THE UNQUENCHABLE THIRST OF ENERGY PRODUCTION

Coal generation and climate impacts on the freshwater resources and ecosystem health in the Maritsa River basin in Bulgaria

GREENPEACE

WATER IS VITAL FOR THE EXISTENCE OF ALL KNOWN FORMS OF LIFE.

A canal diverts water from the Tundzha River to supply the additional demand for cooling in the Maritsa Iztok complex. The continued operation of the energy complex in the future may induce serious water stress on the Tundzha River through the diversion to keep a cooling reservoir constantly available.

Water plays a fundamental role in the ecosystems that support our habitat and is crucial for the evolution of human civilizations. Humans rely on water to live, to grow food and to produce energy. All freshwater ultimately depends on the continued healthy functioning of ecosystems (UN Water, 2021). We are facing an unprecedented level of biodiversity loss and climate change, and water is a critical medium through which we see the impacts of climate change and effects on biodiversity.

Water, energy and climate change are interlinked. Water is a key resource in fossil fuel based electricity production and combustion of fossil fuels continues to add CO_2 to the atmosphere, driving climate change and disturbing the cycles of water. Coal is the single biggest driver of anthropogenic climate change across the globe – coal burning generates a third of the CO_2 emissions resulting from human activities. A timely phase-out of coal is therefore crucial to slowing down climate change and averting a mass-scale ecological catastrophe.

In the meantime, the Bulgarian energy system is still heavily dependent on fossil fuels, with coal being responsible for 40-60% of the total energy production. With no coal phase-out date announced and a National Climate and Energy Plan severely lacking any ambition for transition, key stakeholders insist on relying on coal as a locally available resource beyond 2030 and on continuing the reliance on fossil fuels until 2050. Such a course of development would be in stark contradiction to the recommendations in the United Nations Emissions Gap Report and the IPCC Special Report on the Paris Agreement's 1.5°C threshold (CAN, 2020).

Climate change impacts such as extreme weather events have been exacerbating existing pressure from human activities on water resources. Contrary to common belief, Bulgaria is not that rich on water resources and is projected to experience significant water stress in the coming decades. Climate change scenarios show that South Europe would have increased temperatures (relative to 1986-2005) of around 1.5 to 2°C, with a projected reduction of precipitation as compared to 1971-2000.

None of these prospects has been seriously taken into account in political decision making in the past decade – neither climate change mitigation, nor adaptation to extreme weather events, nor water resource management. That is why Greenpeace Bulgaria is undertaking an innovative investigation into the effects of climate change and energy production on human and ecosystem water security in the Maritsa basin – whose Eastern territories are deemed "the heart of energy production in Bulgaria". This research is conducted by an interdisciplinary team of scientists at the Institute of Environmental Sciences (CML) of the Faculty of Science at Leiden University in the Netherlands, a global player focusing on the environmental pressures of human activities and resource use and sustainable development research for decision-making.

The Maritsa Iztok basin is the source of 90% of the coal-generated electricity in Bulgaria. Historically the industry was developed around substantial lignite fields, now rapidly depleting in quantity and deteriorating in quality. Currently, the official strategy of the Bulgarian state plans for mining expansion and promises continued operations of the power plants beyond 2030. At the same time, the Maritsa River basin is projected to be among the most heavily affected by climate change in all of Europe. This trend would undoubtedly put stress on energy production itself, but would also increase the competition for water with domestic users, agriculture and other industries in this economically well-developed region in Bulgaria. Crucially, the combination of human activities and climate change brings the ecological boundaries of river ecosystems to the brink, damaging a delicate balance.

EXECUTIVE SUMMARY

For the first time, the impact of the Maritsa Iztok complex on water flows and stress in the region is simulated using a process-based global hydrology and water resources model (PCR-GLOBWB2), under three distinct climate scenarios and two different energy transition pathways. By creating a new layer of electricity water use to the state-of-the-art PCR-GLOBWB2 model, future water impacts driven by combined climate change and energy developments were simulated at an unprecedentedly localized scale.

The findings show explicitly that following the current Bulgarian National Climate and Energy Plan with its long delayed coal phase-out date, would contribute significantly to water stress in the region, more dramatically than climate change until 2050. Following that path would result in not only increased carbon emissions but also short- and mid-term increases in the water vulnerability of existing and future water-using activities. The continued operation of the Maritza Iztok complex in the future may induce serious water stress on the Sazliyka River directly and the Tundzha River through the diversion to keep a cooling reservoir constantly available.

Policies should be informed by science, and there is overwhelming evidence to map the multitude of problems to be addressed in near and longer terms. The choices made for new electricity generation in the coming years are going to navigate the potential water stress and impacts on human and ecological systems. This is yet another compelling argument in favor of a swift energy transition to a decentralized system based on renewable energy. What we do now matters for future generations.

Greenpeace is calling for an energy revolution, a revolution away from fossil fuels and nuclear energy towards energy efficiency and renewable energy.
Since fossil-fueled electricity systems – especially coal-based generation – require large volumes of freshwater to operate, this revolution is not only necessary to ameliorate climate impacts but also to reduce unsustainable water use. Many regions are already experiencing disruptions in water availability for electricity generation due to climate change, a trend that is likely to continue. Relying on fossil fuels in the future will only exacerbate these trends.

This report assesses the water flow impacts of the largest coal-based power plant complex in Bulgaria, the Maritsa Iztok complex, on the Maritsa River and several of its tributaries. The study combines future climate change, human water use, and energy use scenarios with a hydrological model.

THE RESULTS SHOW THAT:

1 | Local power plant water withdrawal is significant and leads to heightened pressure on water resources;

2 | Under the current energy system, human water demand often breaches the safe environmental flow requirements in the Sazliyka River tributary, thus requiring additional water from the nearby Tundzha River, supplied via the Hanovo-Skalitsa canal;

3 | The water diversion from the Tundzha River for the cooling water demand of the Maritsa Iztok complex directly correlates with lower water availability downstream of Hanovo which is the start of the canal in the Tundzha River;

4 | Following the current Bulgarian National Energy & Climate Plan (NECP), coal electricity production will result in the continuation of negative water budgets in the Sazliyka tributary for the foreseeable future; and

5 | In the main branch of the Maritsa River, near-term climatic changes by 2050 influence yearly discharge extremes which are the minimal values in dry months (August-October) but have less impact on total water availability.

However, for the worst-case climate scenario, the minimum annual water levels are set to lower even further, indicating high potential for droughts and lower water availability not only for electricity generation, but also for urban, agricultural, and industrial sectors.

TPP Brikel and Rozov Kladenetz water reservoir

KEY TAKEAWAYS

1 | A late national phase-out of coal-fired electricity results in an additional ~536 million m^3 of cooling water extraction to cool the Maritsa Iztok Complex by 2040, directly impacting the water availability for the local ecology within the Sazliyka River basin, a tributary to the Maritsa River. For comparison, this is 1.34 the volume of the Zhrebchevo reservoir. The largest reservoir in the region.

2 | Continuing water extraction for coal-generation cooling can exceed ecologically safe limits with potentially negative consequences for aquatic ecosystems and further constrain human water-using activities for the foreseeable future under every climate scenario.

3 | Coal-based cooling water extraction has a major influence on the surface water dynamics of the Sazliyka River tributary, far surpassing the climate variability estimated by the hydrological model forced with an ensemble of five different global climate models (GCMs) under three Representative Concentration Pathway (RCP) emission scenarios, i.e., RCP 2.6, 6.0, and 8.5.

4 | Under high-emissions scenario, climate change can significantly impact water stress in the Maritsa River basin as early as 2050.

Maritsa River
at the city of Dimitrovgrad

BACKGROUND & PURPOSE

Continuing water extraction for coal-generation cooling can exceed ecologically safe limits with potentially negative consequences for aquatic ecosystems and further constrain human water-using activities for the foreseeable future under every climate scenario.

BACKGROUND OF THE WATER, ENERGY AND CLIMATE CHANGE NEXUS

Water use, energy generation, and climate change are deeply interlinked. Coal-fired electricity generation drives significant levels of climatic change which also alters the availability of the cooling water it relies upon to operate. Although the volume of water varies for the cooling system type, a typical coal power plant consumes about 3 liters of water per kWh, with most of this water evaporating into the atmosphere. Electricity-related water withdrawal already creates water stress and is set to increase, potentially reducing usable power availability in Europe in the short term (Behrens et al., 2017), especially in Mediterranean climates during warm and dry summer seasons (Van Vliet et al., 2012). As such, coal-fired electricity generation poses a climate threat via carbon emissions but at the same time the safe operation of power plants is threatened by climatic impacts on the water system. Electricity generation will continue to compete with other water users, including municipal, agricultural, and industrial sectors. It will continue to have significant and potentially increasing impacts on aquatic ecosystems as the world warms.

Water use in Bulgaria is especially vulnerable, with water withdrawal for energy cooling representing more than half of total freshwater abstraction (Medarac et al., 2018). The level of abstraction for cooling has been increasing in the past 5 years and now represents 70% of total abstraction. It is becoming increasingly important to move from electricity generation based on fossil fuels and nuclear reactors, which require significant amounts of water for cooling, to a decentralized system based on renewable energy.

This report uses the process-based model PCR-GLOBWB2, a state-of-the-art, grid-based global hydrology and water resources model, to evaluate present and future impacts of the Maritsa Iztok complex on the Maritsa River basin. PCR-GLOBWB2 simulates moisture storage in two vertically stacked upper soil layers, as well as the water exchange among the soil, the atmosphere, and the underlying groundwater reservoir. Human water use is fully integrated within the hydrological model with a daily time step. We quantified the potential risk of cooling water demand on human water-using activities and aquatic ecosystems by the coal-fired Maritsa Iztok complex under future climate scenarios. This study is an innovative scientific initiative which looks at the complex relationship of water stress, energy production and climate change for the first time at such a granular local level for a Bulgarian territory experiencing a unique interconnection of these impacts.

This report presents the results of this detailed hydrological study of hydrological changes in the Maritsa River basin up to 2050 based on a variety of scenarios, including potential climate change and electricity generation futures. The report assesses the water stress caused by the coal-fired Maritsa Iztok electricity generation complex.

BACKGROUND ON THE MARITSA RIVER BASIN

The Maritsa River basin is in southern Bulgaria and occupies roughly one third of the country's land surface area (ca. 34,000 km²). Once it exits Bulgaria, it traces the border between Greece and Turkey further south, where the same river bears the names Evros and Meriç respectively. The main branch of the Maritsa River stretches over 300 km within the Thracian valley with an average slope of 7.7%. The sources of the main branch of the river are in the Rila mountain and of its tributaries — in the Balkan Mountains to the north, the Strandzha massif to the east, and the Rhodope mountains to the southwest.
The river basin experiences a Mediterranean-style climate, with maximum precipitation during the winter-spring months. This precipitation is driven in large part by snowfall, representing 30% to 50% of the total precipitation. As such, the discharge of the river is highly seasonal. The spring season represents the peak discharge at Meriç gauging station (with an average 243 m^3/s for 2000-2010 based on this study) and the lowest flows are seen during the autumn (average 116 m^3/s for 2000-2010 based on this study).

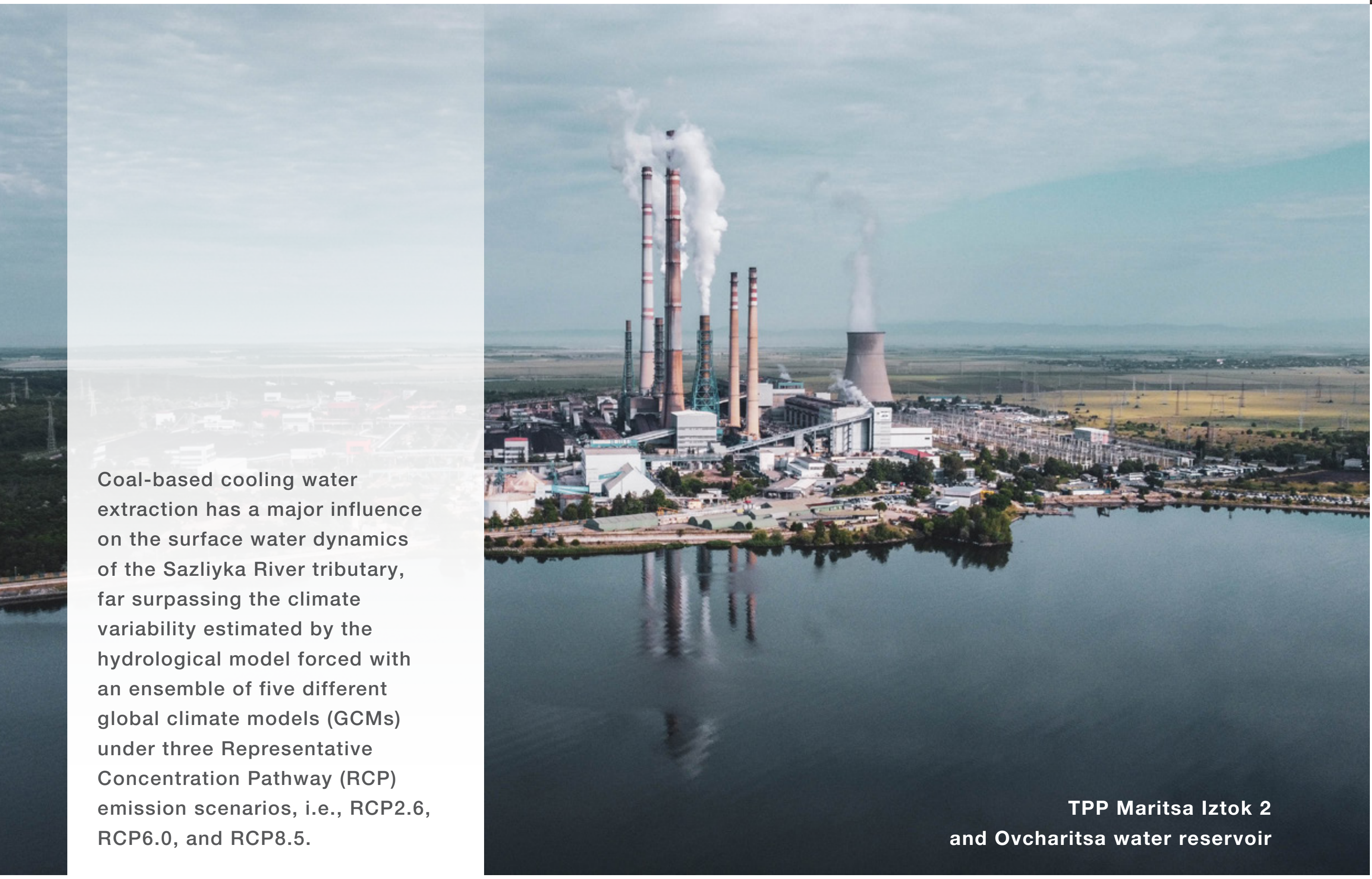
MARITSA RIVER BASIN

CHARACTERISTICS OF COAL POWER PLANTS IN THE MARITSA RIVER BASIN

Coal generation comprises 40-60% of total Bulgarian electricity generation, depending on the season. The bulk of the generation (almost 3.4 GW of installed capacity) sits in the Maritsa Iztok complex, which is within the Sazliyka basin, a single tributary, which accounts for 6% of the Maritsa River basin area. The complex consists of 3 significant coal generating plants and one more – TPP Brikel, which is not included due to a lack of data. TPP AES Galabovo Maritsa Iztok 1 is located near Galabovo on the Rozov Kladenetz reservoir and comprises of two coal boilers with a total capacity of 670 MW. TPP Maritsa Iztok 2 represents the largest plant in the complex and is located on the Ovcharitza reservoir; it comprises 8 units with a total capacity of 1602 MW. TPP ContourGlobal Maritsa Iztok 3 is located about 10 km east of the Rozov Kladenetz reservoir and just south of the open lignite mining operations for the complex. It has an installed capacity of 908 MW. This study is based on data for the electricity production of the power plants listed above, obtained from the European Network of Electricity System Operators ENTSO-E, which collects hourly data on electricity generation. The fourth power plant in the Maritsa Iztok complex – TPP Brikel, has 6 units with an installed capacity of 60 MW each (360 MW in total) and remains under the capacity threshold to make its reporting mandatory. As there is no publicly accessible data on its electricity generation, it could not be included in the study.

Large volumes of water are used for cooling thermo-electric power plants. The specific water demand per plant depends on the fuel, the generating technology, the cooling type (wet tower/once-through), and the efficiency of the generator. The largest power plant in the complex – TPP Maritsa Iztok 2, uses a once-through system for 6 of its units and a wet tower cooling for 2 others. It relies upon the nearby Ovcharitsa reservoir, which sits on the Ovcharitsa River, the largest tributary to Sazliyka. Due to high cooling water demand, the reservoir is additionally supplied with water from Tundzha River, the largest tributary of the Maritsa River, through the Hanovo – Botevo – Skalitsa canal. The Rozov Kladenetz reservoir is supplied with freshwater from the Sazliyka River and tends to the cooling needs of the rest of the coal power plants. TPP AES Galabovo Maritsa Iztok 1 uses wet tower cooling, which uses the evaporation of freshwater. Its tower is also used for the release of emissions in the atmosphere. TPP ContourGlobal Maritsa Iztok 3 uses wet tower cooling with water supplied from the Rozov Kladenetz reservoir. TPP Brikel has a once-through type of cooling system and relies on the same water reservoir.

Maritsa River, the narrow river is the tributary Sazliyka River, photo taken at Simeonovgrad



Coal-based cooling water extraction has a major influence on the surface water dynamics of the Sazliyka River tributary, far surpassing the climate variability estimated by the hydrological model forced with an ensemble of five different global climate models (GCMs) under three Representative Concentration Pathway (RCP) emission scenarios, i.e., RCP2.6, RCP6.0, and RCP8.5.

TPP Maritsa Iztok 2 and Ovcharitsa water reservoir

CLIMATE SCENARIOS

The assessments in this report are based on a set of scenarios developed by the climate modeling community as a basis for long-term and near-term modeling experiments. They are called Representative Concentration Pathways (RCPs) and are considered possible depending on the volume of greenhouse gases emitted in the years to come. For this study, three RCPs were simulated, and they were chosen to cover a range of potential future developments:

1 | one very high baseline emission scenario envisioning no climate action (RCP8.5),

2 | one medium stabilization scenario where emissions peak in 2080 and then decline (RCP6.0), and

3 | one mitigation scenario with emissions starting to decrease in 2020, leading to low forcing level, which is likely to keep global temperature rise below 2°C by 2100 (RCP2.6).

This report uses an ensemble of five different General Circulation Models (GCMs) to evaluate the variability of climate change within each RCP scenario. GCMs, which are regularly used globally, employ a mathematical model of the general circulation of a planetary atmosphere or ocean. They are based on the integration of a variety of physical, chemical and sometimes biological equations.

2 storks on the banks of the Maritsa River

KEY RESULTS

LATE PHASE-OUT OF COAL ELECTRICITY THREATENS THE FRESHWATER SYSTEM IN THE SAZLIYKA RIVER BASIN

Cooling water abstractions for the Maritsa Iztok complex

The policy choices made for the future of Bulgaria's energy system will have significant impacts on the cooling water demands from certain parts of the Maritsa River basin, especially in the Sazliyka and Tundzha tributaries (Figure 1). The most significant policy choice is the timing of the coal energy phase-out. The energy development roadmap that Bulgaria submitted to the European Commission through its National Energy and Climate Plan (NECP) indicates coal-fired electricity generation will be used until 2050. However, there are options for a faster coal phase-out with the International Energy Agency (IEA) showing a scenario that presents a more ambitious roadmap for the country (called the Sustainable Development Scenario or SDS (IEA, 2020). While the SDS will also not see a complete coal phase-out until 2050 there are rapid short-term reductions, starting in the early 2020s. The NECP coal phase-out only begins after 2030, with coal meeting about 30-40% of the country's electricity demand throughout the 2020s (Figure 1a).

An even faster coal phase-out was proposed in the Bloomberg New Energy Finance (BloombergNEF, 2020) scenario for Bulgaria. However, Bulgaria has already seen a large deviation from this pathway (see Figure 1b). Different national coal phase-out schedules lead to significant differences in cooling water abstractions through to 2040. Cooling water withdrawals are largest in winter months owing to the high electricity demands as electric energy is widely used to satisfy heating needs. Following the NECP roadmap, freshwater withdrawals by the Maritsa Iztok complex is as high as 6.8 million m³ per month in January 2030 (in the Sazliyka River basin). Compared to the NECP roadmap, the IEA's SDS sees a reduction of 332 million m³ in freshwater withdrawals from the Sazliyka River basin for the Maritsa Iztok complex over the period 2020-2030 and a reduction of a further 204 million m³ in freshwater withdrawals from 2030 to 2040. The freshwater withdrawals for cooling can be further reduced or eliminated by 2030 if coal power plants are closed as early as 2030 by adhering to the newly decided EU climate target (Pietzcker et al., 2021).

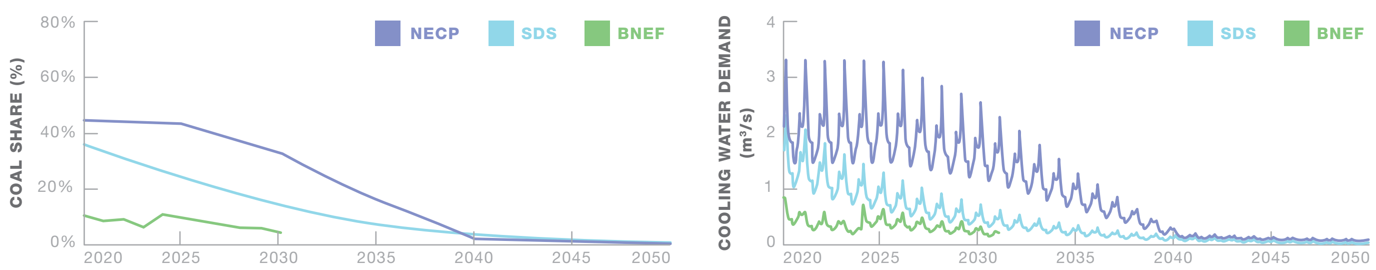


Figure 1. (a) The share of coal-fired electricity in Bulgaria's total electricity generation and (b) cooling water demand from the Maritsa Iztok complex under different energy development scenarios. NECP: the energy roadmap Bulgaria submitted to the European Commission for the National Energy and Climate Plans (NECP). IEA: the Sustainable Development Scenario developed by the International Energy Agency (IEA). BNEF: Bloomberg New Energy Finance scenario, more ambitious than the IEA sustainable scenario but data beyond 2030 is not available.

Ecosystem water flow requirements

Ecosystem health is highly dependent on river flow and short- and/or long-term extremes can threaten aquatic life. Direct (e.g., water abstractions) and/or indirect (e.g., climate change) human activities can have significant impacts on ecosystems (Reid et al., 2019). The streamflow or discharge of rivers is the most important variable for assessing the good ecological status of freshwater ecosystems (Poff and Zimmerman, 2010), and it is therefore important that a sufficient share of streamflow is present for ecosystems. Environmental Flow Requirements (EFRs) measure the volume of freshwater needed to sustain ecosystems. EFRs are expressed as a percentage of "pristine" flow, i.e., water available without accounting for human land use, or water withdrawals for agricultural, industrial, or domestic sectors. According to the definition adopted for this report, EFRs vary throughout the year, depending on whether a month is considered high, intermediate, or low flow (Jägermeyr et al., 2017; Pastor et al., 2014). The EFRs in the region of interest in the Sazliyka River basin (as modeled by the Galabovo sensor station) range between 3.8 and 7.5 m³/s (Figure 2).

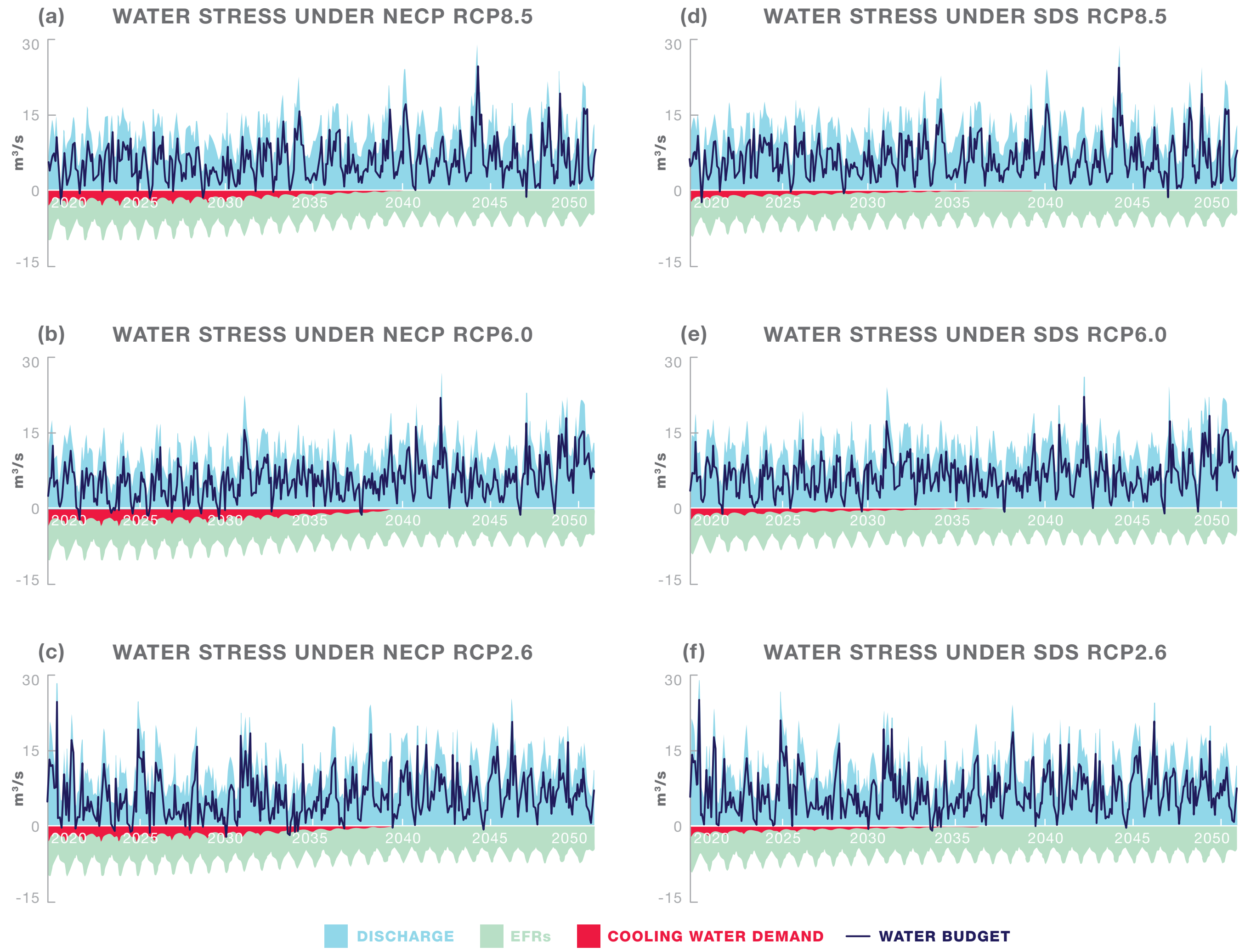


Figure 2. Comparison of water stress under the NECP and SDS for the three different climate scenarios (RCPs) at the Galabovo monitoring station. Results presented for each RCP are based on the median value of the hydrological model results forced with an ensemble of five different global climate models (GCMs). Water budget = Remaining water flows for further water uses = Discharge – EFRs. Cooling water demand for the different setups is represented in red. EFRs and cooling water demand are on the negative part of the axis for representation purposes. The dark blue line shows the net water left after meeting cooling and ecosystem requirements.

Maritsa and Sazliyka Rivers

A late national phase-out of coal-fired electricity results in an additional ~536 million m³ of cooling water extraction to cool the Maritsa Iztok Complex by 2040, directly impacting the water availability for the local ecology within the Sazliyka River basin, a tributary to the Maritsa River. For comparison, this is 1.34 the volume of the Zhrebchevo reservoir. The largest reservoir in the region.

Water risk in the Sazliyka River basin

The remaining water budget availability is defined as the pristine discharge after subtracting EFRs and water uses induced by all human activities. A low remaining water budget means a high constraint on further water using activities from both human and ecological systems. A negative remaining water budget means the EFRs are breached, and ecosystem water demand is not met.

For the period 2020-2050, February sees the highest remaining water budget for further water-using activities (46 million m³/month). August through September sees the lowest remaining water budget for further water-using activities, with only 12 to 16 million m³ per month of fresh-water available after ecosystem requirements are satisfied.

The ecosystem pressure due to lower remaining water budget is consistently lower in the SDS scenario than in the NECP scenario across the Maritsa Iztok complex. There are 13-46 EFR breaches (i.e., negative remaining water budget) at the Galabovo monitoring station under the Sustainable Development Scenario (SDS), compared to 21-62 under the NECP scenario (Figure 3; the range comes from variations of results considering three RCPs and five GCMs). This is equivalent to a gap of 22-91 million m³ due to human water-using activities, such as power plant cooling under the NECP energy scenario. The faster coal phase-out represented by SDS could decrease the exceeded flow to 7-53 million m³ (Figure 4). Moreover, the cooling water withdrawals by the Maritsa Iztok complex may increase the water risk upstream and downstream of Hanovo (Figures A5, A6).

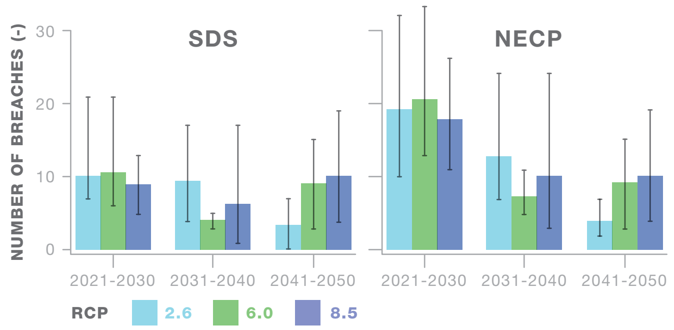


Figure 3. The frequency of Environmental Flow Requirements (EFRs) breaches at the Galabovo gauging station under the different Representative Concentration Pathway (RCP) and energy (SDS-NECP) scenarios. The error bars in black represent the range of values (maximum and minimum) across the different GCM runs.

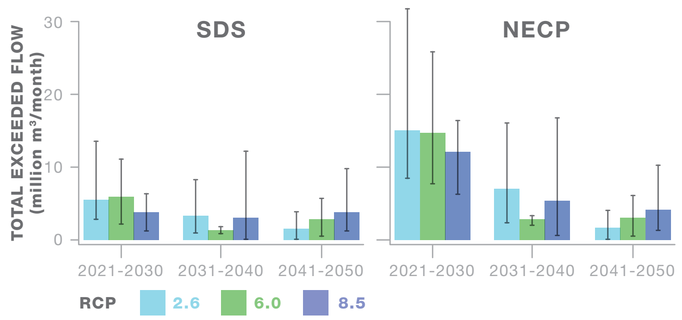


Figure 4. Total volume of flow exceeding the Environmental Flow Requirements (EFRs) at Galabovo gauging station under the different Representative Concentration Pathway (RCP) and energy (SDS/NECP) scenarios. The error bars in black represent the range of values (maximum and minimum) across the different runs according to the various global climate models forcing.

Under both the NECP and the SDS energy scenarios, the 2020s see a high number of environmental breaches and insufficient environmental water flows (Figures 3, 4). By the 2040s, both the NECP and SDS energy scenarios see negligible energy production from coal, and thus the pressures on the water system are related to water use in other sectors. Nevertheless, under the NECP energy scenario, the direct pressures on the Sazliyka basin are significantly alleviated when the coal contribution drops to 16% in 2035 (Figures 1a, 2, 4), and likewise for the SDS energy scenario, which sees an earlier recovery when the coal energy contribution approaches 15% by 2030 (Figures 1a, 2, 4). Thus, an important strategy to alleviate the stress on water environments involves reducing the coal contribution to 15% of the energy mix as soon as possible. This is another argument for setting up a coal phase-out date no later than 2030 in order to meet the United Nations Emissions Gap Report and the IPCC Special Report on the Paris Agreement's 1.5°C threshold for the reduction of emissions (CAN, 2020).

When comparing the water risk differences among the energy transition scenarios, the water risk differences among climate change scenarios by 2050 are less prominent than energy transition scenarios. This is because the differences between warming scenarios become more pronounced after 2050. The worst-case climate scenario, RCP8.5, sees a slightly higher number of EFRs breaches during 2020-2050, with an estimated 4 additional breaches over the lowest-warming scenario RCP2.6 (for the NECP energy scenario). However, for each energy scenario, the various global climate change pathways represented by the three RCPs do not lead to considerable differences in the frequency of EFRs breaches, especially considering the wide spread of the estimates by five GCMs (Figures 3, 4). It is worth noting that the differences between warming scenarios become more pronounced after 2050 than this study's analysis period of 2020-2050 (Figure A2).

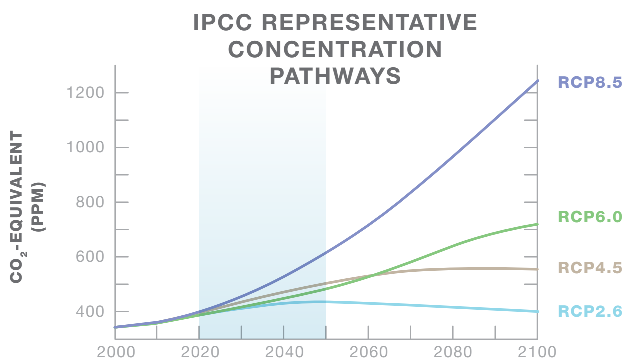


Figure A2. The representative concentration pathways (RCPs) by IPCC.

CURRENT AND FUTURE WATER AVAILABILITY IN THE MARITSA RIVER BASIN

Current and future water stress in the Maritsa River basin

Water stress can be assessed by the ratio of freshwater withdrawals to total renewable water supply in each area. Higher values indicate that human water demand accounts for a higher fraction of available water resources and values above 0.4 are commonly associated with high water scarcity (Brown and Matlock, 2011). As shown in Figure 5, areas of high water scarcity include the upstream part of the Maritsa River (upstream of Plovdiv), while the Tundzha and Sazliyka tributaries (red circles in Figure 5) face medium to high water stress. In some locations, such as where the Maritsa Iztok electricity generation complex is located, more than 40 percent of the total renewable water supply is withdrawn annually by human activities, already experiencing high water scarcity.

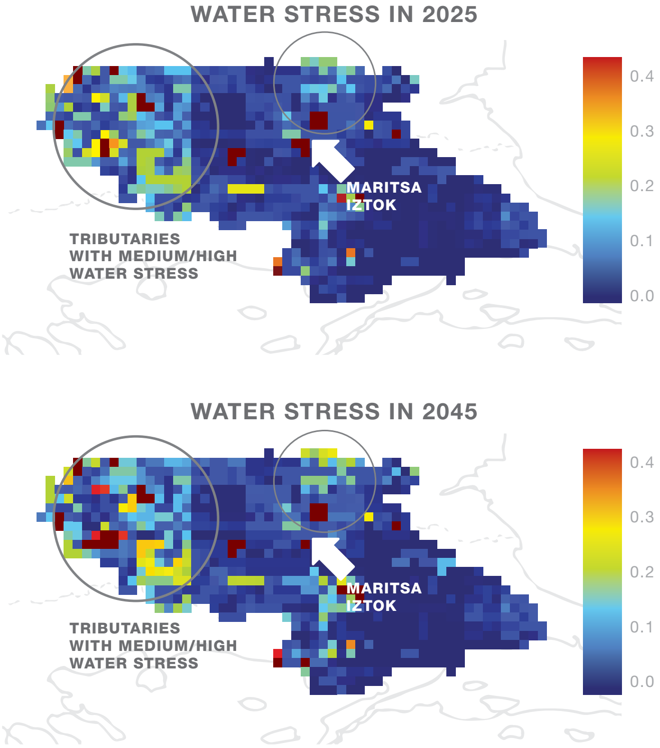


Figure 5. Water scarcity level (total freshwater withdrawal divided by total renewable water availability) in the Maritsa River basin. Results plotted are 10-year moving averages. High water stress values (≥0.4) are highlighted in dark red.

For the worst-case climate scenario, the minimum annual water levels are set to lower even further, indicating high potential for droughts and lower water availability not only for electricity generation, but also for urban, agricultural, and industrial sectors.

Tundzha River at Yambol

CLIMATE CHANGE EFFECTS ON WATER AVAILABILITY IN THE MARITSA RIVER BASIN

Ovcharitsa water reservoir next to TPP Maritsa Iztok 2

The impact of climate change on the overall water balance of the Maritsa River basin can be approximated by the river discharge temporal trends under the different RCPs (Meriç station, Figure 6). While the average yearly flow of each RCP ensemble remains relatively constant, minimum and maximum yearly values – representing extreme weather events and proxies for flooding and droughts, respectively – follow different trends for each RCP.

Climate change impacts are especially significant for RCP8.5, where a statistically significant decrease in annual minimum discharge of about 1.33 m³/s each year is observed. This results in a reduction in the minimum flow from about 140 m³/s in 2020 to about 100 m³/s in 2050, a 29% decrease. No statistically significant decrease is observed for either RCP2.6 or RCP6.0, but some differences would likely be found over a longer time horizon. Regarding maximum annual discharges, while the trends are not statistically significant, RCP8.5 exhibits an increasing trend whereas both RCP2.6 and RCP6.0 exhibit decreasing trends, indicating increasing weather extremes under the worst-case scenario of climate change (RCP8.5). There is significantly more variance, and therefore extremes, for RCP8.5 than for RCP6.0 and RCP2.6 (as shown by the shaded regions in Figure 6). There is discussion in the literature about the likelihood of the RCP8.5 high-emissions pathway and its relevance in quantifying physical climate risk and for informing society decisions (Burgess et al., 2020; Hausfather and Peters, 2020; Schwalm et al., 2020). For this study it is important to note that the RCP8.5 trajectory mainly diverges from other trajectories after 2050 and while the cumulative emissions for RCP8.5 by 2100 are unlikely, RCP8.5 concentrations by 2050 are much more likely. For this work RCP8.5 concentrations by 2050 represent a reasonable worst-case scenario of climate change.

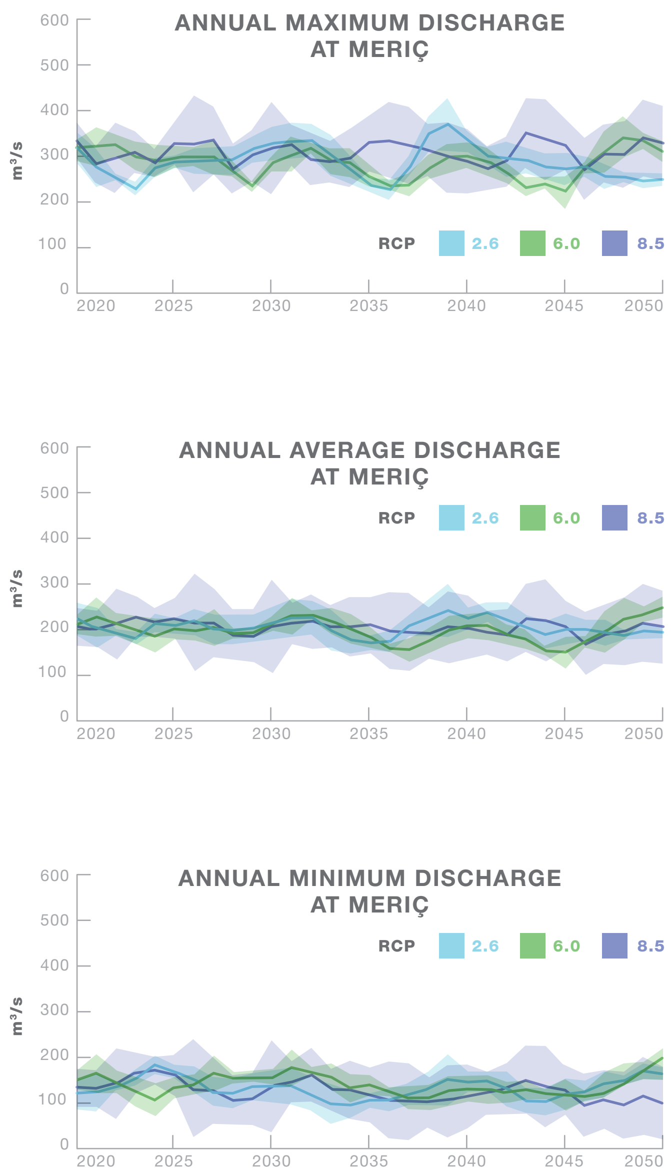


Figure 6. Future annual discharge (top = maximum, middle = average, bottom = minimum) at the Maritsa River mouth (Meriç station) under different RCPs and GCMs. Colored shades represent the standard deviations of GCMs for RCP8.5 (purple), RCP6.0 (green), and RCP2.6 (blue).

Swamp at Tundzha River, Yambol, nowadays used for fishing

Under high-emissions scenario, climate change can significantly impact water stress in the Maritsa River basin as early as 2050

CONCLUSION & OUTLOOK

KEY MESSAGE

Bulgaria's major power plant complex along the Sazliyka tributary of the Maritsa River will likely see serious water stress in the future if it follows a late phase-out of coal as planned in the Bulgarian National Energy & Climate Plan (NECP). The level of increased water stress threatens the freshwater availability for both ecosystems and human activities. This increasing stress agrees with previous studies at a coarser spatial resolution (Behrens et al., 2017). The potential future water stress and impacts on human and ecological systems are, to a very large extent, dictated by the choices made for electricity generation systems in the coming years. Existing national power plans that continue to rely on coal generation would result in not only increased carbon emissions but also short- and mid-term increases in the water vulnerability of existing and future water-using activities.

From today until 2050, the timing of coal-fired electricity generation phase-out represents a larger influence on potential future water stress in the Sazliyka River than the differences between climate change scenarios. There is a significant difference in water stress between the country's energy roadmap submitted with the NECP and the SDS scenario developed by the IEA. The largest water-stress alleviation is seen when coal is retired and replaced with solar and wind energy (solar and wind have negligible water requirements). Given rapid reductions in solar and wind electricity prices and Bulgaria's location, it is likely that solar energy is cheaper there than maintaining existing, paid-for coal power plants (Ray, 2019).

This report highlights the fact that Bulgaria's NECP roadmap for continuing coal generation leads to heightened pressures on ecosystems. This includes a consistently higher number of water budget breaches for the period 2020-2040 in the next two decades when compared to earlier coal electricity generation phase-out around 2030. Indeed, the results reported here likely represent an underestimate of total ecosystem impacts since the model does not include temperature impacts on ecosystem health downstream of power plants (thermal pollution is often increased from heated water rejected from cooling systems and can have significant ecosystem impacts).

Gauging station Galabovo, measuring the water flow of Sazliyka River

APPENDIX

METHODS & DATA

This assessment consists of an integrated model using inputs and data from the energy system, the hydrological system, and the use of water for other sectors (including industry and agriculture). These are modelled from the present day until 2050 using different scenarios as described below. The integrated model, PCR-GLOBWB2 was used to assess both the hydrology and the water use drivers. Two future energy scenarios were used for 2030, 2040, and 2050: The current Bulgarian National Energy and Climate plan (NECP) and the more ambitious (in terms of carbon reductions) Sustainable Development Scenario (SDS) developed by the International Energy Agency (IEA). In doing so the report provides insight into whether the current NECP scenarios represent risks to power generation from water stress. Full information on the energy system model is provided below.

ELECTRICITY AND INDUSTRY WATER USE SUB-MODELS

ELECTRICITY: Large volumes of water are used for cooling thermo-electric power plants. The specific water demand per plant depends on the fuel, the generating technology, the cooling type (wet tower/once-through), and the efficiency of the generator. Once-through cooling draws large volumes of water past a heat exchanger and then returns almost all water to the source (but at a higher temperature). Wet tower cooling uses the evaporation of freshwater. Dry towers use virtually no water, since air flows along the heat exchanger (however they see significant energy efficiency penalties). Pond cooling is a hybrid form between once-through and wet tower cooling, used mainly in the United States. Current trends have seen a move away from once-through cooling and towards wet tower cooling (Davies et al., 2013).

Monthly electricity generation data is collected from ENTSO-E's Transparency Platform (ENTSO-E, 2020), maximum water withdrawal levels are collected from the integrated permits of the power plants, levels of water flow were collected from gauging stations of the National Institute of Meteorology and Hydrology in Bulgaria (NIMH, 2020). This data comprises public information, stored by the institute as part of its monitoring work and was obtained upon request. This study explored the following stations: Galabovo station, which monitors the flow of Sazliyka upstream where the coal power plants are located; Meriç station, outside of Bulgaria, at the mouth of the Maritsa River. The ratios of water withdrawal to water consumption intensities for the Electricity Sector are sourced from a previous study (Bijl et al., 2016).

INDUSTRY: The industry sub-model groups all industrial activities (chemicals, paper, sugar, beer, cement, iron, fabrics, crude steel) together (Bijl et al., 2016). To assess future water demand from industry we used total industry value added forecasts (TIVA) (after correcting for inflation and purchasing power parity to 2005 dollars). We use TIVA because it covers a wide range of industrial processes and is reported annually for almost all countries (Bank, 2020). Whereas a model with specific water-intensive industrial activities would be more process-based, it would also require assumptions on long-term production volumes and water intensities for each industrial activity in every region. Industrial water withdrawal was modelled as:

$$W^I_r(t) = E_r(t) * a * G_r(t)^b * E^I_r(t) * R^I_r$$

Where $\mathbf{W^I_r}$ is the industrial withdrawal (m^3/yr) in region **r** at time **t**. $\mathbf{E_r}$ represents the driving force of economy, total industry value added (TIVA/yr) which is specified by scenarios. The withdrawal intensity (m^3/TIVA) follows the power $\mathbf{a * G_r(t)^b}$, where $\mathbf{G_r}$ is GDP/capita/yr which is used as a proxy for the development and structure of the economy. $\mathbf{E^I_r(t)}$ is the efficiency factor (0-1), $\mathbf{R^I_r}$ is the region factor which follow the global trend.

REGION NAME	YEAR	INTENSITY (L/IVA)	GDP PER CAPITA (PPP)	REGION FACTOR	DATA SOURCE USED FOR INTENSITY	WATERGAP CONSUMPTION-WITHDRAWAL % IN 2011
Bulgaria	2011	14.0	15,58	0.91	WaterGAP	54%

Table A1. Parameters for modeling industrial water demand.

THE HYDROLOGICAL MODEL: PCR-GLOBWB2

PCR-GLOBWB2 (Figure A1) is a state-of-the-art, grid-based global hydrology and water resources model. It is a component-based model implementation in Python using open-source PCRaster Python routines (www.pcraster.geo.uu.nl, last access: 15 April 2021). The computational grid covers all continents except Greenland and Antarctica. The spatial resolution is 5 arcmin (approximately 10 km at the equator). Typical time steps for hydrology and water use are 1 day. For each grid cell and each time step, PCR-GLOBWB 2 simulates moisture storage in two vertically stacked upper soil layers (S_1+S_2 in Figure 1), as well as the water exchange among the soil, the atmosphere, and the underlying groundwater reservoir (S_3 in Figure A1).

The exchange with the atmosphere is comprised of precipitation, evaporation from soils, open water, snow and soils, and plant transpiration. The model also simulates snow accumulation and snowmelt. Sub-grid variability in land use, soils, and topography is included and influences the schemes for run-off–infiltration partitioning, interflow, groundwater recharge (from S_2 to S_3), and capillary rise (from S_3 to S_2). Run-off, generated by snowmelt, surface run-off, interflow, and baseflow, is routed across the river network to the ocean or endorheic lakes and wetlands. Routing can either be simple accumulation, simplified dynamic routing using a method of characteristics, or kinematic wave routing. In case the kinematic wave routing is used, it is also possible to use a (simplified) floodplain inundation scheme and to simulate the surface water temperature.

PCR-GLOBWB2 includes a simple reservoir operation scheme applied to over roughly 6000 human-made reservoirs. These reservoirs are progressively introduced into the model according to their construction year (based on the GRAND database (Lehner et al., 2011). Human water use is fully integrated within the hydrological model, meaning that at each time step (1) water demands are estimated for irrigation, livestock, industry, and households, (2) these demands are translated into actual withdrawals from groundwater, surface water (rivers, lakes, and reservoirs), and desalinization, subject to availability of these resources and maximum groundwater pumping capacity in place, and (3) consumptive water use and return flows are calculated per sector. (Lehner et al., 2011)

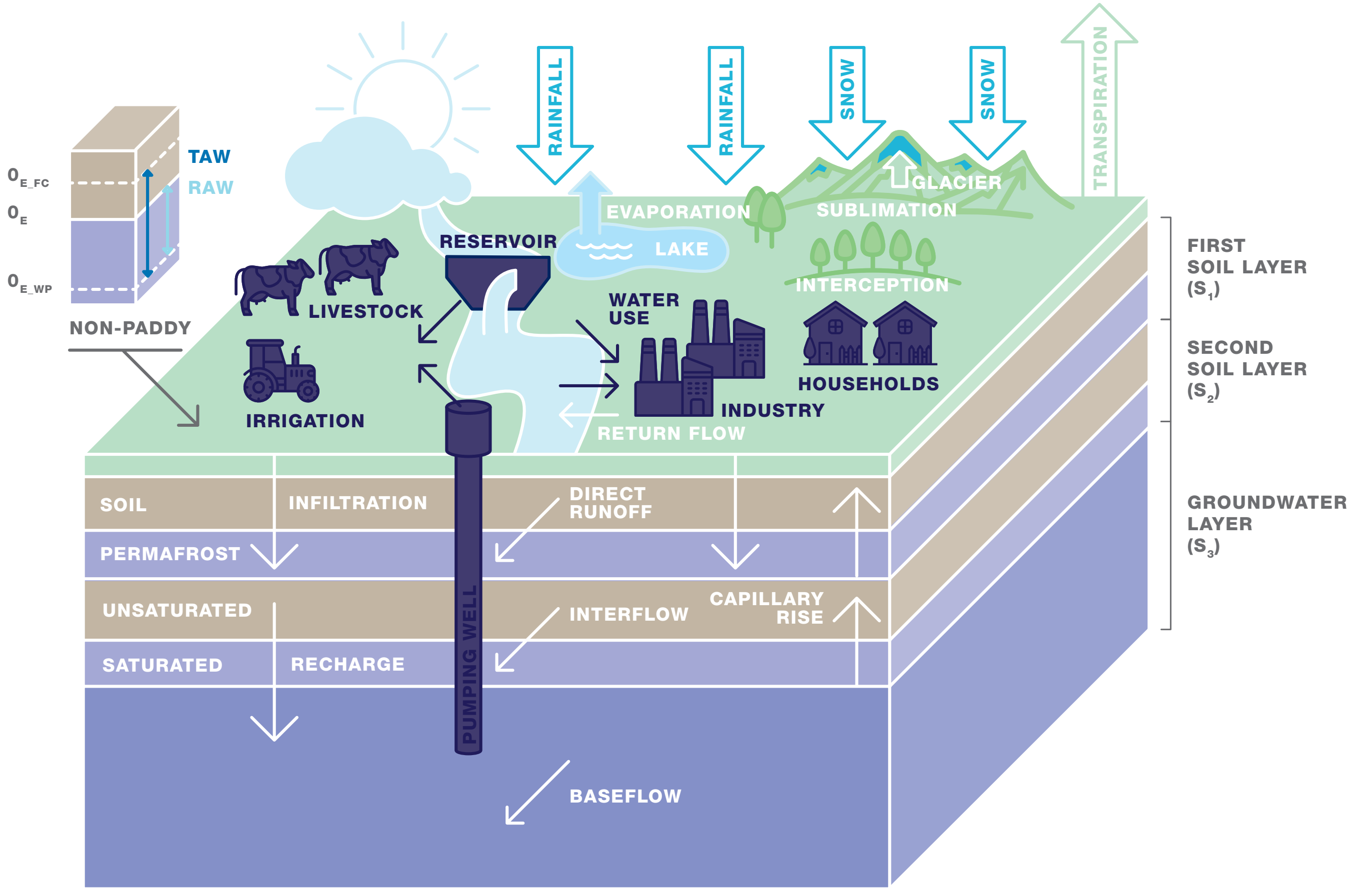


Figure A1. Scheme of fluxes in one grid cell in PCR_GLOBWB (Figure adaptation from (Wada et al., 2014))

FUTURE SCENARIOS

Energy system transition and socioeconomic development

This report investigates different scenarios for the level of coal electricity generation combined with different assumptions on human development using Shared Socioeconomic Pathways (SSPs) (for the combination see Table A1).

The NECP scenario is based on Bulgaria's energy development roadmap submitted to the European Commission through the National Energy and Climate Plan (NECP). There is no significant phasing out of coal before 2035 (Figure 1a). As such the cooling water demand follows the same trend, it remains high for the coming decades (Figure 1b). The other parameters (for instance, GDP, population) used to calculate industry water demand are based on the fossil-fueled development scenario as represented by SSP5.

The Sustainable Development Scenario (SDS) is a renewable energy scenario developed by the International Energy Agency to meet the UN's sustainable development goals (IEA, 2020). The Scenario includes future energy sources from oil, coal, fossil gas, nuclear, hydro, solar and wind until 2050. In comparison with the NECP scenario, the Sustainable Development scenario has more rapid phasing out of coal before 2035 (Figure 2a). The cooling water demand decreases rapidly in the next decade.
The other parameters (for instance, GDP, population) used to calculate industry water demand is based on Sustainability development scenario (SSP1).

Climate change

The Representative Concentration Pathways (RCPs) are a set of scenarios developed by the climate modeling community as a basis for long-term and near-term modeling experiments (Figure A2). The RCPs are the product of collaboration between climate modelers, terrestrial ecosystem modelers, emission inventory experts and integrated assessment modelers. The RCPs are named based on the additional forcing of greenhouses gases by 2100. For this study, three RCPs which cover the range of the potential futures were simulated, one very high baseline emission scenario (RCP8.5), one medium stabilization scenario (RCP6.0), one mitigation scenario leading to low forcing level (RCP2.6). Five different General Circulation Models (GCMs) which are the main models used globally were used to calculate every RCP (Table A1).

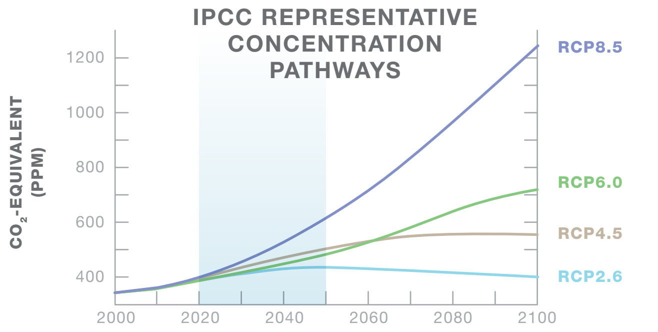


Figure A2. The representative concentration pathways (RCPs) by IPCC.

ENERGY CHANGE SCENARIO	CLIMATE CHANGE SCENARIOS & GCMS
NECP Roadmap Bulgaria submitted to the European Commission	RCP8.5-GFDL
	RCP8.5-HadGEM
	RCP8.5-IPSL
	RCP8.5-MIROC
	RCP8.5-NorESM
	RCP6.0-GFDL
	RCP6.0-HadGEM
	RCP6.0-IPSL
	RCP6.0-MIROC
	RCP6.0-NorESM
Sustainable Development Scenario by IEA	RCP2.6-GFDLAv
	RCP2.6-HadGEM
	RCP2.6-IPSL
	RCP2.6-MIROC
	RCP2.6-NorESM
	RCP6.0-GFDL
	RCP6.0-HadGEM
	RCP6.0-IPSL
	RCP6.0-MIROC
	RCP6.0-NorESM

Table A1. Future scenarios setting up.

The largest water-stress alleviation is seen when coal is retired and replaced with solar and wind energy – solar and wind have negligible water requirements.

Solar park at Karadzhalovo, close to Parvomay

MODEL VALIDATION

The model results show a good agreement with the observed data both at the mouth of the river – at Meriç station and upstream at Galabovo station (Figure A3, A4). The agreement is good at both monthly (Figure A4a) and annual scales (Figure 2b). The Root Mean Square Error (RMSE) for the monthly discharge is 51%. Considering that the PCR_GLOBWB2 is a global model based on global data and parameter settings, the agreement with the available measurements is satisfactory.

Figure A3. Location of Galabovo and Meriç stations

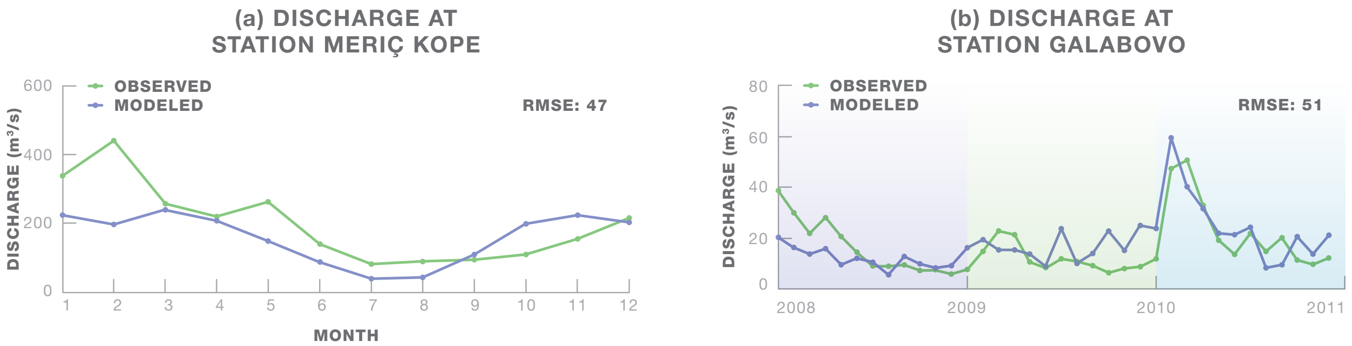


Figure A4. Comparison of measurements (green line) and modeled (purple line) discharge in the station Meriç (a) river mouth of Meriç and Galabovo stations (b) mouth of tributary Sazliyka.

FUTURE DISCHARGES AT DIFFERENT GAUGING STATIONS IN THE MARITSA RIVER BASIN

The average discharge in autumn is 18 m³/s (2000-2010). To maintain the water level in Ovcharitsa reservoir, it is necessary to extract water with maximum of 2.5 m³/s through the canal Hanovo – Botevo – Skalitsa derivation from the Tundzha River. We extracted the modeled data at Hanovo station (Figure A5) which is the start point of the canal in Tundzha. Because the water budget closing to zero (Figure A5) in some months, the water derivation for cooling water demand of the complex do increase the ecosystem upheaval upstream of Hanovo. The historical observations indicate the current water diversion has been causing the decline (even to negative which means water diversion caused significant decrease of water availability downstream of the canal station Hanovo) of the water discharge difference, (downstream of the canal station Hanovo – upstream of the canal station Hanovo).

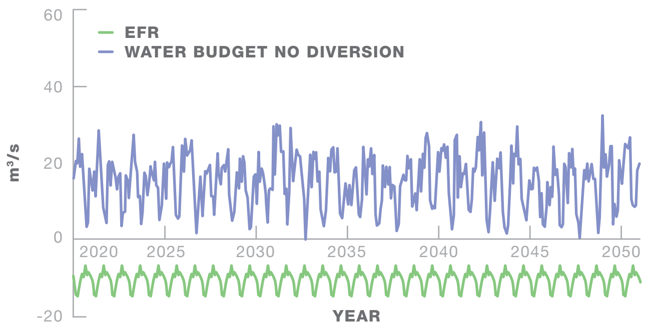


Figure A5. Future monthly discharge and Environment Flow Requirement at the Hanovo where there is a canal supply water to the Maritza Iztok complex in Sazliyka tributary. Water budget = Remaining water flows for further water uses = Discharge – EFRs. The EFRs is set to negative for better presentation.

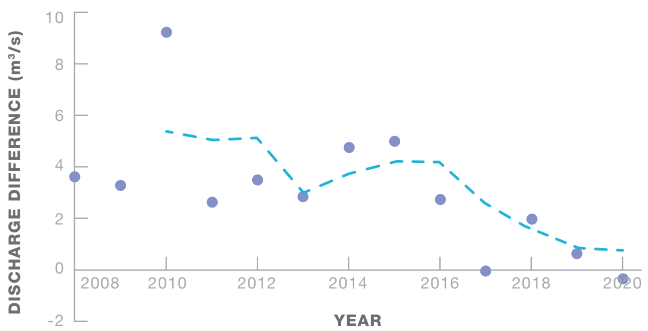


Figure A6. Historical discharge difference (downstream of the canal station Hanovo – upstream of the canal station Hanovo). Dash line is the 3 year's moving average.

The Maritsa River basin is projected to be heavily affected by climate change. This trend would increase the competition for water between energy and other domestic activities, which depend on water.

Ovcharitsa water reservoir

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Ovcharitsa water reservoir
with Hanovo — Botevo — Skalitsa derivation

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