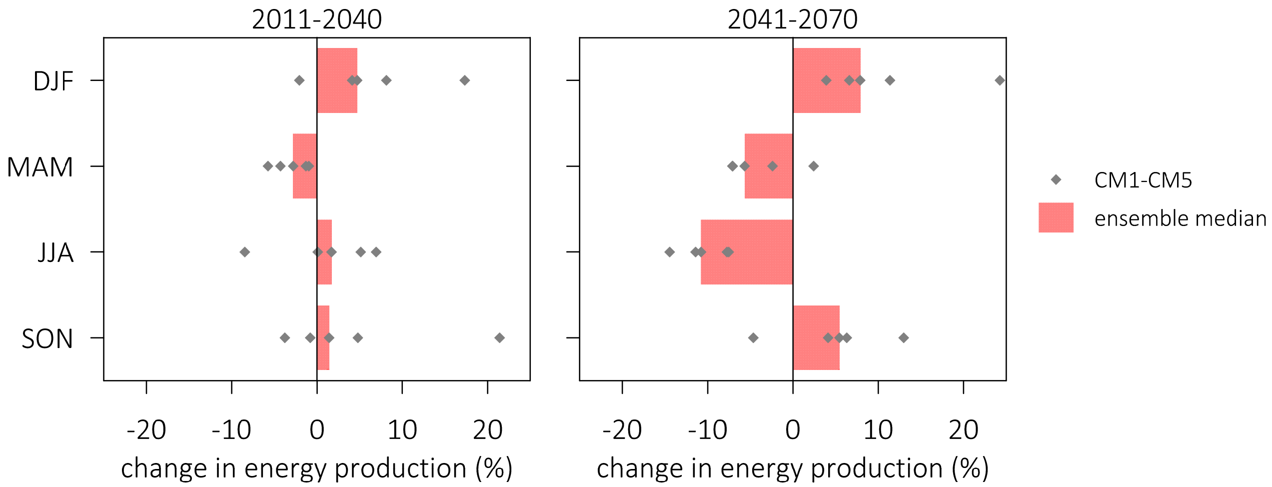


Figure 3: Change in the seasonal energy production for HPP Bajina Bašta under A1B emission scenario for five climate model chains CM1-CM5 in near future (left) and distant future (right)

DJF=December-January-February,
MAM=March-April-May,
JJA=June-July-August,
SON=September-October-November

5 Adaptation and Mitigation Guidelines

Although predictions of climate scenarios vary over the SRB and by different scenario, it is likely that in the near future no severe alterations of climate that would substantially affect the hydropower sector will happen, while in the distant future water availability would decrease and with it energy produced in hydropower facilities.

Although the SRB is predicted to have small (near future) and moderate (distant future) decreases in overall hydropower production as a consequence of CC, these changes are not expected to be severe and it is highly unlikely that this would cause detrimental effects on human activities. Furthermore, there are other green power sources available (e.g. solar, wind etc.) and a lot of possible measures for adaptation and mitigation to counteract these CC effects.

Notwithstanding, on average dependence on hydropower energy for all SRB countries is around 45%, defined as a percentage of hydropower produced from the total energy used (see Table 3). Consequently, hydropower is very important for the SRB and it follows that work on adaptation and mitigation measures should be started now in order to assure proper and timely resilience to climate change in the future.

Table 3: Electricity consumption and production from the hydropower sector for the SRB countries

SRB country	Average yearly electricity consumption [Billion kWh] 2000-2010	Average yearly electricity production from the hydropower sector [Billion kWh] 2000-2010	Share of used electricity from hydropower compared to total electricity consumption [%]
Bosnia and Herzegovina	8.70	5.49	63.15
Croatia	14.12	5.98	42.36
Montenegro	3.37	1.87	55.41
Serbia	28.62	10.49	36.67
Slovenia	12.56	3.73	29.71
Sum:	**67.35**	**27.56**	**Average 45.5%**

Data source: U.S Energy Information Administration

Adaptation and mitigation options, both structural and non-structural for the estimated climate change impact on Sava River Basin are summarized below:

5.1 Structural adaptation measures

- Enhance dam structural parameters-diverting upstream tributaries to decrease river runoff, new reservoir storage, modifying spillways, changing number and/or types of turbines;
- Build robust dams with large reservoirs that can cope with extreme events;
- Flexible design for installed capacity;
- Consideration of planned structural measures before implementation. This includes all uses of the reservoir (e.g. hydroelectricity, irrigation, drinking water supply, tourism, etc.) before reservoir construction or enlargement.

5.2 Non-structural adaptation measures

- Consideration of ecological aspects, as structures can generate significant impacts on the water courses (morphological changes, barriers to fish migration, etc.);
- Reduce energy demand by promoting public awareness campaigns and training in energy efficiency;

- Improving hydrological forecasting to improve operational rules and utilization of HPP capacity,
- Improve operation and maintenance practices at power stations;
- Incorporate future reduced or increased generation capacity in design, depending on specific location on the basin;
- Consider using more pumped storage hydropower technology in order to match the energy available to the needs of the consumers and in order to cover peak loads;
- Adoption of an integrated water resources and disaster management approach;
- Integration of climate change considerations into the management and operation of HE power generation, transmission and distribution system;
- Replacement of incandescent bulbs with ones with low energy consumption;
- Assess and use other renewable energy production facilities such as wind power or solar power plants;
- More profound analysis for most likely estimation of projected climate variations over HPP lifetime;
- Identification of cost-effective new designs and modification of existing designs to deal with specific risks for the HPP construction site;
- Undertaken regular reviews of permitting and licensing of hydropower schemes to assess river flow regimes and minimum and maximum water levels according to season, to ensure sufficient storage in the reservoir to absorb the spring flood and to tie this into the RBMPs;
- Incorporating climate change into existing codes and guidelines concerning hydropower;
- Establish a mandatory reporting mechanism for all hydropower companies to provide full operational details on river flow and discharge to improve future monitoring records;
- Development of guiding principles on integrating environmental aspects in the use of existing hydropower plants such as increase in HPP efficiency, flow regulation, as well as in the planning and construction of new hydropower plants;
- Better development / implementation of strict rules (riparian rights) for discharge of water into rivers and for water withdrawal.

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