# Report on the existing risks and observed vulnerabilities on climate change on the Energy sector, with proposed adaptation measures

Authors:

Marko Adamović, PhD.B.Sc. Hydrogeology
The European Commission’s Joint Research Centre,ISPRA

# List of Abbreviations

| | |
|---|---|
| **DJF** | December-January-February |
| **JJA** | June-July-August |
| **JRC** | The Joint Research Centre |
| **MAM** | March-April-May |
| **RCP** | Relative Concentration Pathway |
| **SON** | September-October-November |
| **UNFCCC** | United Nations Framework Convention on Climate Change |

# CONTENTS

# 1. Introduction

As global warming and climate change impacts continue to intensify, governments across the world, including Serbia have to scale up climate change adaptation, mitigation, and risk management measures, all three being identified as key worldwide priorities, to avoid major economic damage. Paris Climate Agreement (UNFCCC, 2015), the Sendai Framework for Disaster Risk Reduction 2015-2030, and European actions like the EU Climate Change Adaptation Strategy are global frameworks pointing out on the importance of limiting global warming below 2°C and pursuing 1.5°C, while simultaneously enhancing adaptive capacity, strengthening resilience and reducing vulnerabilities.

Climate change changes usually driven by political, demographical, and economic factors, will affect the balance between water availability and water demand of various sectors, especially of the energy sector. Thus, quantifying water availability and impact estimates of natural hazards (i.e. drought, floods) under different climate change scenarios and different degrees of global warming, plays an important role in informing and supporting climate policymakers for mitigation and adaptation strategies.

# 2. Methodology

In this section, climate change as an important driver in the hydrological cycle and water-energy nexus has been evaluated using the open-source LISFLOOD model.

### The LISFLOOD hydrological model

The water resources calculations are done with the fully open-source LISFLOOD 2.0 model code (moreinfo can be found on the repository: https://ec-jrc.github.io/lisflood/). LISFLOOD 2.0 is a GIS-based spatially-distributed hydrological rainfall-runoff-routing model, developedat the EC-Joint Research Centre (JRC) since 1997 (De Roo et al., 2000; Van der Knijff et al., 2010).

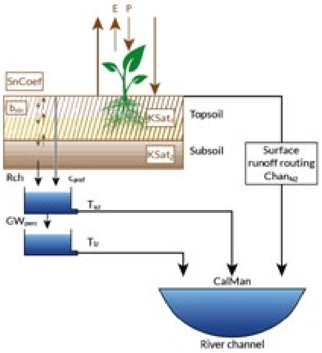


*Figure 1: Overview of the LISFLOOD model. P: precipitation; E: evaporation & evapotranspiration; SnCoef: snow melt; bxin: infiltration; ChanN2: surface runoff; GWperc: drainage from upper- to lower groundwater zone; Tuz: outflow from upper groundwater zone; Tlz: outflow from lower groundwater zone; Rch: drainage from the subsoil to upper groundwater zone; drainage from top-to subsoil; Cpref: preferential flow to upper groundwater zone (source: https://ec-jrc.github.io/lisflood/)*

The standard LISFLOOD model setup is made up of the following components (https://ec-jrc.github.io/lisflood/):

- 3-layer soil water balance sub-model
- Sub-models for the simulation of groundwater and subsurface flow (using 2 parallel interconnected linear reservoirs)
- Sub-model for the routing of surface runoff to the nearest river channel
- Sub-model for the routing of channel flow

The processes that are simulated by the model include also snowmelt, infiltration, interception of rainfall, leaf drainage, evaporation and water uptake by vegetation, surface runoff, preferential flow (bypass of soil layer), exchange of soil moisture between the two soil layers and drainage to the groundwater, sub-surface and groundwater flow, and flow through river channels.
General description

Driven by meteorological forcing data, LISFLOOD 2.0 calculates a complete water balance
at a daily time step and every grid-cell defined in the model domain (Figures 1 and 2).

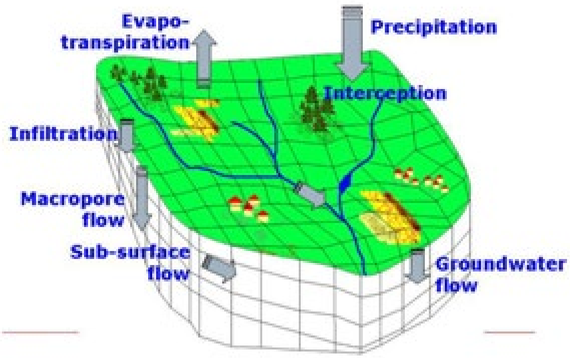


*Figure .2 Spatial schematisation of the LISFLOOD model for a single river basin (Bisselink et al., 2018)*

Lakes, reservoirs and retention areas or polders are simulated by giving their location, size, inflow and outflow boundary conditions, and estimation steering parameters. Since in many cases no data are available of the actual reservoir operations, an estimation of their steering rules has been with the assumption that on a multi-annual basis the reservoir volume stays the same. Static maps used by the model are related to topography (i.e., digital elevation model, local drain direction, slope gradient, elevation range), land use (i.e., land use classes, forest fraction, fraction of urban area), soil (i.e., soil texture classes, soil depth), and channel geometry (i.e., channel gradient, Manning's roughness, bank-full channel depth, channel length, bottom width and side slope).

Soil texture and depth data were derived from the ISRIC 1km SoilGrids database (Hengl et al., 2014). Elevation data was derived from the Hydrosheds database – using SRTM elevation data

(Lehner et al., 2008, http://www.worldwildlife.org/pages/hydrosheds). The river network was taken from the work by Wu et al. (2012). Land use is derived from the 100m resolution Corine dataset for Europe.

In this study, the LISFLOOD 2.0 model was run on the constant spatial 5x5km grid resolution. The model distinguishes for each grid the fraction open water, urban sealed area, forest area, paddy rice irrigated area, crop irrigation area, and other land uses derived from the 100m resolution CORINE and LUISA land use model. The sum of these 6 fractions is 100% of the grid. Specific hydrological process (evapotranspiration, infiltration etc.) are then calculated in a different way for these land use classes. At the end of a model calculation timestep, the outgoing water fluxes are then accumulated and routed to the river network for discharge production.**CORDEX climate input data**

Climate projections data are taken from the Coordinated Downscaling Experiment over Europe (EURO-CORDEX; Jacob et al., 2014), which is an international climate downscaling initiative that aims to provide high-resolution climate projections up to 2100. Scenario simulations within EURO-CORDEX use the new Representative Concentration Pathways (RCPs) (Moss et al, 2010). RCP scenarios are based on greenhouse gas emissions and assume pathways to different target radiative forcing at the end of 21st century. Within EURO-CORDEX, a number of Regional Climate Models (RCM's) to downscale a number of CMIP5 Global Circulation Models (GCMs).

In this work, historical climate scenarios (1981-2010) and future projections (2011-2100) from 7 EURO-CORDEX climate projections (see Table 1) under the RCP4.5 and RCP8.5 emissions pathways (Riahi et al., 2011) were used to drive the LISFLOOD hydrological model at a daily scale. The 7 EURO-CORDEX models were run at 0.11 degree horizontal resolution (~12km).

Meteorological variables extracted are average (tas), minimum (tasmin) and maximum (tasmax) surface air temperature, total precipitation (pr), surface air pressure (psl), 2 m specific humidity (huss), 10 m wind speed (sfcWind), surface downwelling shortwave radiation (rsds), surface upwelling shortwave radiation (rsus) and surface upwelling longwave radiation (rlus).

All the meteorological variables are re-gridded at 5 km x 5 km and for each time step potential evapotranspiration maps are computed using the Penman–Monteith formulation. The hydrological model LISFLOOD is then run for the period 1981–2010 and for the future climate scenarios, 2011–2100 forced by both RCP4.5 and RCP8.5 using the bias-corrected daily precipitation, average temperature, and the generated potential evapotranspiration maps.Ensemble water resources simulations are produced using the 7 EURO-CORDEX climate projections for the 30-year periods centered on the year of exceeding the global-mean temperature of 2oC according to the used Global Climate Model (Table 1).

| s | Institute | GCM | RCM | 2°C | 2 degree period evaluated |
|---|---|---|---|---|---|
| 1 | CLMcom | EC-EARTH | CCLM4-8-17 | 2041 | 2027-2056 |
| 2 | SMHI | HadGEM2-ES | RCA4 | 2030 | 2016-2045 |
| 3 | SMHI | MPI-ESM-LR | RCA4 | 2044 | 2030-2059 |
| 4 | SMHI | EC-EARTH | RCA4 | 2041 | 2027-2056 |
| 5 | DMI | EC-EARTH | HIRHAM5 | 2043 | 2029-2058 |
| 6 | KNMI | EC-EARTH | RACMO22E | 2042 | 2028-2057 |
| 7 | CLMcom | MPI-ESM-LR | CCLM4-8-17 | 2044 | 2030-2059 |

*Table 1. Climate projections within CORDEX and the corresponding year of exceeding 2oC warming with the 30-year evaluation period*

For the global models considered here, the 2nd degree is reached on average around the year 2040 in the RCP8.5 scenario, which is when very little emission mitigation will take place. Simulations using the 7 EURO-CORDEX data are run with a changing climate to assess climate change effects on future water resources.

# 3. Projected changes in temperature and precipitation in Europe and Serbia

For a better temperature overview, projected changes of temperature are shown for the wholeof Europefor the RCP8.5 end of the century climate in Figure 3. Serbia and the Balkan region are projected to experience much higher winter temperatures than the average global temperature increase in Western Europe. On another side, Serbia, the Mediterranean and theAlps are projected to experience much higher summer temperatures than the global temperature increase. Precipitation is by far the most important driver for water resources. Figure 4 shows the projected changes of precipitation in Serbia for an RCP4.5 beginning, middle, and end of the century climate. In general, decreases are projected for all three periods for Southern Serbia. For Northern Serbia, increases in precipitation are projected for all three periods, which lead to an increase of 9 % for the end of the century.

Figure 5 shows the projection of precipitation change in Serbiafor an RCP8.5 beginning, middle, and end of the century climate (average of 7 EURO-CORDEX models). Increases are projected predominantly for Northern Serbia, especially for 2041-2070 and the end of the century period. During this time window under the RCP 8.5 scenario, the global temperature increase is already 3.5-4.0 degrees. This represents a situation when little emission reductions would be implemented and the Paris targets would not have been met.

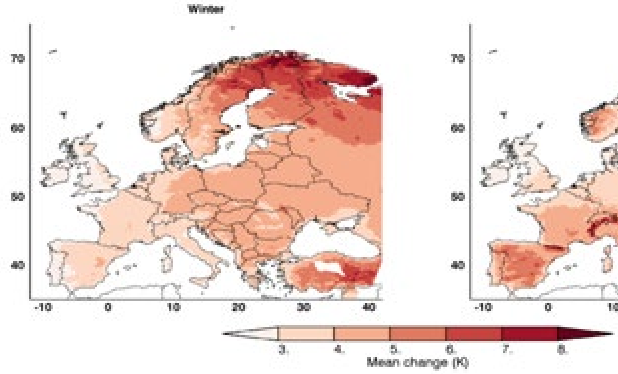


*Figure 3. Projected change of seasonal mean daily temperature for winter and summer, at the end of the century (2071-2100) compared to present day climate (1981-2010), under RCP8.5 (Dosio, 2016)*

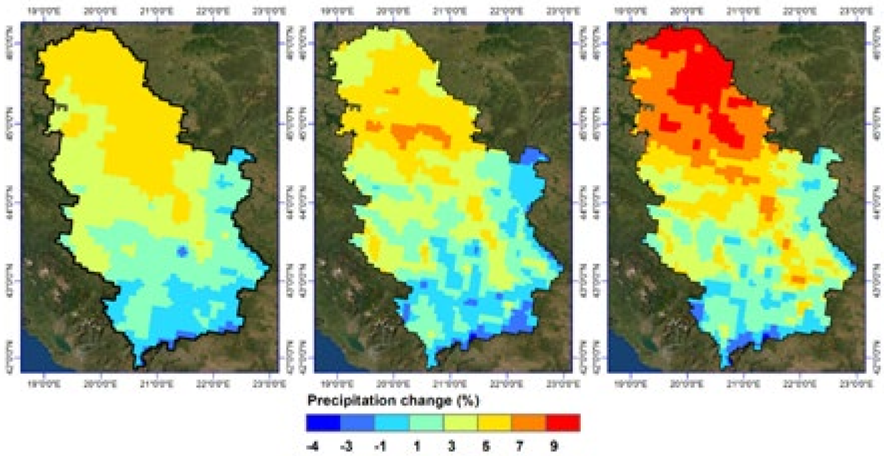


*Figure 4. Projected change of daily precipitation for 2011-2040 (left), 2041-2070 (middle), and at the end of the century (2071-2100) compared to present day climate (1981-2010), under RCP4.5 for ensamble scenarios*

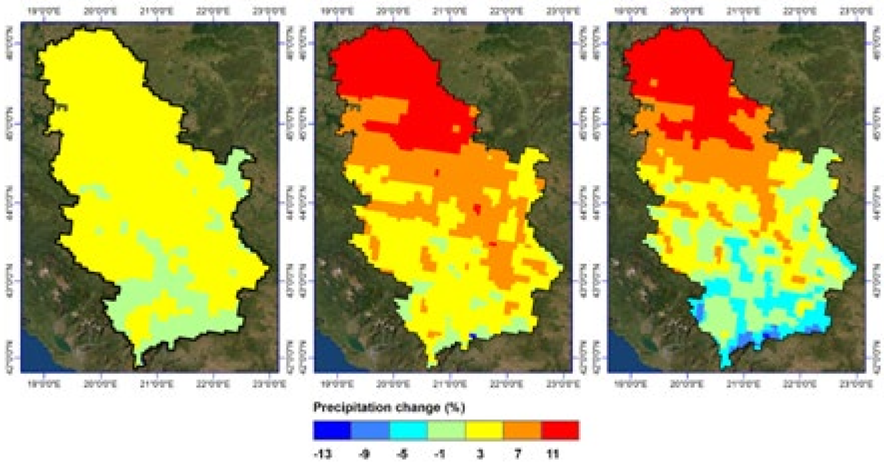


*Figure 5. Projected change of daily precipitation for 2011-2040 (left), 2041-2070 (middle), and at the end of the century (2071-2100) compared to present-day climate (1981-2010), under RCP8.5 for ensemble scenarios*

# 4. Impacts of climate change on water resources in Serbia

This chapter describes the results of the water resources calculations obtained with the LISFLOOD model. In total 14 model simulations (7 for RCP4.5 and 7 for RCP 8.5) with the LISFLOOD water resource model for 30-90 year periods including climate changes has been evaluated for their impact on Serbian water resources.

In the next paragraphs, we describe the impacts of changing climateon water resources for various energy aspects such as hydropower and cooling. More informationabout power plants characteristics included in this study can be found on the https://github.com/energy-modelling-toolkit/hydro-power-database and JRC Open Power Plants Database (JRC-PPDB-OPEN)[1].

# 5. Impact on water availability for hydropower and thermal power plants

The energy sector needs freshwater as a source for hydropower and for cooling thermoelectric power plants. We examined the results of the water resources modeling here for both hydropower and cooling power plants.

Figure 6 gives an overview of studied hydropower and thermal power plants in Serbia. We examined 13 main hydropower plants (green circles) in Serbia on their water availability, specifically by their mean inflow into their reservoirs. Their specifications can be found in Table 2. Figure 6 right, show the mean yearly hydropower generation (bigger circle means higher GWh production). We can observe that the mean yearly hydropower generation atĐerdap I & II and Bajina Basta are among the highest energy producers with over1500 GWh per year (Figure 6, right). More detailed information about the average hydropower production can be found in Table 2.

---

[1] Hidalgo Gonzalez, Ignacio; Kanellopoulos, Konstantinos; De Felice, Matteo; Bocin, Andrei (2019): JRC Open Power Plants Database (JRC-PPDB-OPEN). European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/9810feeb-f062-49cd-8e76-8d8cfd488a05

| Hydro ID | Plant name | Capacity [MW] | Latitude | Longitude | GWH |
|---|---|---|---|---|---|
| 1 | Uvac | 36 | 43.42 | 19.93 | 60 |
| 2 | HE Bajina Basta G1 | 364 | 43.96 | 19.41 | 1462 |
| 3 | HE Djerdap 1 | 1083 | 44.67 | 22.53 | 5580 |
| 4 | KokinBrod | 22.7 | 43.52 | 19.81 | 55 |
| 5 | Medjuvrsje | 7 | 43.91 | 20.23 | 31 |
| 6 | Ovcar Banja | 6 | 43.90 | 20.18 | 28 |
| 7 | HE DJERDAP II | 208 | 44.33 | 22.53 | 1510 |
| 8 | HE Vrla 1-4 | 128.6 | 42.71 | 22.32 | 279 |
| 9 | RHE Bajina Basta Pumped Storage | 614 | 43.87 | 19.41 | 635 |
| 10 | Bistrica | 104 | 43.52 | 19.74 | 332 |
| 11 | Zvornik | 96 | 44.37 | 19.11 | 454 |
| 12 | Pirot | 80 | 43.16 | 22.62 | 99 |
| 13 | Potpec | 51 | 43.52 | 19.58 | 195 |

*Table 2. Hydro power plants and their characteristics in Serbia*

We also examined 8 thermal plants (red circles) across Serbia (Table 3) and we assessed their yearly cooling water demand (Figure 6, right). We observe that Kostolac, Novi sad and Nikola Tesla thermal plants required the highest cooling water demand (over 107 m3/yr). It should be mentioned that cooling water demand depends on the system efficiency and the cooling technology (once-through, closed-loop and dry cooling)that will determine water usage. In Serbia, almost all thermal plants have once-through cooling systems as shown in Figure 3.

We evaluate the average increase/decrease in streamflow for the ensemble of scenarios for RCP4.5 and RCP8.5 compared to the 1981-2010 control climate window (Figure 7). Both RCPs show the increase of discharge and thus increase of water availability for hydropower production at Đerdap 1 and 2 power stations (increase in range 200-600 m3/s) and increase water availability for cooling along the Danube river for Novi Sad, Kostolac A and B thermal plants and Nikola Tesla plants along the Sava river.These results confirm previously mentioned rainfall results that Northern Serbia will experience higher rainfall intensity for both RCP 4.5 and RCP 8.5.For the rest of the power plants we observe a slight discharge increase all (up to 100m3/s) or no increase at all. It should be mentioned that seasonal patterns of change sometimes differ from this general multi-annual average. That is why it is preferred to execute the water resources simulations at a daily time resolution, and results averaged at seasonal scale depending on the observed trends.

The results of the seasonal water resources impact simulation forRCP4.5 (Figure 8) and RCP 8.5 (Figure9) show a more nuanced picture, with marked differences between summer and winter streamflows. Both Figures show seasonal average discharge differences between the RCP4.5 or RCP 8.5 climate compared to the control climate (1981-2010). Figures are the result of the ensemble of the 7 studied Cordex models and show the water availability for the whole territory of the Republic of Serbiafor four seasons: December-January-February (DJF); March-April-May (MAM); June-July-August(JJA) and September-October-November (SON). We can see the general increase of water availability along the Danube and Sava rivers for DJF and MAM season in RCP 4.5. In the summer months (JJA), water shortage can be observed along Sava river but also across Southern Serbia.  Figure 9 shows less available water in comparison with RCP 4.5  and Figure 8 along Danube and Sava river in DJF and MAM season. Higher shortages are observed along Sava and Morava rivers in JJA season.From Figures 8 and 9 we can conclude that in general Serbia is projected to experience increased water availability in winter, and decreased water availability over the summer months.

Tables 4-7 show impacts of the RCP4.5 and RCP 8.5 (in %) on average seasonal discharge as compared to the 1981-2010 control climate for hydro-power and thermal plants.

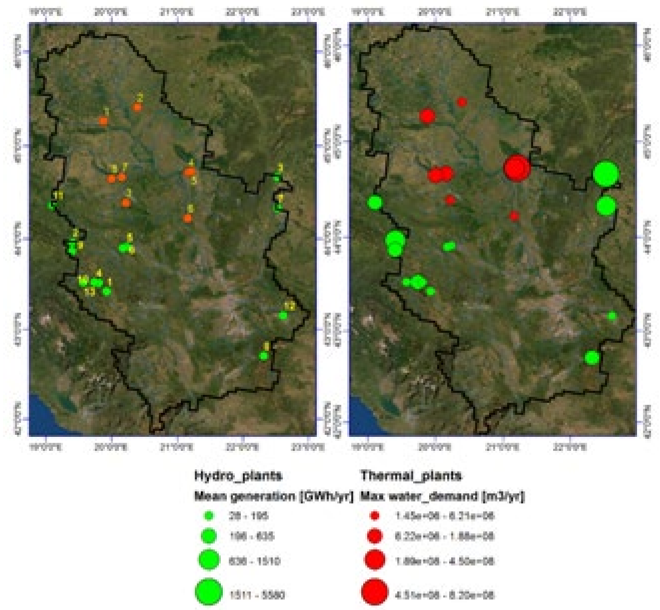


*Figure 6. Overview of studied hydropower and thermal power plants in Serbia*

| Thermal ID | Plant name | Capacity [MW] | Fuel | Latitude | Longitude | Water_demand in m3/year | Cooling type |
|---|---|---|---|---|---|---|---|
| **1** | Novi Sad A1 | 135 | GAS | 45.27 | 19.88 | 83,220,000 | Once-through |
| **2** | Novi Sad A2 | 110 | GAS | 45.27 | 19.88 | 105,120,000 | Once-through |
| **3** | Zrenjanin | 120 | GAS | 45.41 | 20.39 | 1,445,400 | |
| **4** | Kolubara A | 110 | LIG | 44.39 | 20.22 | 4,015,000 | Mechanical Draught Tower |
| **5** | Kostolac A | 100 | LIG | 44.72 | 21.17 | 166,440,000 | Once-through |
| **6** | Kostolac A | 210 | LIG | 44.72 | 21.17 | 283,824,000 | Once-through |
| **7** | Kostolac B | 366 | LIG | 44.73 | 21.21 | 409,968,000 | Once-through |
| **8** | Kostolac B | 366 | LIG | 44.73 | 21.21 | 409,968,000 | Once-through |
| | Morava | 125 | LIG | 44.22 | 21.16 | 6,205,000 | Once-through |
| | Nikola Tesla A1 | 210 | LIG | 44.67 | 20.16 | 8,760,000 | Once-through |
| | Nikola Tesla A2 | 210 | LIG | 44.67 | 20.16 | 8,760,000 | Once-through |
| | Nikola Tesla A3 | 335 | LIG | 44.67 | 20.16 | 9,490,000 | Once-through |
| | Nikola Tesla A4 | 308.5 | LIG | 44.67 | 20.16 | 9,490,000 | Once-through |
| | Nikola Tesla A5 | 308.5 | LIG | 44.67 | 20.16 | 9,490,000 | Once-through |
| | Nikola Tesla A6 | 348.5 | LIG | 44.67 | 20.16 | 9,490,000 | Once-through |
| | Nikola Tesla B1 | 620 | LIG | 44.65 | 20.01 | 26,280,000 | Once-through |
| | Nikola Tesla B2 | 620 | LIG | 44.65 | 20.01 | 26,280,000 | Once-through |

*Table 3. Summary of thermal power plants in Serbia*

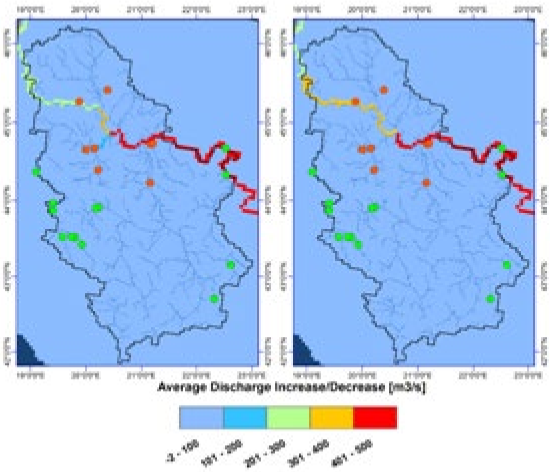
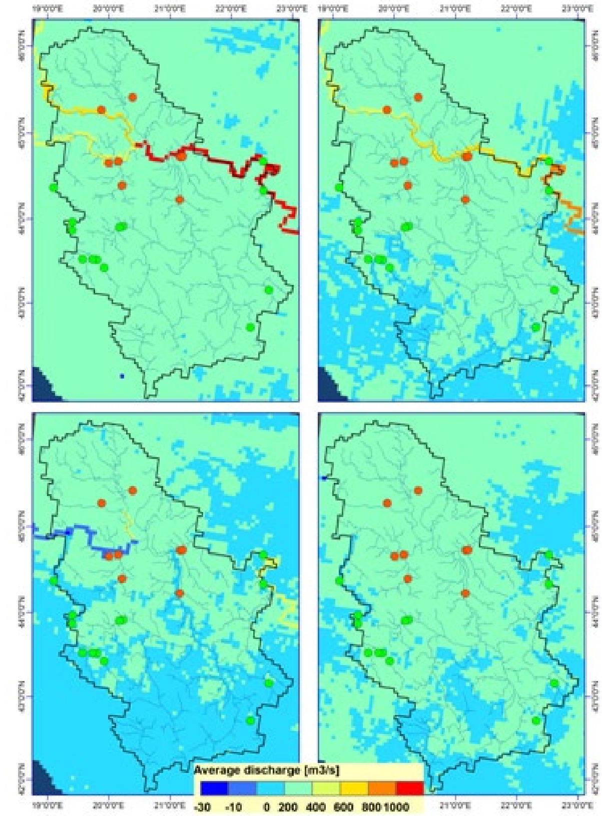


*Figure 7. Average increase/decrease in streamflow for changed climate (left: RCP4.5; right: RCP8.5) compared to the 1981-2010 control climate window*

*Figure 8. Seasonal average discharge differences between the RCP4.5 climate compared to the control climate (1981-*



*2010) (ensemble of the 7 studied Cordex models); top left: DJF; top right: MAM; bottom left: JJA; bottom right: SON season*

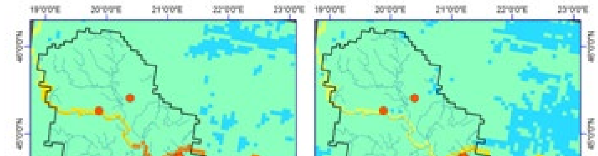


*Figure 9. Seasonal average discharge differences between the RCP8.5 climate compared to the control climate (1981-2010) (ensemble of the 7 studied Cordex models); top left: DJF; top right: MAM; bottom left: JJA; bottom right: SON season*

Table 5 gives a detailed overview of how much water surplus/deficit we could expect at considered hydropower locations regarding the RCP4.5. We observe that all stations are expected to have an increased water availability in DJF period. Some shortages are foreseen for HE Vrla 1-4, Bajina Basta, Zvornik, Pirot and Potpec plants especially in JJA period (i.e. up to -17% for Vrla 1-4). Looking at yearly average, all hydropower plants are expected to face a water availability increase.

| Hydro ID | Plant name | DJF | MAM | JJA | SON | Average |
|---|---|---|---|---|---|---|
| 1 | Uvac | 34.38 | 11.22 | 7.92 | 19.31 | 18.21 |
| 2 | HE Bajina Basta G1 | 30.23 | 6.43 | -6.31 | -4.58 | 6.44 |
| 3 | HE Djerdap 1 | 22.40 | 11.36 | 4.69 | 3.37 | 10.46 |
| 4 | KokinBrod | 28.07 | 14.50 | 7.76 | 16.46 | 16.70 |
| 5 | Medjuvrsje | 24.42 | 4.58 | 7.90 | 8.12 | 11.26 |
| 6 | Ovcar Banja | 24.26 | 3.47 | 7.13 | 8.82 | 10.92 |
| 7 | HE Djerdap II | 22.39 | 11.37 | 4.68 | 3.32 | 10.44 |
| 8 | HE Vrla 1-4 | 43.86 | -0.32 | -17.17 | 8.51 | 8.72 |
| 9 | RHE Bajina Basta Pumped Storage | 10.66 | 1.89 | -1.80 | -0.74 | 2.50 |
| 10 | Bistrica | 28.53 | 13.75 | 7.22 | 15.86 | 16.34 |
| 11 | Zvornik | 25.91 | 7.18 | -3.82 | -3.43 | 6.46 |
| 12 | Pirot | 23.23 | 4.93 | -11.92 | -0.26 | 4.00 |
| 13 | Potpec | 43.29 | 0.27 | -11.08 | 3.91 | 9.10 |

*Table 4. Impact of the RCP4.5 climate change (in %) on average seasonal discharge as compared to the 1981-2010 control climate for hydro power plants*

Table 5 gives a detailed overview of how much water surplus/deficit we could expect at considered thermal power locations regarding the RCP4.5. We observe the highest water availability in DJF period with some negative tendency in JJA period for Novi Sad, Zrenjanin and Kostolac power plants. Nevertheless, a general annual increase is foreseen for all thermal plants with RCP 4.5.

| Hydro ID | Plant name | DJF | MAM | JJA | SON | Average |
|---|---|---|---|---|---|---|
| 1 | Novi Sad A1 and A2 | 23.87 | 6.32 | -3.13 | 2.75 | 7.45 |
| 2 | Zrenjanin | 23.95 | 6.46 | -2.94 | 2.90 | 7.59 |
| 3 | Kolubara A | 21.69 | 16.44 | 1.54 | 13.57 | 13.31 |
| 4 | Kostolac A | 27.07 | 7.28 | -2.35 | 7.15 | 9.79 |
| 5 | Kostolac B | 20.73 | 13.21 | 5.16 | 4.17 | 10.82 |
| 6 | Morava | 58.21 | 23.29 | 13.26 | 32.73 | 31.87 |
| 7 | Nikola Tesla A | 41.65 | 27.59 | 35.07 | 46.43 | 37.68 |
| 8 | Nikola Tesla B | 22.79 | 10.73 | 3.99 | 4.54 | 10.51 |

*Table 5. Impact of the RCP4.5 climate change (in %) on average seasonal discharge as compared to the 1981-2010 control climate for thermal power plants*

| Hydro ID | Plant name | DJF | MAM | JJA | SON | Average |
|---|---|---|---|---|---|---|
| 1 | Uvac | 14.66 | 5.59 | 0.12 | 3.89 | 6.07 |
| 2 | HE Bajina Basta G1 | 15.73 | -0.93 | -12.92 | -14.83 | -3.24 |
| 3 | HE Djerdap 1 | 17.85 | 8.08 | 5.78 | 4.64 | 9.09 |
| 4 | KokinBrod | 9.25 | 7.66 | -0.04 | 4.18 | 5.26 |
| 5 | Medjuvrsje | 3.35 | -3.54 | -7.93 | -6.98 | -3.77 |
| 6 | Ovcar Banja | 2.73 | -3.60 | -8.91 | -5.96 | -3.93 |
| 7 | HE Djerdap II | 17.84 | 8.08 | 5.78 | 4.61 | 9.08 |
| 8 | HE Vrla 1-4 | 30.16 | 2.90 | -15.06 | 5.35 | 5.84 |
| 9 | RHE Bajina Basta Pumped Storage | -0.20 | -3.37 | -8.25 | -5.26 | -4.27 |
| 10 | Bistrica | 9.45 | 6.81 | -0.72 | 3.32 | 4.72 |
| 11 | Zvornik | 13.70 | 0.11 | -9.36 | -10.42 | -1.49 |
| 12 | Pirot | 18.47 | 3.26 | -12.97 | -3.65 | 1.28 |
| 13 | Potpec | 23.59 | -4.69 | -14.30 | -7.55 | -0.74 |

*Table 6. Impact of the RCP8.5 climate change (in %) on average seasonal discharge as compared to the 1981-2010 control climate for hydro power plants*

Table 6 gives a detailed overview of how much water surplus/deficit we could expect at considered hydropower locations regarding the RCP8.5 scenarios. We see that HE Đerdap 1 and 2 are expected to get an increase in discharge of about 18 % in DJF (December-January-February) season, which reduces towards more warmer seasons, with average discharge change of about 5 % for the SON (September, October, November) season. This suggest that more water will be available for hydropower production in general (yearly change of +10%) but also for other water usages such as agriculture and tourism in this region, which suggest that an efficient and proper balance mechanism should be established so that water demand from all users is satisfied.

All others hydro-power plants show the same increasing discharge tendency for DJF period. However, all of them show negative tendencies, especially in JJA period when electricity demand will be even higher (due to more air-conditioning, water-gardening),pointing out the possible water shortage problem for producing enough electricity.

Table 7 gives a detailed overview of how much water surplus/deficit we could expect at considered thermal power locations regarding the RCP8.5. As was the case for hydropower plants located in Northern Serbia, the same positive tendency discharge change was obtained for all thermal power plants for DJF period (13%-32 % increase). However, some negative tendency was observed in JJA period for Kostolac A, Zrenjanin and Novi Sad plants that could negatively affect the cooling water demand and thus potentially affect the electricity production. By comparing seasonal discharge changes of RCP 4.5 and RCP 8.5 for all power plants, we could expect more critical situations for power plants with RCP 8.5 where many plants seemed to become more vulnerable in the future.

| Hydro ID | Plant name | DJF | MAM | JJA | SON | Average |
|---|---|---|---|---|---|---|
| 1 | Novi Sad A1 and A2 | 14.23 | 0.66 | -3.49 | 3.78 | 3.79 |
| 2 | Zrenjanin | 14.28 | 0.73 | -3.34 | 3.84 | 3.87 |
| 3 | Kolubara A | 13.05 | 9.16 | 3.09 | 6.65 | 7.99 |
| 4 | Kostolac A | 15.05 | 2.52 | -10.63 | -1.52 | 1.35 |
| 5 | Kostolac B | 20.41 | 14.50 | 8.30 | 6.82 | 12.51 |
| 6 | Morava | 32.49 | 8.84 | 7.24 | 16.46 | 16.26 |
| 7 | Nikola Tesla A | 25.10 | 5.13 | 24.70 | 33.17 | 22.02 |
| 8 | Nikola Tesla B | 18.10 | 7.67 | 5.43 | 5.37 | 9.14 |

*Table 7. Impact of the RCP8.5 climate change (in %) on average seasonal discharge as compared to the 1981-2010 control climate for thermal power plants*

# 6. The need for adaptation

The severity of some of the projected changes in water availability suggests that various adaptation mechanisms will be needed to lessen the effects on population and economic activities exposed to water availability reduction, especially under higher magnitudes of warming. Water dependency on upstream water requires further water diplomacy efforts between Serbia and neighboring countries as well as international multi-member-state management of river basin water resources. This is already operating under the Water Framework Directive and in various River Basin Commissions, such as for the Danube and Sava.

We saw that almost all thermal power plants in Serbia are based on the once-through system meaning that water is taken directly from a river, diverted through a condenser where it absorbs heat from the steam, and then it is discharged back to the river at higher temperatures. Even though this is the most energy-efficient way of cooling, this leads to very high volumes of daily water withdrawals as shown in Table 3. The water intake structures at power plants with this type of cooling can kill several millions of fish annually, and due to the higher discharge temperatures downstream and sometimes even above the ecologically desirable ranges, this can also affect the whole aquatic ecosystem. Future water temperature modeling could give answers to how extensively the fish ecosystem might be affected by changing climate and thermal power plants operations.

Since this is the predominant type of cooling, with a changing climate, the water required to operate once-through cooling systems would not be available all year long, which consequently would make power plants vulnerable in times of drought and extreme heat (JJA season). As an adaptation option, shifting to recirculating tower cooling alternative would considerably reduce water use compared to once-trough cooling systems. Recirculating tower cooling still considers a water intake from a water body, but the amount withdrawn is 95% lower than in once-trough cooling systems, in addition to a comparable reduction of negative impacts on ecosystems.
Results show that hydropower generation which depends on the availability of water will be affected by the impacts of climate change, especially in Southern Serbia with either RCP4.5 or RCP8.5. In these regions, climate change can result in water scarcity, leading to lower river flows, lower water accumulation, and hence to a lower amount of water that can pass through turbines to generate electricity. Conversely, climate change in Northern Serbia, especially in DJF period for both RCPs, can increase the frequency and intensity of extreme precipitation. We can conclude that some locations across Serbia will be more prone to water scarcity issues and others to the sudden abundance of water.

This variability of expected hydro-meteorological changes across Serbia as shown with precipitation patterns is the rationale for adaptation options discussed here. From a climate change adaptation perspective, it is essential for hydropower plants operators to get familiar with future conditions in which each plant will operate. Climate change will result in seasonal variation of the water circle, with longer dry spells during which water will be scarcer than usual, earlier snow melting in Central Europe that will result in an initial increase in water availability along Danube and Sava River, followed by a worsening of water availability. All these phenomena will require a thorough revision in the planning of hydropower plants' operation, maintenance, and possibly climate-proofing engineering interventions. In water scarcity situations it would also ask for assessing the timing of demands by the various users besides electric utilities: farmers, fisheries, residential use, water transport, recreation, etc.

On another side, periods with increased precipitation and increase flow could result in an increased occurrence of flooding at dam sites including overtopping, outages, damage to equipment and adverse downstream impacts. In these situations, water needs to be discharged safely to minimize damages to the plant, downstream ecosystems and human infrastructures and activities. Numerous engineering options can be applied to manage dam spills, such as spillways and gated systems.

We show that in central and southern regions of Serbia, and particularly along the Sava, Morava and Drina rivers, the projected reduction in water availability in summer months negatively affects hydro production at one side and cooling water demand for thermal plants on another. Thermal plants act as thesame player as hydro in Serbia. In order to ensure demand in periods of reduced hydropower, the thermal power capacities have to increase production. This is generally more expensive than hydropower generation. Increasing the development of wind and solar contributes to filling the gap left by hydro and thermal.

Results of this study suggest that energy policies in Serbia should consider climate change impacts in their electricity production capacity planning. With global warming, hydropower plants will become even more valuable assets thanks to increased water availability, especially in Danube regions. On the other hand, reduced water availability will reduce the available capacity of hydropower as well thermal plants in central and southern Serbia. Adaptation, through the upgrade to less water-intensive cooling technologies, could avoid most of the loss in capacity by using once-through river cooling. Expanding inter-regional electricity interconnections is a way to balance the evolving production patterns across the Balkans and their associated costs.

# 7. References:

1. Bisselink B., Bernhard J., Gelati E., Adamovic M., Guenther S., Mentaschi L., et al: Impact of a changing climate, land use, and water usage on Europe's water resources, EUR 29130 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-80288-1, doi: 10.2760/09027, JRC110927, 2018
2. De Roo, A.P.J., Wesseling, C.G., and W.P.A. Van Deursen (2000), Physically-based river basin modelling within a GIS: The LISFLOOD model, Hydrological Processes, Vol.14, 1981-1992.
3. Dosio A. (2016), Projections of climate change indices of temperature and precipitation from an ensemble of bias-adjusted high-resolution EURO-CORDEX regional climate models, J. Geophys. Res. Atmos. 121: 5488–5511, https://doi.org/10.1002/2015JD024411.
4. Hengl, T., de Jesus, J.M., MacMillan, R.A., Batjes, N.H., Heuvelink, G.B.M., et al. (2014), SoilGrids1km — Global Soil Information Based on Automated Mapping. PLoS ONE 9(8): e105992. doi:10.1371/journal.pone.0105992.
5. Jacob, D., et al. (2014), EURO-CORDEX: new high-resolution climate change projections for European impact research, Reg. Environ. Change, 14, 563–578, doi:10.1007/s10113-013-0499-2.
6. Lehner, B., Verdin, K., and A. Jarvis (2008), New global hydrography derived from spaceborne elevation data, Eos, Transactions, AGU, 89(10), 93-94.
7. Moss, R., et al. (2010), The next generation of scenarios for climate change research and assessment, Nature, 463, 747-756.
8. Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., and P. Rafai (2011), RCP 8.5—A scenario of comparatively high greenhouse gas emissions. Climatic Change, 109, 33–57, doi:10.1007/s10584-011-0149-y.
9. UNFCCC (2015), The Paris Agreement, https://unfccc.int/process-and-meetings/theparis-agreement/the-paris-agreement.
10. Van der Knijff J.M., Younis, J., and A.P.J. De Roo (2010), a GIS-based distributed model for river-basin scale water balance and flood simulation, International Journal of Geographical Information Science, Vol. 24, No.2, 189-212.
11. Wu, H., Kimball, J.S., Li, H., Huang, M., Leung, L.R., and R. F. Adler (2012), A new global river network database for macroscale hydrologic modeling, Water Resour. Res., 48(9), doi:10.1029/2012WR012313.