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D1.2 From Global to Local Scenario Narratives

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Publishable Executive Summary

This document begins with a historical overview of the global climate change scenario framework. In Chapter 1, it delves into a description of three Representative Concentration Pathways-Shared Socioeconomic Pathways (SSP-RCP) scenarios (1-2.6, 3-7.0, and 5-8.5) chosen as eligible for underpinning the development of local narratives and scenarios within each of the four SOS-Water project case studies, namely: the Danube, Júcar, Mekong Delta, and Rhine. Chapter 2 then presents the case studies themselves, outlining their current environmental challenges and the projected hydrometeorological and socio-economic changes anticipated under the three chosen SSP-RCP scenarios. Chapter 3 details the methodology employed to create local narratives and pathways that maintain consistency with the corresponding global frameworks. Chapter 4 focuses on the techniques used to model the local pathways and associated adaptation strategies. The document concludes with a final chapter containing key remarks about each of the case studies.

In the Danube Basin, Delta protection, water pollution, habitat alteration, invasive species, microplastics and groundwater pressure are widely recognised as current key issues affecting the Basin. In the future these issues are expected to be extended by others caused by climate change. All future scenarios project rising temperatures in the Danube Basin, with significant increases by the end of the century. Precipitation patterns are expected to change, with wetter winters and springs and potentially drier summers, especially under high-emission scenarios. Economic projections suggest a widening gap between the upper basin (richer) and middle/lower basin (less wealthy). Population projections show an increase in urban areas and a decrease in rural populations (except under the SSP3 "regional rivalry" scenario). Water availability is projected to decrease slightly throughout the century, with more frequent extreme weather events (droughts and floods). Climate change and economic changes will put even more strain on the Danube Basin's resources. To address these challenges, the SOS project is involving stakeholders in creating shared adaptation scenarios for sustainable water management. Stakeholders highlighted the need for a holistic approach that considers environmental, social, and economic aspects. Baseline climate change scenarios will be built upon existing frameworks (SSP-RCP scenarios 1-2.6, 3-7.0 and 5-5.85). Measures suggested by researchers and stakeholders that align with these frameworks will then be incorporated to develop adaptation scenarios. The Community Water Model (CWatM) will be used to simulate both baseline and adaptation scenarios in the Danube Basin. This model can account for natural and human influences on the water system, as well as the effects of different adaptation measures, such as building new reservoirs or improving irrigation efficiency. Overall, the methodology devised for the Danube Basin emphasizes stakeholder involvement in creating relevant and credible future scenarios for the Basin, in conjunction with integrated water modelling. These scenarios can inform water management strategies and adaptation planning.

The Jucar River Basin is one of the most important rivers in eastern Spain. Divided into upper, middle and lower hydrological sub-basins, the Jucar faces various water management challenges and a tight balance between water resources and demands, with negative net balances concentrated in the Mancha Oriental and the lower Jucar rivers. Climate change projections suggest an increase in temperature of 2-6 degrees (depending on the scenario) and a decrease in rainfall, which will affect water availability and demand. The severity of the impacts depends on the SSP, but in general, greater and more diverse impacts are expected in the long term. The development of local narratives for the JRB was carried out using a bottom-up approach through scenario-building workshops. Two baseline scenarios ('protectionism' and 'globalization') were developed for the Jucar, in line with SSP3 and SSP5, respectively, and applied to La

Mancha Oriental and the Lower Jucar through participatory workshops involving local stakeholders. These scenarios considered the absence of any intervention by the Jucar River Basin Agency (CHJ), apart from existing measures already in place. Adaptation measures were explored and evaluated for their impact and suitability by stakeholders during the scenario-building workshops. The local narratives of the Jucar River, developed for the Mancha Oriental and the Lower Basin under both protectionist and globalization scenarios, provide insights into the possible future trajectories of agriculture in the JRB. These narratives describe expected changes in cropping patterns, water use efficiency, technological advances, socio-economic factors and potential territorial and social conflicts over water resources. The combination of global scenarios and local narratives in the JRB will be achieved by combining hydro-economic modelling for hydrological scenario building with a bottom-up participatory approach in which global narratives will be adapted to the local scale.

The Mekong River Basin supports rich biodiversity and sustains the livelihood of millions of people. However, it faces challenges due to upstream dam construction reducing seasonal variations and impacting fish migration. Furthermore, climate change is expected to bring increased temperatures and changes in precipitation patterns, including potentially drier dry seasons and more intense floods. The Mekong Delta, located at the end of the Basin, is particularly vulnerable to adverse dam and climate change impacts. The SSP-RCP projections for the Mekong show that temperature will likely increase, precipitation might see a shift towards wetter wet seasons and drier dry seasons, and the population is expected to grow, especially in urban areas. Also, land use is projected to change, with increases in cultivated land, pastureland, and urban areas, potentially at the expense of natural habitats. Water availability is projected to remain relatively stable or slightly increase but with a higher frequency of extreme events like droughts and floods. Water demand is expected to rise, particularly for irrigation, potentially leading to water stress. These findings highlight the importance of considering the long-term consequences of development choices on the Mekong Delta's water resources and ecosystems. Sustainable development strategies that balance economic growth with environmental protection are crucial for the Basin's future. To aid the governance of these future challenges, three scenarios of development alternatives (DAs) have been created, each prioritizing one of the following three pillars: economic development, environmental protection, or social development. The remaining two pillars are considered but maintained at a minimum acceptable level in each scenario. Stakeholder input is incorporated through scoring various development criteria for each DA. The Vietnamese River System Analysis Program and the Danish Hydraulic Institute's Mike 11 will be used to model the Mekong River Delta scenarios. These models cover a large geographical area and consider various inputs, including upstream flow data, water level data, rainfall data and water demand from all users. By employing diverse management strategies and incorporating relevant boundary conditions, the models provide a comprehensive framework for modelling water resource management in the Mekong Delta.

The Rhine basin, a crucial European waterway, faces challenges from climate change and human activities. Rising temperatures are likely, with the severity depending on global emission levels. Winter precipitation is projected to increase, while summers may become drier. Socio-economic factors will also play a role. Strong international cooperation could lead to economic growth (SSP1 scenario), while other scenarios depict population decline and varying economic trajectories (SSP3, SSP5). Despite these challenges, there is a positive outlook on water scarcity. Water demand is expected to decrease across all future scenarios by 2075. To understand how the Rhine basin will navigate its future, the SOS-Water project explores three potential pathways ("Rest," "Warm," and "Steam") based on global scenarios. These pathways consider both climate change and socio-economic development. A hydrological model (PCR-GLOBWB2.0) will be used to assess future water availability. This model is unique because it considers both climate and human water management practices, allowing researchers to analyse how changes in irrigation and reservoir operations (adaptation strategies) can influence water availability in the Rhine basin.

Table of Contents

List of Tables and Figures

1. Global scenario framework

IPCC scenario framework of SSPs and RCPs

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess the scientific, technical and socio-economic information relevant to the understanding of the risk of human-induced climate change. The IPCC has evolved into an internationally accepted authority on climate change, and leading climate scientists and all member governments (195) endorse its findings.

Among others, the IPCC has produced a series of comprehensive Assessment Reports (ARs) on the state of understanding of the causes of climate change, its potential impact and options for response strategies. The Synthesis Report of the latest Sixth AR was released in March 2023. Scenarios have played an important integrating element in the ARs. Integration supports a consistent, coherent assessment, new insights and the opportunity to address policy-relevant questions that would not be possible otherwise, for example, which impacts are unavoidable, which are reversible, what is a consistent remaining carbon budget to keep temperatures below a certain level and what would be a consistent route of action to achieve that goal.

Initiated with the 'Special Report on Emission Scenarios (SRES, Nakicenovic et al., 2000) used in the Third AR, scenario narratives and framing have evolved in a collaborative effort through an "open process" with input and feedback from a community of experts. In the meantime, the Scenario Model Intercomparison Project (ScenarioMIP) (O'Neill et al., 2016), one of the Coupled Model Intercomparison Projects (CMIP[1]), has taken on a coordinating role in integrating the development of climate scenarios.

The Fifth AR introduced the Representative Concentration Pathways (RCPs, Moss et al. 2010; van Vuuren et al. 2011)and the Shared Socioeconomic Pathways (SSPs, O'Neill et al., 2017). This matrix framework (Riahi et al., 2017) combines SSPs with RCPs to create a set of possible future climate change scenarios and emphasises integrated scenarios that consider both socio-economic and climate factors.

RCPs describe possible trajectories of climate change forcing agents, resulting in radiative forcing trajectories expressed as changes of energy flux with respect to pre-industrial levels and measured in W/m^2 (van Vuuren et al. 2011). The RCPs are labelled according to possible radiative forcing values in the year 2100, ranging from 1.9 to 8.5 W/m^2 and representing increasingly strong climate change. The higher the radiative forcing, the more GHGs are emitted, leading to higher global temperatures and more pronounced climate change impacts. RCPs were originally developed to meet the requirements of climate modelling and to enable rapid processing of Global Circulation Models (GCMs). The SSPs provide a standardised framework linking societal changes to climate-forcing levels to determine which societal changes and policy measures can lead to a given RCP.

The SSP narratives were designed along two axes, representing socio-economic challenges for adaptation mitigation, respectively. One narrative (see Figure 1) was developed for each possible combination of

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[1] CMIP is a project of the World Climate Research Programme (WCRP) providing climate projections to understand past, present and future climate changes. CMIP and its associated data infrastructure have become essential to the Intergovernmental Panel on Climate Change (IPCC) and other international and national climate assessments. See https://wcrp-cmip.org/

high/low levels of challenges, plus a fifth narrative laying at the intersection of all challenge levels (O’Neill et al. 2017).

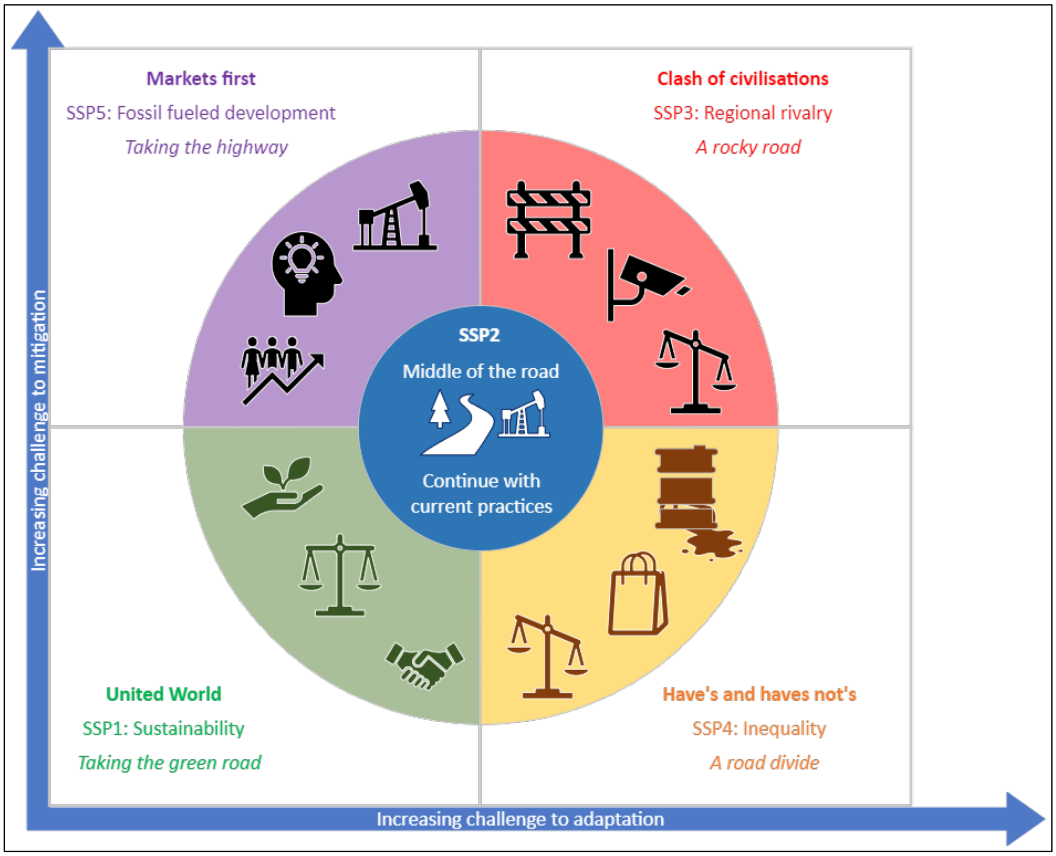


Figure 1 SSP position along the mitigation and adaptation axis.

The key features of each SSP emerging from the narratives are summarised in Table 1. Storyline descriptions were converted into qualitative (KC & Lutz, 2017; O'Neill et al., 2017) and then quantitative inputs for models projecting population growth, education, urbanisation (Jiang & O'Neill, 2017), and several GDP projections (Dellink et al. 2017; Crespo Cuaresma 2017; Leimbach et al. 2017). Of these multiple GDP projections, the one from Dellink et al. (2017) was chosen as a "marker" to provide GDP and population input projections to Impact Assessment Models (IAM). Details on the SSPs' socio-economic characteristics and land use projections are reported in Figure 4 and Figure 5.

IAM produced CO_2 emissions and Greenhouse Gasses (GHG) projections (Fricko et al. 2017; van Vuuren et al. 2017; Calvin et al. 2017; Fujimori et al. 2017; Kriegler et al. 2017), which were then used to model possible forcing levels associated with each SSP (Meinshausen, Raper, and Wigley 2011; Meinshausen, Wigley, and Raper 2011). Emission scenarios and forcing levels inform GCMs of several climate modelling groups, which calculate future trajectories of climate variables (Figure 2). As a result, IAMs could determine a set of plausible RCP SSP combinations.

It is important to remark that the SSPs are developed as possible futures stemming from the present but without implementing any further climate policy besides those already in place. To assess the outcomes of global climate and adaptation measures, a second set of scenarios, built on the SSP and called Shared

Climate Policy Assumptions (SAP), was developed (Riahi et al., 2017). However, this latter set of scenarios is irrelevant to the rest of this report and was just mentioned for completeness.

Table 1 Main features of SSP scenarios. Based on O'Neill et al. (2017)

Shared Socio-economic Pathway	Features
SSP1: sustainability, taking the green road (low challenges to mitigation and adaptation)	• Global, gradual cooperation towards sustainability • Rapid and inclusive technological development • Global commons management improves slowly but steadily • Educational and health investments drive low population growth • Inequity declines, and economic growth shifts towards human well-being • Use of renewable energy sources and development of efficient energy and resource systems
SSP2: middle of the road (medium challenges to mitigation and adaptation)	• Economic, technological and social development follow historical patterns • Globally uneven income growth, inequality persists or slowly reduces • Global but slow cooperation towards sustainable development goals • Moderate population growth, stable in the second half of the century • Social and environmental vulnerabilities are still challenging
SSP3: regional rivalry, a rocky road (high challenges to mitigation and adaptation)	• Nationalism drives competition among regions and focuses on domestic issues. • Low technological development and decline in investments in education • Low priority for social and environmental goals, an increase in inequality • Focus on domestic resources and national and security matters • High population growth in developing countries, low growth in industrialised ones • Slow economic growth of developing countries and material-intensive consumption • Low priority of environmental issues leads to degradation in some regions
SSP4: inequality, a road divide (low challenges to mitigation, high challenges for adaptation)	• Increasing disparities in economic opportunity and political voice between and within countries • Widening of the gap between globally connected technological and economically wealthy and low-income, capital intensive-low education and low-tech societies • Decreasing social cohesion, an increase in social unrest • Energy sources diversify in both fossil and renewable sectors • Environmental policies implemented locally in middle-to-high-income regions
SSP5: fossil-fuelled development, taking the highway (high challenges to mitigation, low challenges to adaptation)	• Great trust in competitive markets, innovation and participatory society • Rapid economic growth and development of human capital • Global population peaks and declines in the 21st century • Free, global trade sustained by carbon-intensive fuels • High technological development • Local environmental issues successfully managed • Trust in technological development to manage ecological systems

To reduce complexity and allow comparison of the many GCMs, the ScenarioMIP project protocol defined a set of plausible SSP-RCP combinations relevant to current policy agreements and the debate around it. For CMIP Phase 6 (CMIP6), the forcing levels are inherited from RCP scenarios with the addition of levels 1.9, 3.4 and 7.0 W/m2, to fill gaps that emerged from RCP-based climate-science practices (O'Neill et al., 2016). Using these predefined subsets of scenarios, climate research institutes all over the world have performed climate change simulations for CMIP6 to serve as a basis for the Sixth AR of the IPCC (IPCC 2021).

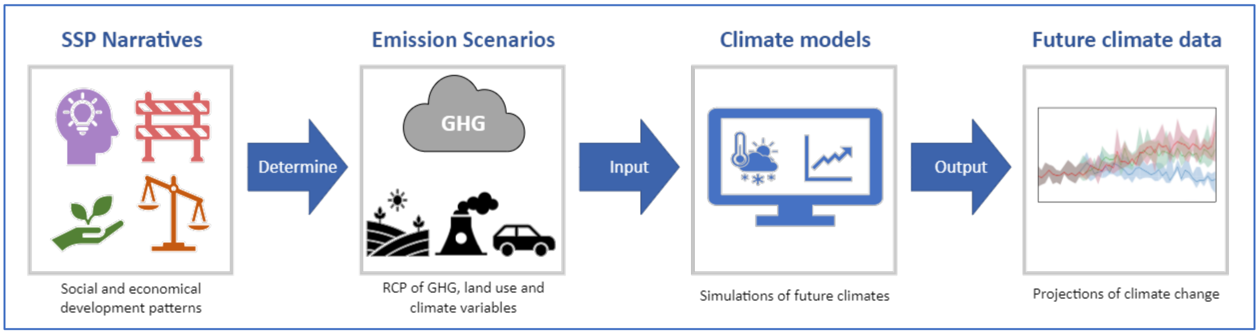


Figure 2 From narratives to climate projections workflow. Based on https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/, accessed 12-12-2023

The SSP-RCP scenarios' names are composed of the SSP narrative followed by a radiative forcing suffix. Therefore, for example, the scenario combining SSP1 and radiative forcing level 2.6 is addressed as SSP1-2.6. The full range of forcing levels is on the left axis of Figure 3. Each cell in Figure 3 shows a possible combination of SSP and forcing; solid cells in Figure 3 show the combinations used to produce climate projections, and hollow cells are those not simulated because they are deemed unrealistic. The rationale for combining one SSP with one or more forcing levels was to associate SSP-based IAM with forcing levels that were realistically achievable by the SSP. Therefore, not all combinations have been simulated—the cells of Figure 3 with colours other than light blue mark the scenarios selected for this project. other than light blue mark the scenarios selected for this project.

Unlike the original RCPs used in CMIP5, the new SSP-based scenarios provide economic and social reasons for the assumed emission pathways and changes in land use. The denomination of individual scenarios comprises the name of the basic socioeconomic pathway followed by two numerals indicating the additional radiative forcing achieved by the year 2100 (in units of tenths of watts), as follows:

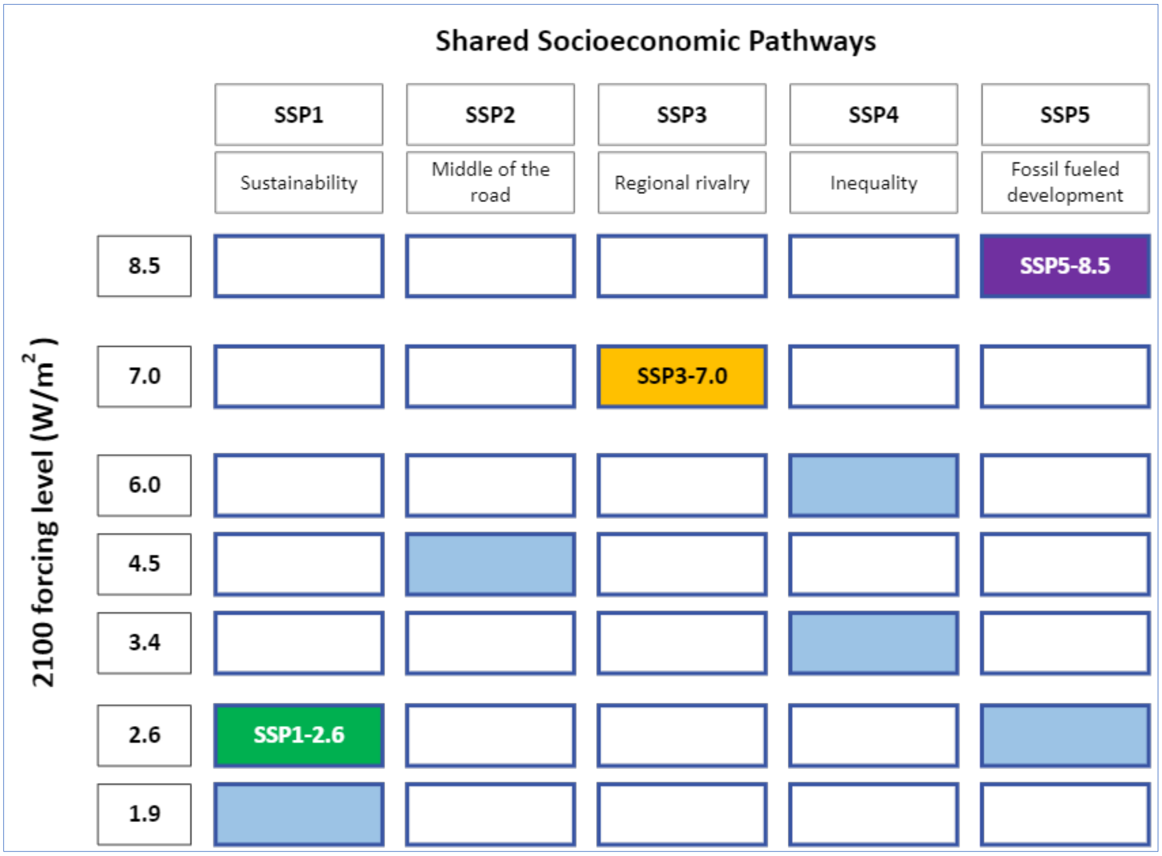
SSP5-RCP8.5: Reaching a radiative forcing of 8.5 W/m² by the year 2100, this scenario represents the upper boundary of the range of scenarios described in the literature. It can be understood as an update of the CMIP5 scenario RCP8.5, now combined with socioeconomic reasons.

SSP3-RCP7.0: With 7 W/m² by the year 2100, this scenario is in the upper-middle part of the full range of scenarios. It was newly introduced after the RCP scenarios, closing the gap between RCP6.0 and RCP8.5.

SSP2-RCP4.5: As an update to scenario RCP4.5, SSP245 with an additional radiative forcing of 4.5 W/m² by the year 2100 represents the medium pathway of future greenhouse gas emissions. This scenario assumes that climate protection measures are being taken.

SSP1-RCP2.6: This scenario with 2.6 W/m² by the year 2100 is a remake of the optimistic scenario RCP2.6 and was designed with the aim of simulating a development that is compatible with the 2°C target. This scenario assumes that effective climate protection measures are being taken.

The casual naming convention of these combined SSP-RCP scenarios usually adopts the name of the SSPs, i.e., ‘Sustainability’ for SSP1-RCP2.6, ‘Regional rivalry’ for SSP3-RCP7.0 and ‘fossil fuelled development’ for SSP5-8.5.



Shared Socioeconomic Pathways

2100 forcing level (W/m²)	SSP1 Sustainability	SSP2 Middle of the road	SSP3 Regional rivalry	SSP4 Inequality	SSP5 Fossil fueled development
8.5					SSP5-8.5
7.0			SSP3-7.0		
6.0				🟦	
4.5		🟦			
3.4				🟦	
2.6	SSP1-2.6				🟦
1.9	🟦				

Figure 3 SSPs and radiative forcing combinations. Adapted from O 'Neill et al. (2016)

2. Global SSP-RCPs scenarios selected for the SOS Water project

The scenarios selected for this project are SSP1-2.6, SSP3-7.0 and SSP5-8.5. Thus, including an optimistic 'Sustainability' scenario, the only one where global temperature can be kept below 2 degrees Celsius. The SSP3-7.0 assumes a resurgent nationalism and concerns about competitiveness and security, with regional conflicts pushing countries to focus increasingly on domestic or, at most, regional issues. In the current geopolitical context, SSP3-7.0 does not seem unlikely, albeit a high-emission scenario on an unsustainable path. In this scenario, global warming will reach 2 degrees Celsius before 2050 and 3 degrees Celsius before 2080. Although the high-end emission scenario SSP5-8.5, which leads to a warming of around 5 degrees Celsius by 2100, is unlikely to be included in the next generation of scenarios for CMIP7, it is explored in the SOS-Water project to reflect uncertainty in the climate models. Uncertainty could arise, for example, from surpassing tipping points, which could push GHG emissions beyond the level that is emitted by human activities alone.

The following paragraphs summarise the narratives of each SSP scenario and describe the associated global energy system structure and the changes in cropland, forest, natural areas, GDP, and equality. These descriptions are the global context against which the local narratives will be developed and with which the local narratives will have to maintain a strong degree of consistency.

SSP1-2.6 scenario (sustainability)

This scenario is the most optimistic, for it is anticipated to produce a mean global warming of less than 2°C and, therefore, poses a lesser level of mitigation and adaptation challenges.

The SSP1, "taking the green road", narrative describes a future where the world is gradually and comprehensively moving towards a more sustainable path, prioritising inclusive development within recognised environmental limits. The shift is motivated by increased awareness and consideration of environmental degradation and inequality's social, cultural, and economic costs. Collaboration among local, national, and international entities, including the private sector and civil society, facilitates improved management of global resources. Investments in education and health contribute to a demographic transition, resulting in a relatively low global population. High-income countries lead the way in emphasising human well-being over rapid economic growth, guided by a commitment to Sustainable Development Goals (SDGs), leading to reduced inequality globally. Environmental technology investments and changes in tax structures enhance resource efficiency, decrease overall energy and resource use, and improve environmental conditions. Renewable energy becomes more attractive through increased investment, financial incentives, and changing perceptions. Consumption trends focus on low material growth and reduced resource and energy intensity. The directed development of eco-friendly technologies, a positive outlook for renewable energy, and cooperative institutions result in relatively low challenges to mitigation. Simultaneously, improvements in human well-being, supported by robust global, regional, and national institutions, imply **low challenges to adaptation** (O'Neill et al., 2017).

Global population growth is the lowest in this narrative, together with SSP5 of all narratives. The population will grow up to 8 billion by approximately 2050 and then begin to decline; nevertheless, urbanisation steadily grows, also after the beginning of the population decline. GDP steadily increases and reaches a level second only to SSP5. Similarly, the GDP per capita is the highest after the one in SSP5. To feed the population, the cropland global area does not substantially increase, a unique case among the SSPs, although the uncertainty is quite high for this projection. At the same time, land used for pasture decreases, confirming an attitude towards a diffuse change in dietary habits. As pastures decrease, forests and other natural lands steadily and substantially increase their area, starting around 2030. Although these two variables have high uncertainty, the values of this SSP are remarkably more elevated than the other narratives. The global energy required to sustain the world of this narrative increases up to 2070 and then levels out. Energy requirements are the lowest among the narratives. Primary energy sources global mix see a gradual decline of oil and gas, starting from 2030, replaced by non-fossil fuels and renewables while coal remains steady. The prediction for 2100 shows a mix composed of roughly 40% renewables and fossil fuels and the remaining 20% coal (Riahi et al., 2017).

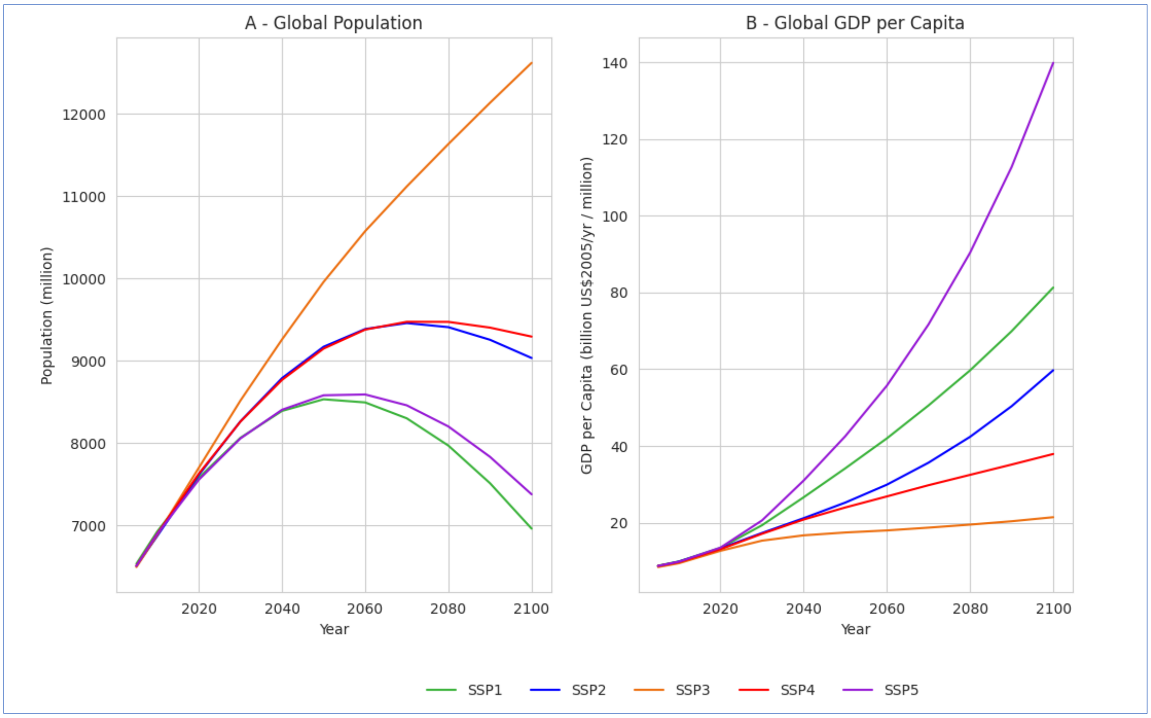


Figure 4 SSP scenarios projections of population and GDP per capita. This figure is based on the SSP database hosted by the IIASA Energy Program at https://tntcat.iiasa.ac.at/SspDb.

SSP3-7.0 scenario (regional rivalry)

This scenario is relevant because it exhibits conspicuous changes in land use, high emissions, and high societal vulnerability.

The SSP3- "regional rivalry" narrative assumes that, in the future, countries are increasingly turning inward due to a resurgence of nationalism, concerns about competitiveness and security, and regional conflicts. The lack of strong global institutions contributes to uneven coordination and cooperation in addressing global issues. Policies shift towards national and regional security, leading to barriers in trade, especially in energy and agriculture. Focus on achieving energy and food security at regional levels results in authoritarian governance in some regions, accompanied by declines in education and technological investments. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen, particularly in developing countries. Many struggle to maintain living standards and provide essential services. Limited international attention to environmental concerns leads to degradation, hindering progress toward sustainability. Population growth varies between industrialised and developing countries, with challenges in resource management, fossil fuel dependency, and international cooperation. Slow technological change and ineffective institutions pose **high challenges** for both **mitigation** and **adaptation** globally (O'Neill et al., 2017).

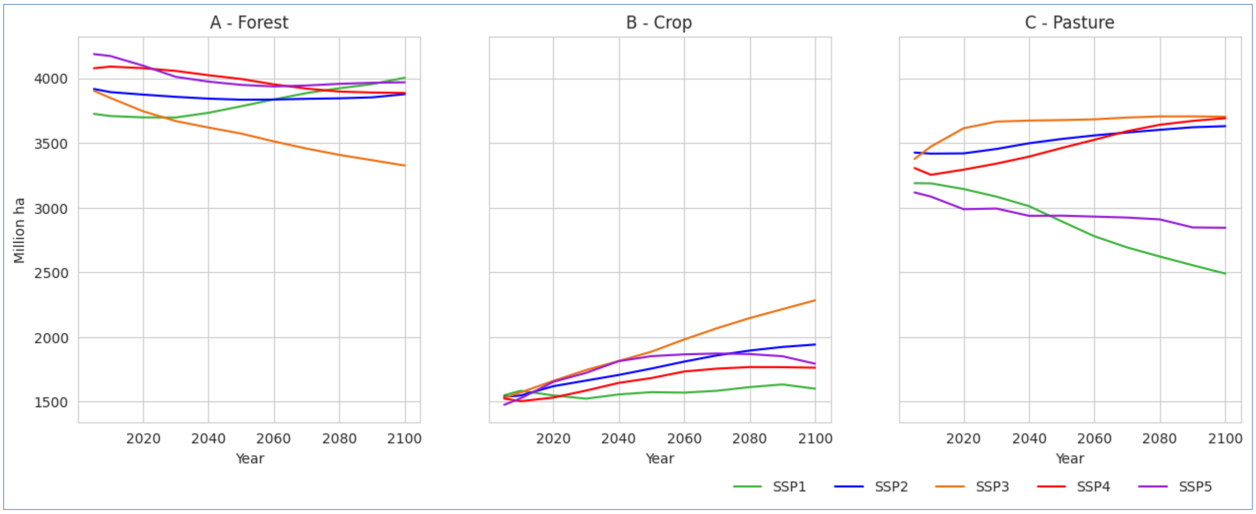


Figure 5 SSP scenarios projections of cropland, forest and pasture. This figure is based on the SSP database hosted by the IIASA Energy Program at https://tntcat.iiasa.ac.at/SspDb*.*

In this narrative, the global population grows constantly until reaching 12 billion in 2100. Such growth is the highest among the SSPs, although it produces the lowest level of urbanisation and the lowest levels of GDP and GDP per capita.

Growth in population size accompanied by low levels of technological development and trade barriers cause the largest and constant increase in cropland area among the SSPs at the expense of forest and other natural land areas. Pastures instead, although growing in area, do not further increase significantly after 2030 and stabilise on levels similar to those of SSP4. The energy requirements of SSP3 are intermediate among the SSP, although they have the greatest range of uncertainty. The energy mix sustaining the development of the SSP3 narrative has a share of renewables and nuclear of less than 20% for the whole 2010-2100 period. The share of fossil fuels starts at about 60% and steadily decreases to roughly 40% in 2100. The decrease in fossil fuel use is compensated by increased coal consumption (Riahi et al., 2017).

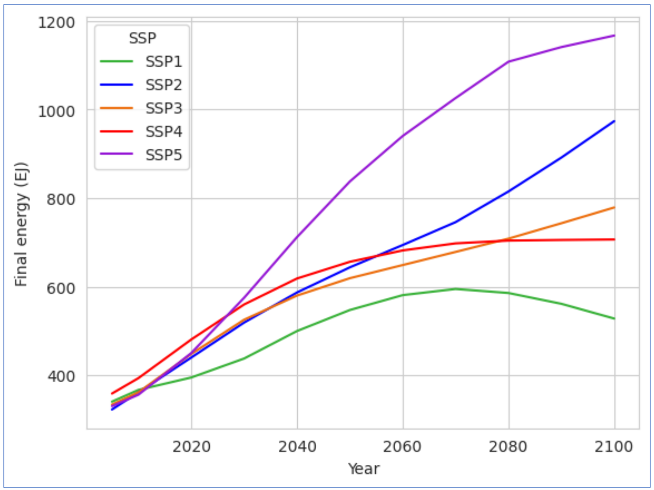


Figure 6 Global energy demand of the SSPs. This figure is based on the SSP database hosted by the IIASA Energy Program at https://tntcat.iiasa.ac.at/SspDb.

SSP5-8.5 scenario (fossil fuelled development)

The relevance of this scenario is mostly related to the level of forcing representing the far end of the possible forcing level pathways.

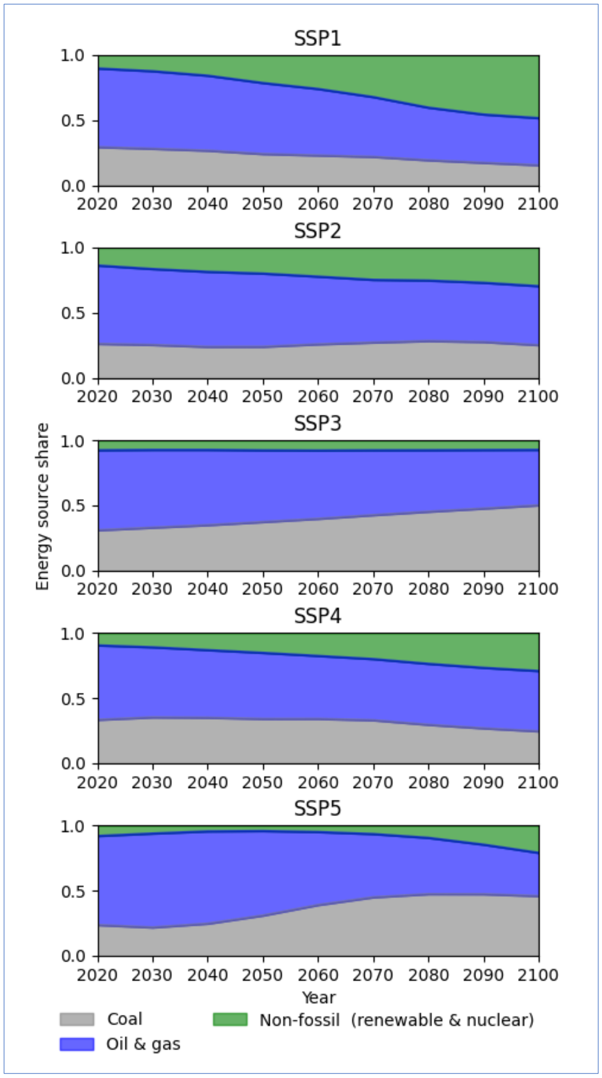


Figure 7 Projected energy sources of the SSPs. This figure is based on the SSP database hosted by the IIASA Energy Program at https://tntcat.iiasa.ac.at/SspDb.

In the SSP5, "**taking the highway**", the world, driven by economic success, increasingly relies on competitive markets, innovation, and participatory societies for rapid technological progress and sustainable development. Global integration and interventions aim to maintain competition and remove barriers for disadvantaged groups. Significant health, education, and institutional investments enhance human and social capital. However, economic and social development coexists with the exploitation of fossil fuel resources and energy-intensive lifestyles worldwide, leading to rapid global economic growth. The belief in effective management of social and ecological systems, even through geo-engineering, is prominent. While local environmental impacts are addressed with technology, there is limited effort to prevent potential global environmental impacts, which is seen as a trade-off with economic progress. The global population peaks and declines in the 21st century, with developing countries experiencing rapid fertility declines while high-income countries maintain relatively high fertility levels. Increased international mobility accompanies reduced income disparities. A significant dependence on fossil fuels and a lack of global environmental awareness poses **high mitigation challenges**. However, achieving human development goals, experiencing robust economic growth, and having well-engineered infrastructure generally lead to **low adaptation challenges**, with only a few exceptions (O'Neill et al., 2017).

The global population dynamic in this SSP is similar to the one in SSP1: growth of up to 8 billion individuals in 2030, followed by a decline to approximately 7 billion by 2100. Similar to SSP1, in this narrative, there is a strong growth of urbanisation, with 90% of the global population estimated to reside in urban areas within 2100. The strong economic focus of this narrative produces the highest global GDP and GDP per capita among all the SSPs. Cropland area increases until approximately 2050 at the expense of forest. After this year, there is a small decline in cropland, allowing a slight rebound of forest area. Pastures slightly decline while other natural areas exhibit a small increase. The energy requirements are by far the largest of all SSPs. The demand is satisfied mainly by using fossil fuels, with 60% of the mix, until 2050, when coal begins to take over, reaching 40% in 2100. Nuclear and renewables remain below 20% of the mix.

3. Case studies introduction and local drivers informed by global SSP-RCP scenarios

The following paragraphs present the main features of each case study basin and describe the expected changes in terms of hydrometeorological (i.e. precipitation, temperature, discharge) and socioeconomic (e.g. population, GDP) over time for each SSP-RCP scenario used in the project. Hydrometeorological and socioeconomic data are derived from global models downscaled to fit the resolution required to model the basins and represent the assumptions onto which the local scenarios will be designed.

Danube

The Danube Basin

The Danube Basin (DB) is the most international basin in the world, including 19 countries home to 79 million people (see Table 2) and covering an area of around 801,000 km2, making it the second largest basin in Europe and the 21st in the world. The Danube stretches over 2,850 km from the Black Forest (Germany) and flows south-eastward through Europe to the shores of the Black Sea. Its diversity is reflected in the number of names used to address it: The Danube is called Donau in German, Dunaj in Slovakian, Duna in Hungarian, Istros in Greek, Dunav in Serbian and Bulgarian, Duna in Russian, Dunăre in Romanian, and Danubius in Latin.

Source: US National Park Service

Figure 8 Danube Basin states and basin divisions.

Due to its extent, variety of habitats, flowing conditions, and diversity of characteristics, the DB is conventionally divided into three sub-regions: the upper, middle, and lower Danube Basin (Figure 8). The upper basin extends from the source, in the German Black Forest, to the capital city of Slovakia, Bratislava. This sub-region exhibits depths between 1 to 8 m and high mean flow velocities between 2 and 2.5 m/s, particularly along the tributaries flowing from the Central European Highlands and the Northern Alps.

The middle basin stretches from the Gate of Devin Castle, near Bratislava, to the Iron Gate Gorge, at the border between Serbia and Romania. The gorge also marks the border between the Southern Carpathian Mountains and the Balkans. In this section, the Danube becomes a typical lowland river with slow flow, low banks, and expansive width, widening, in some stretches, to over 1.5 km. There are two narrow stretches at Visegrad (Hungary) and the Iron Gates, where it flows through canyon-like gorges. After the Hungarian Gates Gorge near Bratislava, the river enters the Little Alföld Plain, slowing down significantly and causing deposition of gravel and sand, forming two large islands on the Slovakian and Hungarian sides. The Danube continues through Budapest and the Great Alföld Plain until it reaches the Iron Gate Gorge. Along this stretch, the riverbed is shallow and marshy, with numerous islands formed due to deposition. It is joined by major tributaries, namely the Drava, Tisza, and Sava, significantly increasing its flow.

*Table 2 Countries of the Danube Basin, their population within the basin and their share of the basin area. *EU countries; **EU candidate countries. Data source ICDPR, https://www.icpdr.org/danube-basin/countries accessed 24-1-2024.*

Country	Coverage in DRB (km2)	Share of DRB (%)	Percentage of land territory within the DRB (%)	Population within the DRB (Mio.)
Albania**	126	0.02	0.4	< 0.01
Austria*	80,593	10.03	96.1	8.4
Bosnia and Herzegovina**	38,289	4.77	74.9	3.2
Bulgaria*	47,235	5.88	42.6	3.57
Croatia*	35,111	4.37	62.1	2.9
Czech Republic*	21,681	2.7	27.5	2.7
Germany*	56,250	7	15.7	10.07
Hungary*	93,000	11.58	100	9.8
Italy*	565	0.07	0.2	0.02
Republic of Moldova**	12,505	1.56	36.9	1.1
Montenegro*	7,260	0.9	52.5	0.18
North Macedonia**	109	0.01	0.4	< 0.01
Poland*	430	0.05	0.1	0.04
Romania*	232,193	28.91	97.4	19.5
Serbia**	81,974	10.21	92.6	7
Slovakia*	47,084	5.86	96	5.2
Slovenia*	16,420	2.04	81	1.8
Switzerland	1,809	0.23	4.4	0.02
Ukraine**	30,626	3.81	5.1	3.03

The lower basin begins downstream of the Iron Gates. From there, the Danube meanders across a vast plain, spreading out and becoming shallower and marking a natural border between Romania and

Bulgaria. Numerous large islands dot its course, and the current loses its speed. In this stretch, smaller tributaries like the Iskar, Olt, Yantra, Siret, and Prut join the main river, contributing modestly to the overall flow rate. The course of the Danube ends and opens up into the Danube Delta, formed by the river splitting into three. The three channels are named Chilla, Sulina and Sfintu Gheorghe (St. George), caring for approximately 63%, 16% and 21% of the discharge, respectively. The delta is the largest in Europe, covering an area of approximately 6,000 km². It is a biodiversity hotspot and is critical in filtering pollutants that otherwise would drain into the Black Sea.

The hydrological character regime of the upper and part of the middle basin, down to the confluence with the Morava River, is glacio-nival, with peak discharges in July and lows in winter (January-February, see, for example, Achlein or Linz gauging stations in Figure 9). While the influence of the glacial regime persists to the mouth of the Tisza River, the discharge pattern changes further downstream where the influence of larger tributaries like the Tisa and Sava Rivers lead to a bimodal discharge regime similar to the lower Sava and Drina Rivers. This bimodal regime features two annual peak discharges and low flows occurring in late autumn and spring (high flows) and winter and summer (low flows), respectively (see Ceatal Izmail and Pancevo gauging stations in Figure 9).

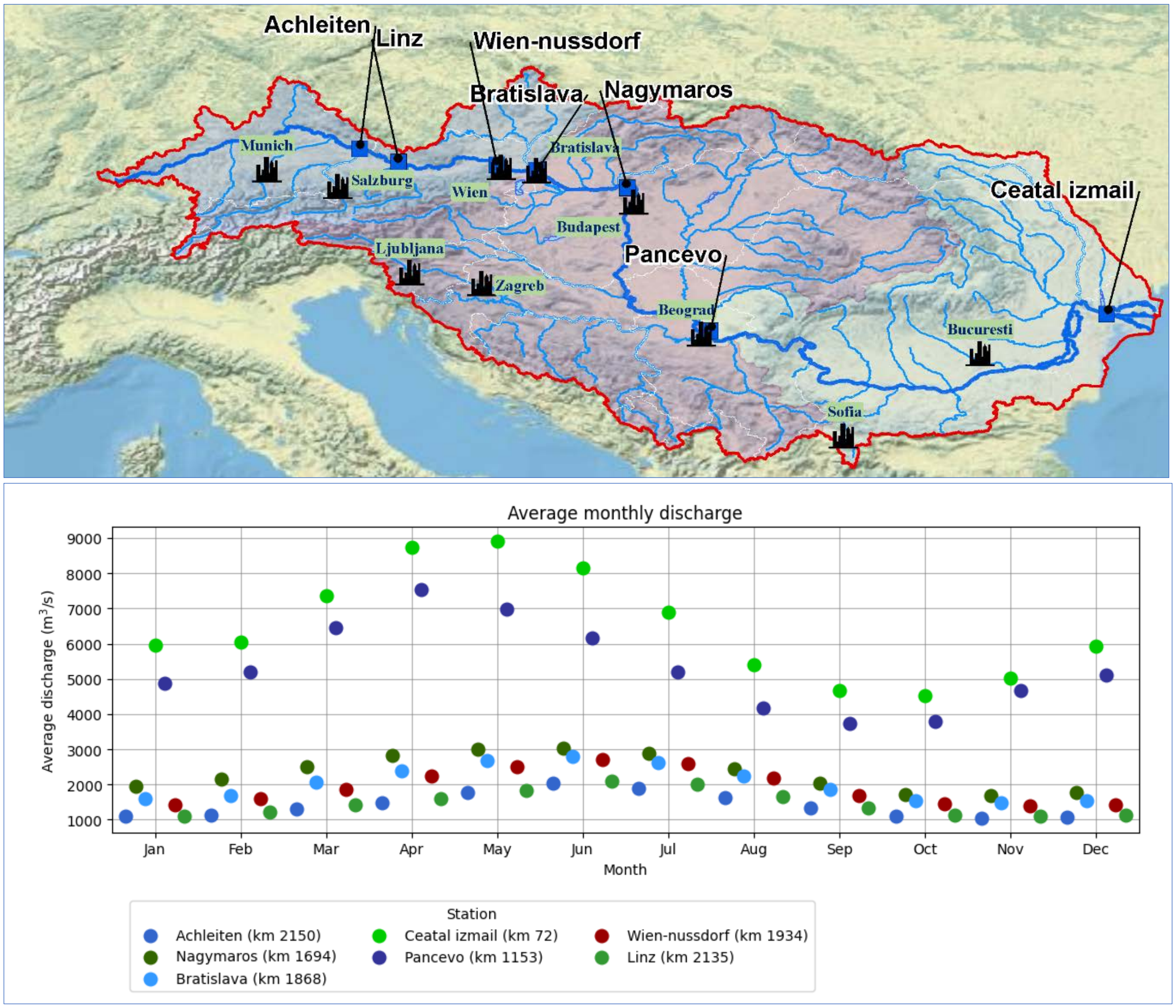


Figure 9 Position of the gauging stations and average monthly discharge along the Danube River.

Current Danube Basin management issues

The large number of people living within the DB inevitably leads to the rise of several environmental management issues in the basin. The following are those recognised by the International Commission for the Protection of the Danube River (ICPDR) as the leading environmental pressures currently affecting the DB (ICPDR, 2021).

1. Organic pollution from urban wastewater and industrial emissions. Both sources are decreasing due to better water treatment and industrial technological advancement. However, there is still a margin for substantial improvement by further developing treatment and technologies in non-EU and new EU countries.
2. Nutrient pollution. Agriculture and urban water management are the primary sources of nutrient emissions. Loads are decreasing due to urban wastewater treatment plants and lower agricultural intensity, but they still exceed the long-term historical values.
3. Hazardous substances. 180-point sources from industrial facilities have been recorded to release 32 compounds into surface waters. Other sources are effluents from UWWTP, potentially nearly 500 industrial facilities, and 200 tailings ponds with a significant risk of accidental pollution.
4. Hydromorphological alterations. The three critical hydro-morphological alterations in the DB are I) hydrological, II) interruptions of longitudinal river continuity and sediment balance alterations, and III) morphological alterations. These alterations negatively impact river health and aquatic species, causing many surface water bodies to fail to meet the WFD objectives.
5. Alien species. The DB is experiencing significant colonisation by invasive species. The biocontamination level is estimated to be moderate to high, with higher levels in the upper and middle reaches of the Danube compared to the lower Danube.
6. Macro and microplastics. Macro and microplastics are widely recognised issues, but little quantitative data are available for precisely estimating the problem dimension.
7. Pressures on groundwater. Pressures on the chemical status of groundwater are pollution by nutrients and over-abstraction. Since 2015, there has been a decrease in the number of groundwater bodies not achieving good quantitative status, and one groundwater body has improved from poor to good status.

Besides the issues recognised by the ICPDR, in the early stages of the project, an extensive pool of DB stakeholders from different countries was selected and requested to voice their water values, priorities, concerns and issues related to the present and future management of the basin. The elicitation of their values took place in a live workshop held in Vienna on the 22nd of November 2023. The most frequent themes across the values include environmental protection, climate change adaptation, food affordability, water quality for agriculture, cooperation, and sustainable water resources management. These values, objectives, and benefits collectively advocate for a holistic and sustainable approach to water management in the entire catchment area, which integrates environmental, social, and economic aspects, stakeholder involvement and compliance with regulatory frameworks. The ultimate goal of management, according to the stakeholders, should be to provide an efficient, resilient, and sustainable water management system, emphasising water services delivery and water-related risk mitigation.

Drawing from the proceedings of the workshop, the most prominent objectives suggested by the stakeholders are:

1. Increase the focus on groundwater use, ecological status and sustainability.
2. Integration of climate adaptation into tourism, recreation and cultural actions.
3. Foster stakeholders' cooperation.
4. Improve sediment management, particularly continuity.
5. Foster connections among people from the regional to the local level.
6. Balance historical emphasis on water quality with increasing concerns about water quantity.
7. Address the shrinking water resources as a potential source of conflicts for water.

Danube basin hydrometeorological and socio-economic local drivers

Temperature projection from SSP-RCP scenarios

Figure 10 shows the projected mean annual temperature in the DB for the near future (up to 2050) and the distant future (2050-2100) periods in comparison with the historical reference (1850-2014). All SSP-RCP scenarios have higher monthly mean temperatures. It is interesting to notice how, historically, the months of January and December had an average below 0 °C, while in the close and the distant future it is above 0 °C. Regarding the differences among SSP-RCP scenarios, in the near future, the mean temperature increase is similar for all SSP-RCPs, while the distant future (2050-2100) temperatures expected for SSP-RCP 3-7.0 and 5-8.5 are consistently higher than for SSP-RCP 1-2.6.

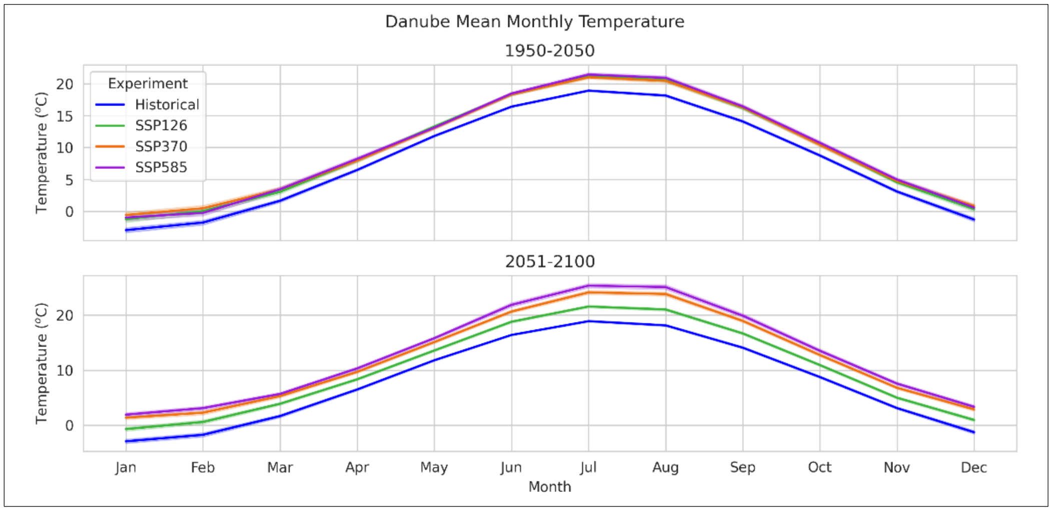


Figure 10 Monthly mean temperature in the Danube basin for the historical reference 1850-2014 and SSP-RCPs projection divided into 1950-2050 and 2051-2100 periods. Data source: Annex I Table 6.

Differences among scenarios are also clear from the annual mean temperatures in Figure 11, which also shows how, in the near future, the temperatures are quite similar among SSP-RCPs, while in the distant future, SSP-RCP 3-7.0 and 5-8.5 are conspicuously higher. Figure 11 also shows that for SSP-RCP 3-7.0 and 5-8.5, the precautionary +1.5 °C limit or the more risk-taking +2 °C above pre-industrial period targets are largely overshot.

Precipitation projection from SSP-RCP scenarios

Figure 12 shows how, for all SSP-RCP scenarios in the near future, compared to the historical period, precipitation is expected to be higher in the winter and spring months and of similar intensity or higher in the summer or autumn months, respectively. Larger differences are observed for the SSP-RCP 3-7.0 and 5-8.5 than for SSP-RCP 1-2.6.

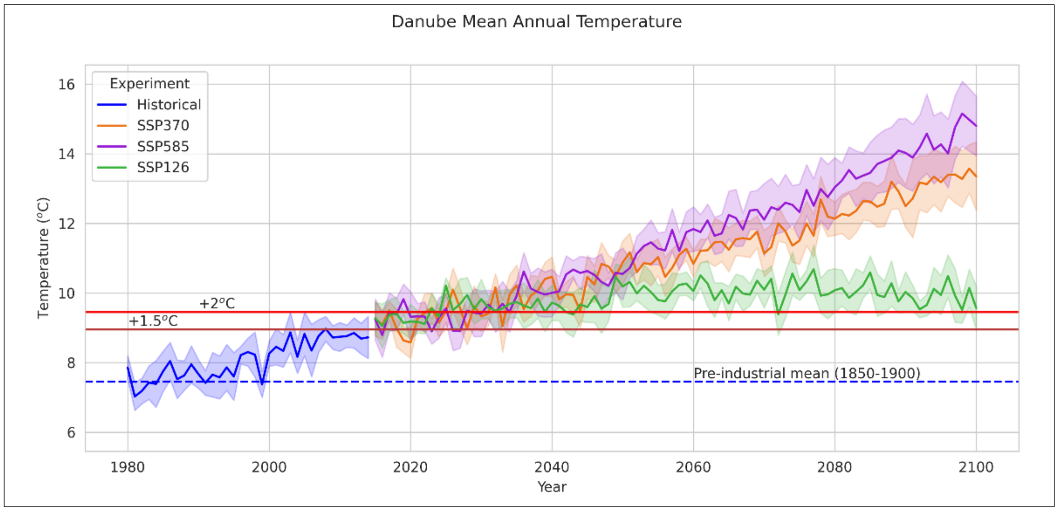


Figure 11 Annual mean temperature in the Danube basin for the historical period until 2010 and SSP-RCPs. The blue dotted line marks the pre-industrial mean annual temperature, and the two red lines mark the +2º and +1º increase with respect to the pre-industrial level. Data source: Annex I Table 6.

In the distant future, winter and late autumn months are projected to be wetter for all SSP-RCPs. For SSP-RCP 1-2.6, the spring and early summer months are projected as wetter, while for SSP-RCP 3-7.0 and 5-8.5, these months are expected to be dryer than the historical period. Also, summers and early autumn in SSP-RCP 3-7.0 and 5-8.5 are projected to be dryer.

Figure 12 shows a great variability of the projected data, which is not due to the uncertainty of models but is rather due to the fact that the lines in the charts represent an average over the whole DB, while great spatial differences are expected between the upper and lower parts of the basin. As an example, in Figure 13 we report the projections of the expected per cent changes in terms of seasonal precipitations for the period 2021-2040 for the SSP-RCP 5-8.5. Figure 13 shows how the increase and decrease of precipitation are not homogenous over the basin.

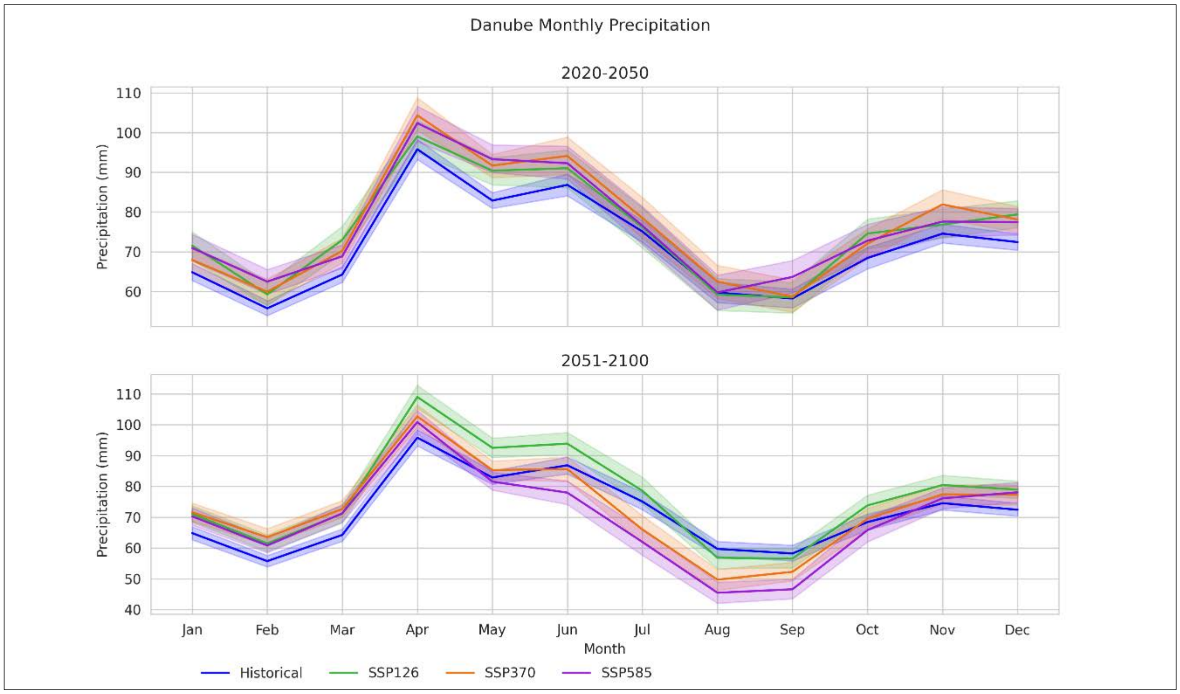


Figure 12 Mean monthly precipitation over the Danube basin for the historical reference 1850-2014 and SSP-RCPs projection divided into 1950-2050 and 2051-2100 periods. Data source: Annex I Table 7.

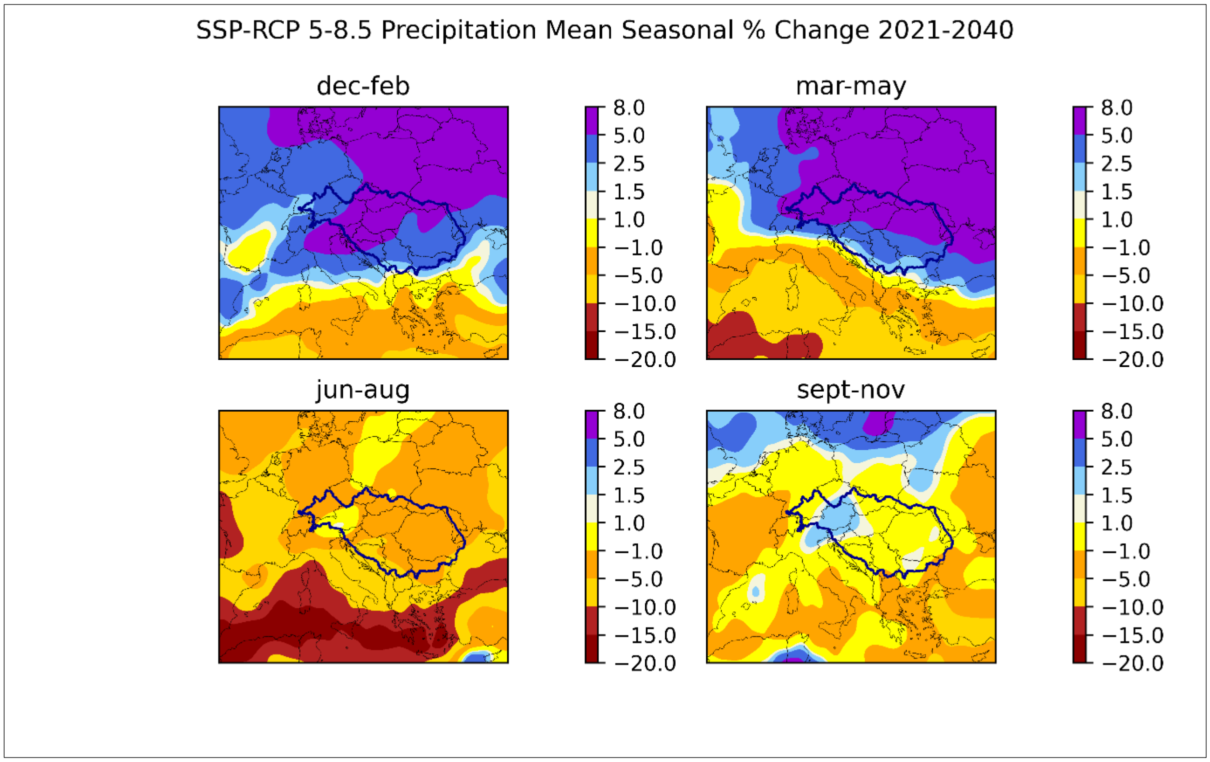


Figure 13 Maps of the mean seasonal precipitation variation projections in the Danube basin for the SSP-RCP 5-8.5 between 2021 and 2040 compared to the 1981-2010 mean. Data source: Annex I Table 2.

Socio-economic drivers

Figure 14 presents the projected GDP per capita in the whole DB and in the upper, middle and lower basin sections. The choice of breaking the GDP per capita into basin regions originates from the existing economic disparities within the DB.

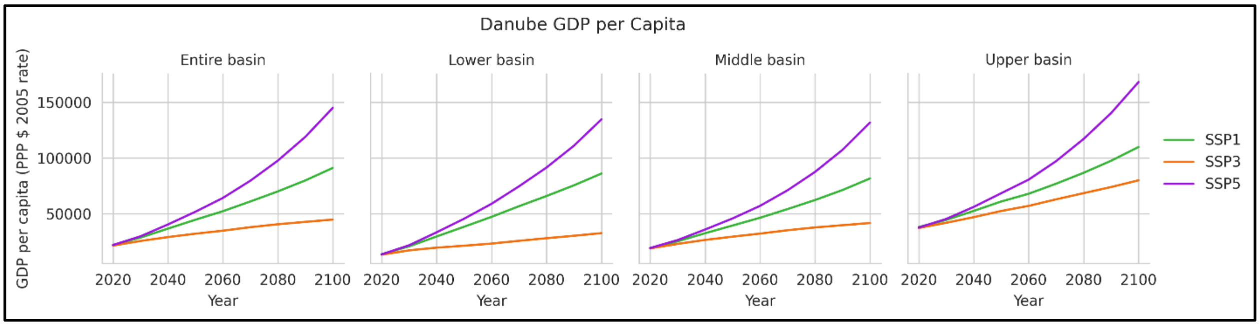


Figure 14 GDP per capita in Purchasing Power Parity (PPP) projections of the three SSPs in the Danube basin and lower, middle and upper basins. Data source:

Annex I Table 3.

The wealth of a region directly influences its investment capacity and, thus, the ability to cope with climate change impacts and deploy adaptation measures. We thought it was informative for the formulation of local storylines to understand how large these projected differences are within the basin. From Figure 14, it emerges that the upper basin produces significantly higher GDP per capita than the middle and lower basin. The overall tendency for the Danube is in line with the global SSPs: a fast-growing SSP5, a fairly growing SSP1 and a poorly growing SSP3.

The projected changes in rural, urban and total population reported in Figure 15 Figure 35 are quite consistent with the global SSP projections (see section “2.

Global SSP-RCPs scenarios selected for the SOS Water project", Figure 4). The exception is represented by SSP3, which, in the DB, shows a decline, while globally, it increases steadily.

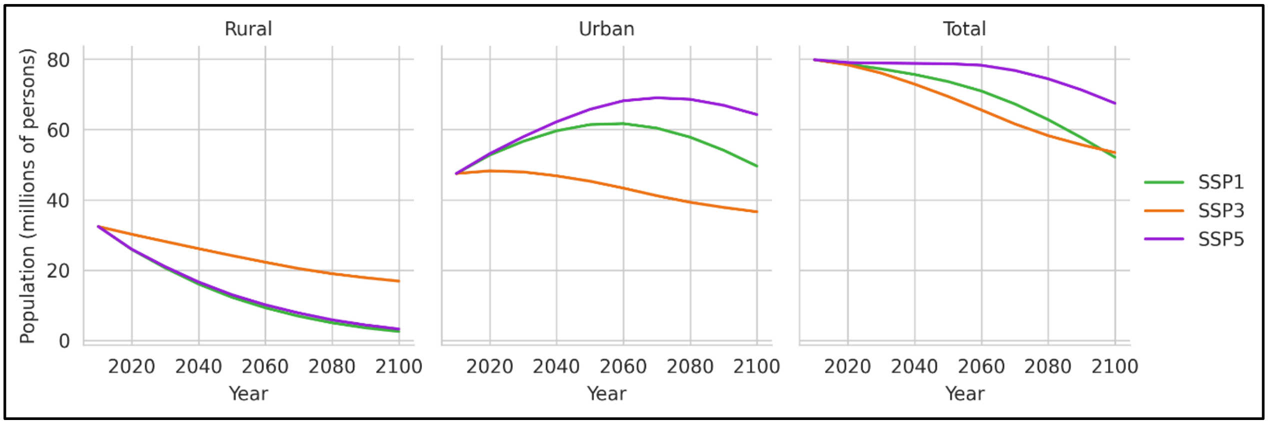


Figure 15 Population projections of the three SSPs in the Danube basin. Data source: Annex I Table 5.

The discrepancy is explained by the reduction in immigration towards the DB caused by the tenets of SSP3 ("regional rivalry") preventing fluxes of immigration towards the countries of the DB. Nevertheless, consistently with the regional rivalry narrative, SSP3 exhibits a lower reduction of the rural population compared with SSP1 and SSP5. Conversely, the urban population in SSP3 tends to decline, while in SSP1 and SSP5 increases.

The projections of land use (Figure 16) in Figure 16 show a slight increase in crop area and natural vegetation and a decrease in pasture for SSP1, which is in line with the "Taking the green road" narrative, where dietary habits shift towards a more plant-based nutrition style. For narratives SSP3 and SSP5, in contrast with the global narratives where both see croplands and pastures expanding, within the DB, these areas remain instead quite stable.

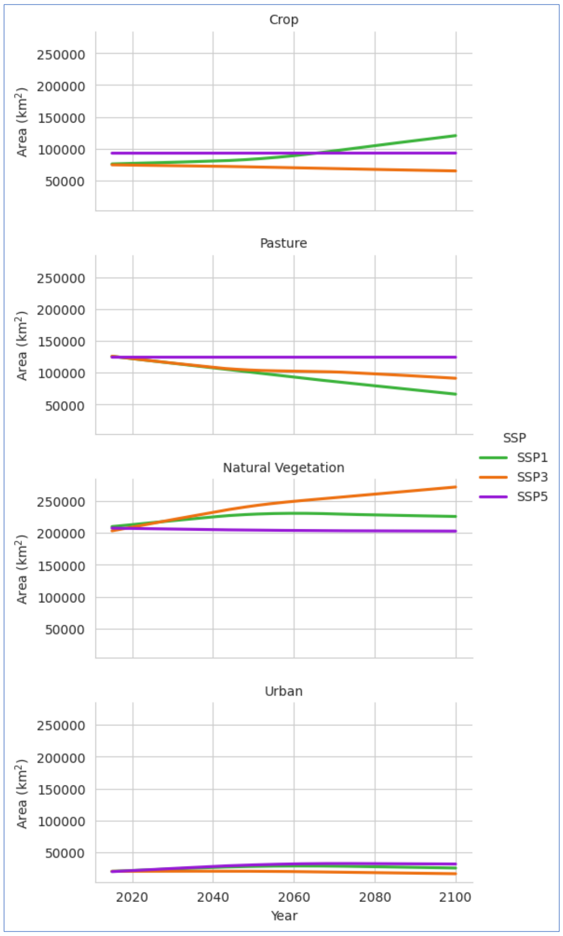


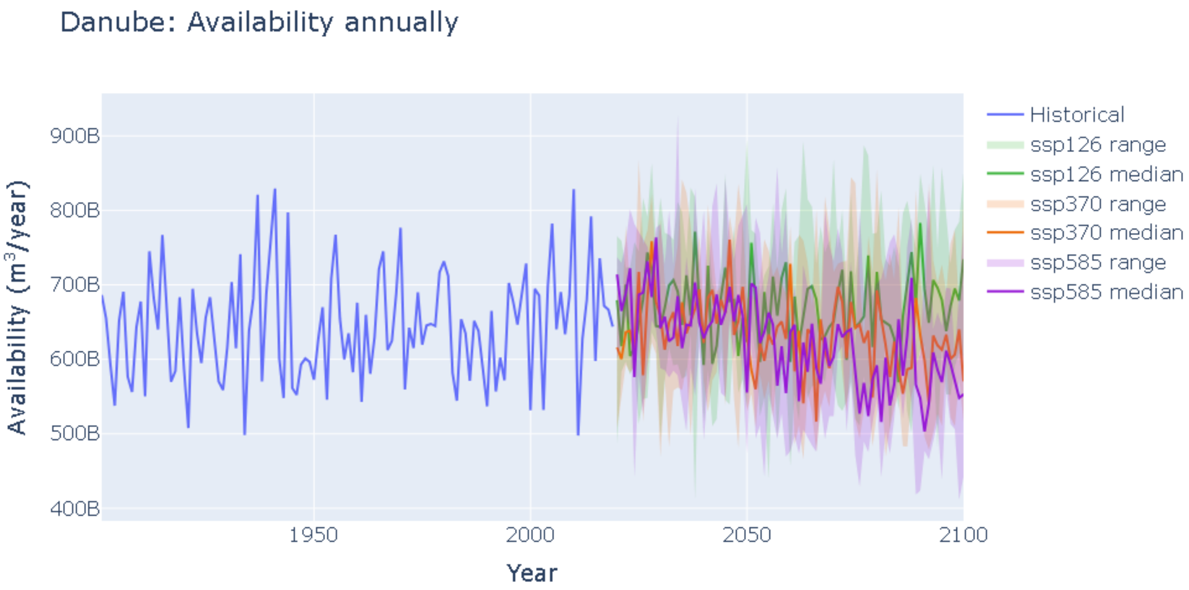
Figure 16 Land use projections for the Danube basin. Data source: Annex I Table 4.

This is probably because a large part of the DB is already farmed, and there is little room for further development. Urban areas slightly increase for SSP1 and SSP5 while maintaining constant for SSP3.

Water availability, water demand and water stress

This section provides future projections up to 2100 for select water security indicators, such as water availability and demand. The projections are the results of simulations conducted with the global hydrological models CWatM (Burek et al. 2020). For each RCP, we used the projections of five climate models: GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, and UKESM1-0-LL6F6F (Copernicus Climate Change Service 2024). Climate models provide projections of climate conditions (e.g., temperature, precipitation) under the various RCP scenarios. Figure 17 presents a comparative analysis of annual water availability spanning the historical period (1900-2020) and future projections (2020-2100). Our examination reveals a steady or slightly decreasing trend in annual water availability throughout the 21st century. Specifically, the median yearly water availability is projected to experience a -2 to 4% change compared to the 20th century.

Moreover, our analysis suggests an elevated frequency of hydrological anomalies, with drier and wetter years more extreme than those experienced in the 20th century. Figure 18 presents the projected total water demand across various sectors. The analysis indicates a significant decline in industrial water demands around 2050, while domestic water demands are expected to change slightly, either slightly increasing or decreasing. Irrigation demand relative to industrial and domestic demands remains low. In these simulations, water demand projections do not incorporate potential alterations in irrigated areas, which are set in the simulations to stay constant at the 2000 level. The interplay between projected changes in water availability and demand produces increasing to steady water stress until around 2050 and then decreasing water stress, albeit with intermittent periods of extreme water stress up to 60% higher than historical levels (in SSP3-7.0 and SSP5-8.5), as depicted in Figure 19.



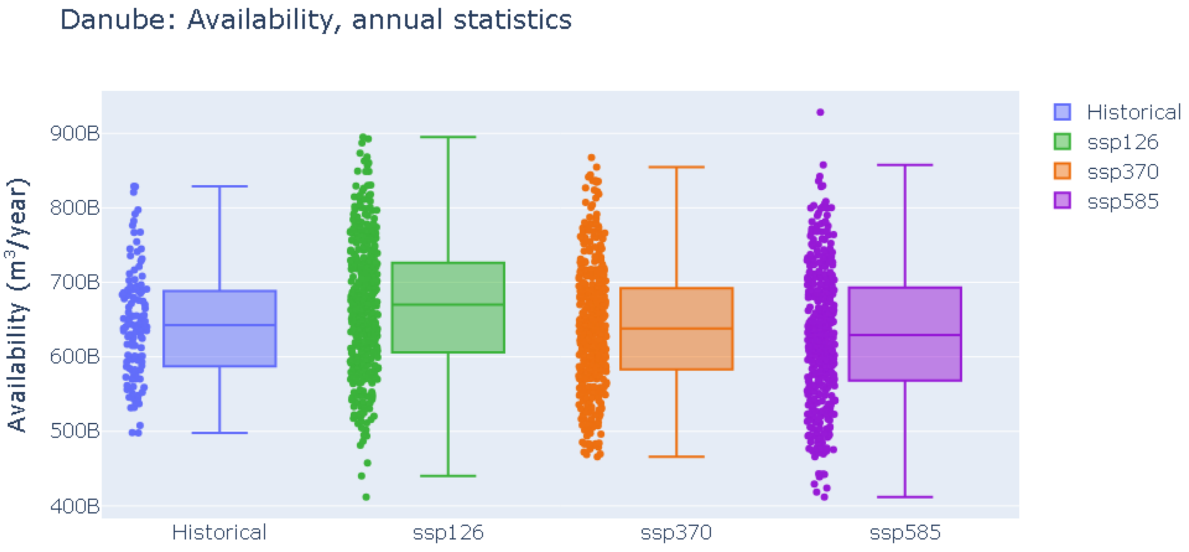


Figure 17 Annual water availability for historical and three future scenarios. Top) Line graphs show the median of the five models for each scenario and the entire range as a shadow. Bottom) Box-whisker plots showing the data variance through quartiles – quartile.

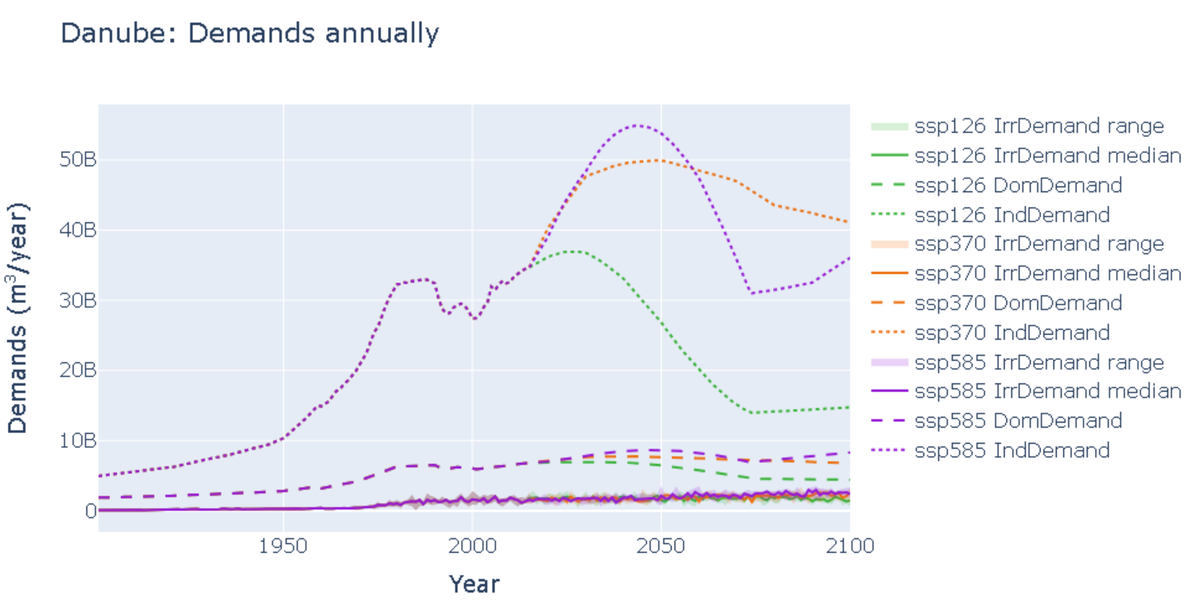


Figure 18 Sectoral demands for historical and future scenarios. Source: Burek et al. (2020). IrrDemand: Irrigation Demand, DomDemand: Domestic Demand, IndDemand: Industry Demand.

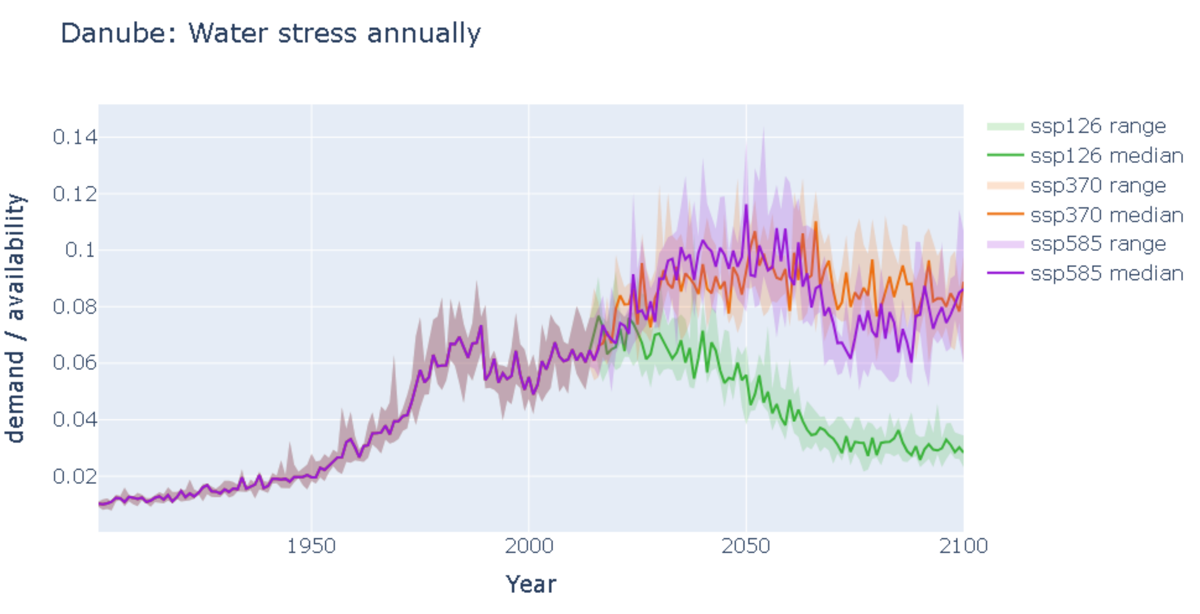


Figure 19 Annual water stress for historical and future scenarios. Source: Burek et al. (2020).

Jucar

The Jucar Basin

The Jucar River Basin (JRB) covers 22,261 Km^2 being one of the most important rivers in Eastern Spain. It flows through two Spanish regions (Castilla – La Mancha and Comunitat Valenciana) and three provinces (Cuenca, Albacete and Valencia) until it meets the Mediterranean Sea (Figure 20). The climate is mostly semiarid, with annual average precipitation ranging between 300 and 820 mm. Its precipitation pattern is typically Mediterranean, with rainfall concentrated in Autumn and dry summers.

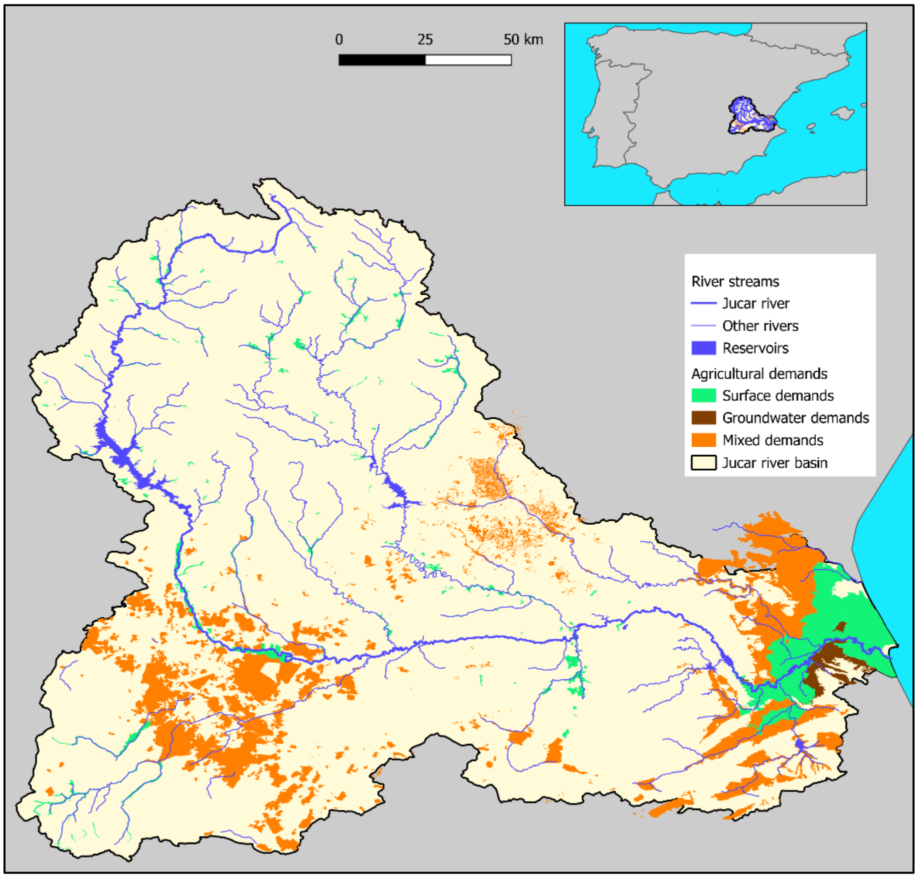


Figure 20 Location map of the Jucar River Basin.

Its mean total annual discharge is equal to 1,456 Mm^3/year (1940-2018 period, decreasing to 1,245 if the period 1990-2018 is considered), following the same pattern as rainfall does (CHJ,2023). The majority of this discharge is provided by groundwater and stream-aquifer interaction. The annual demand is equal to 1,486 Mm^3/year, with the principal uses for water being agricultural use (89%), followed by urban (9%) and industrial uses. The hydrological sub-basins in which the Jucar is divided are shown in Figure 20. The Alarcon and Contreras sub-basins form together the upper basin, the Mancha and Middle sub-basins cover the middle part of the Jucar, while the Lower, Magro and Albaida belong to the lower part of the basin. There are also two endorheic zones with no direct surface connection with the Jucar River: one north of its mouth, which drains to l’Albufera wetland, and one in the south whose discharge is collected at the Almansa reservoir and serves local farmers. The first endorheic zone receives water from the Jucar in an indirect way through the surface, and groundwater returns from the neighbouring agricultural demands.

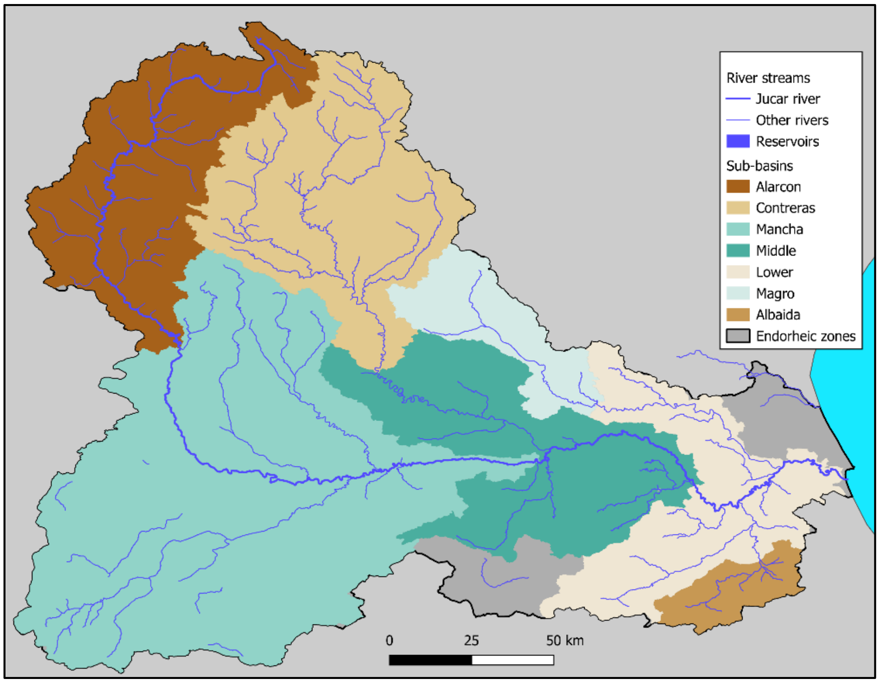


Figure 21 Jucar River sub-basins.

Underneath the JRB there are 41 groundwater bodies that in almost all cases interact with surface bodies. This interaction is performed either by stream-aquifer interactions or by spring discharges river streams with a positive balance between discharges from and losses to groundwater bodies (gaining reaches) concentrate in the upper areas of the river basin, while streams with a negative net balance (losing reaches) are found in the Mancha Oriental and the lower Jucar streams.

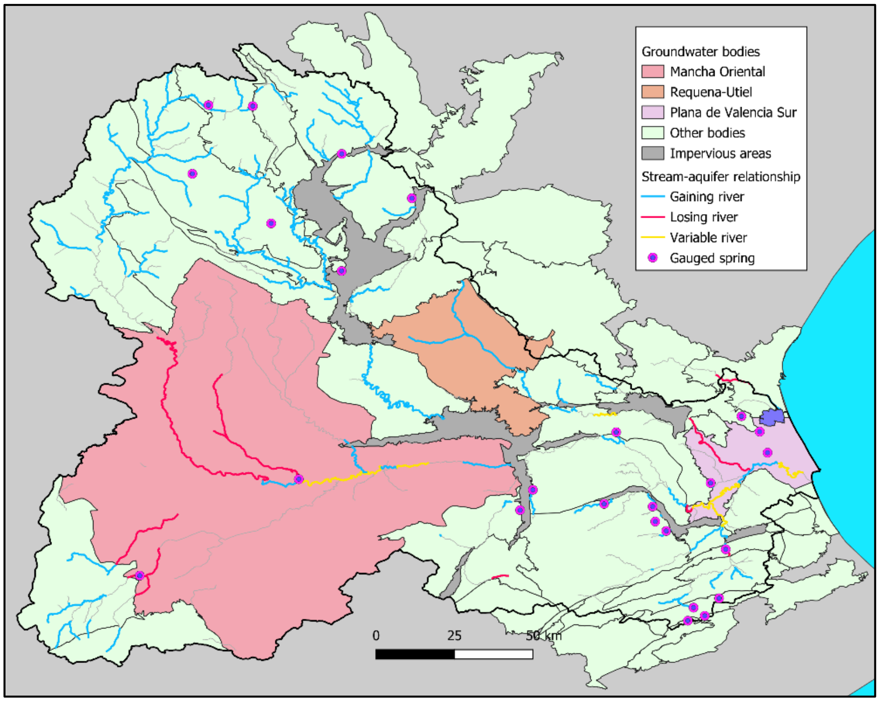


Figure 22 Relationships between the Jucar River and groundwater bodies.

Given the tight balance between water resources and demands, the Jucar River has distinct infrastructure development (Figure 23).

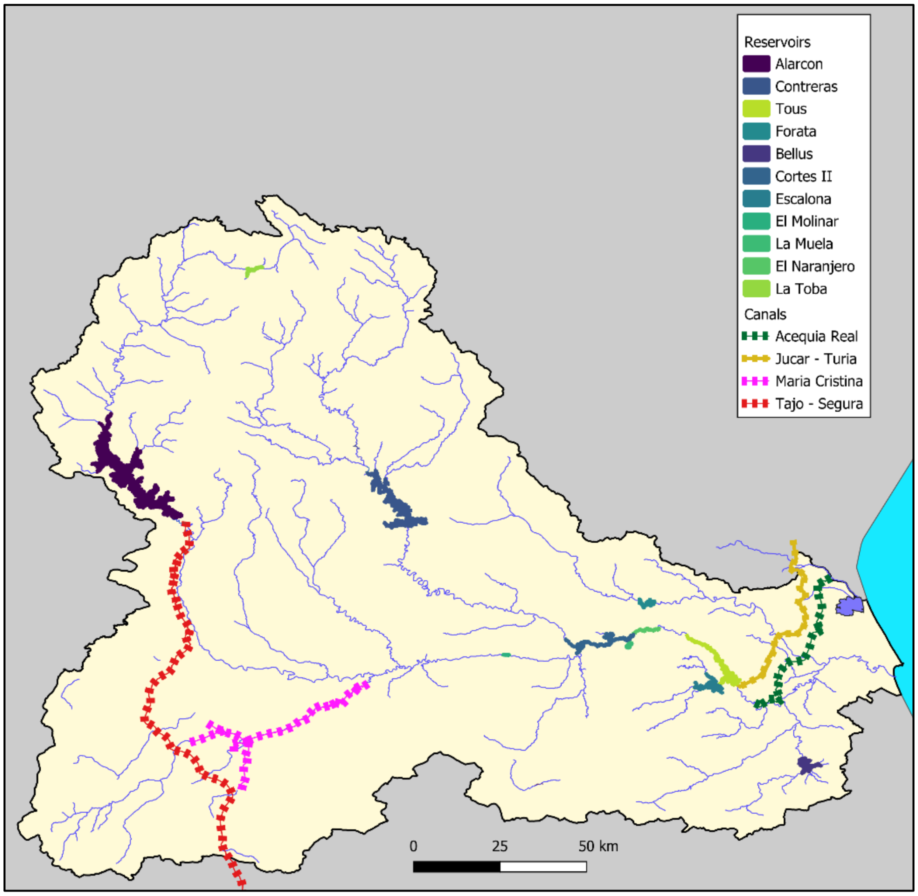


Figure 23 Jucar river main infrastructures.

The Jucar has 11 reservoirs with more than 1 Mm^3 of capacity, the most important ones being the Alarcon, Contreras and Tous reservoirs. Alarcon and Contreras are placed at the end of the upper sub-basins of the Jucar, in the Jucar and Cabriel rivers, respectively. On the other hand, Tous is located at the end of the middle basin of the Jucar. Furthermore, there is a significant concentration of hydropower reservoirs in the downstream part of the middle basin of the Jucar (Molinar, Cortes II, Naranjero).

Moreover, the Jucar River system has four main canals, mainly devoted to the conveyance of water for urban and irrigation demands. The only exception is the Maria Cristina canal, which was built to drain the former endorheic area of the Mancha Oriental and serves as an artificial surface connection between itself and the Jucar. On the other hand, part of the Tajo-Segura canal flows through the JRB, including Alarcon as one of the main milestones in its trajectory. Although the main purpose of this canal is to convey water from the Tagus to the Segura basins, the Jucar River system is allowed to use it to convey water from the Alarcon reservoir to the Mancha Oriental area.

Current water management challenges in the Jucar River Basin

During each water planning cycle, the Jucar River Basin Agency (Confederacion Hidrografica del Jucar, CHJ), issues a list of relevant challenges for the water resource planning of its basin (Esquema de Temas Importantes, CHJ 2020). This list sets the main action lines of the future Jucar River Basin Management Plan (JRBMP, CHJ, 2021), whose objective is to achieve the goals of the Water Framework Directive and the Spanish legislation and achieve a sustainable use of the JRB.

Table 3 The main features of the Jucar River system reservoirs

Name	River	Built in	Planned capacity (Mm^3)	Use
Alarcon	Jucar	1944	1118	Cons./ Hydr.
Molinar	Jucar	1989	4.3	Hydropower
Contreras	Cabriel	1973	852	Cons./ Hydr.
Cortes II	Jucar	1989	118	Hydropower
Naranjero	Jucar	1989	26.25	Hydropower
Tous	Jucar	1994	379	Cons./ Flood
Escalona	Escalona	1997	99	Flood
Bellus	Albaida	1998	69	Consumptive
Forata	Magro	1968	37	Consumptive
La Muela	off-stream	1989	20	Hydropower
La Toba	Jucar	1944	10	Hydropower

The main water management challenges identified in the current water planning cycle (2022-2027) for the Jucar are:

1. Implementation of ecological flows and water requirements of wetlands.
2. Hydromorphological alterations.
3. L'Albufera lake.
4. Nitrate pollution.
5. Pesticide pollution.
6. Pollution from urban and industrial sources.
7. Protection of water sources devoted to urban supply.
8. Sustainability of irrigation activities in the lower Jucar.
9. Sustainable management of groundwater bodies.
10. Control of the Public Hydraulic Domain.
11. Optimal management of water infrastructures.
12. Climate change adaptation.
13. Cost recovery and funding of programs of measures.
14. Management of flood risks.

Table 4 Main features of the Jucar River system canals

Name	Built in	Length	Use
Tajo-Segura	1979	292 Km	Urban, irrigation
Maria Cristina	19th century	32 Km	Lagoon drainage
Jucar-Turia	1979	60 Km	Urban, irrigation
Acequia Real	13th-19th century	60 Km	Irrigation

Jucar basin hydrometeorological and socio-economic local drivers

Temperature projection from SSP-RCP scenarios

The future evolution of the mean annual temperature for the JRB, according to the CMIP6 scenarios, displays a similar behaviour to the rest of the SOS-WATER case studies (Figure 24). All scenarios show a similar trend up to 2040, reaching an increase of 2 ºC with respect to pre-industrial means by this year approximately. However, beyond 2040 the evolution patterns diverge, in particular for the case of the

SSP1-2.6 scenario, in which temperature increase would be halted around 2 °C. On the other hand, the baseline SSP3-7.0 scenario and the most pessimistic SSP5-8.5 scenario show a steady increase that would result in temperature increases around 5 and 6 °C respectively. Consequently, achieving the goals foreseen by the Paris Agreement to limit global warming to 2 °C (which would correspond to the SSP1-2.6 scenario) would be crucial to limit the temperature increases in the JRB.

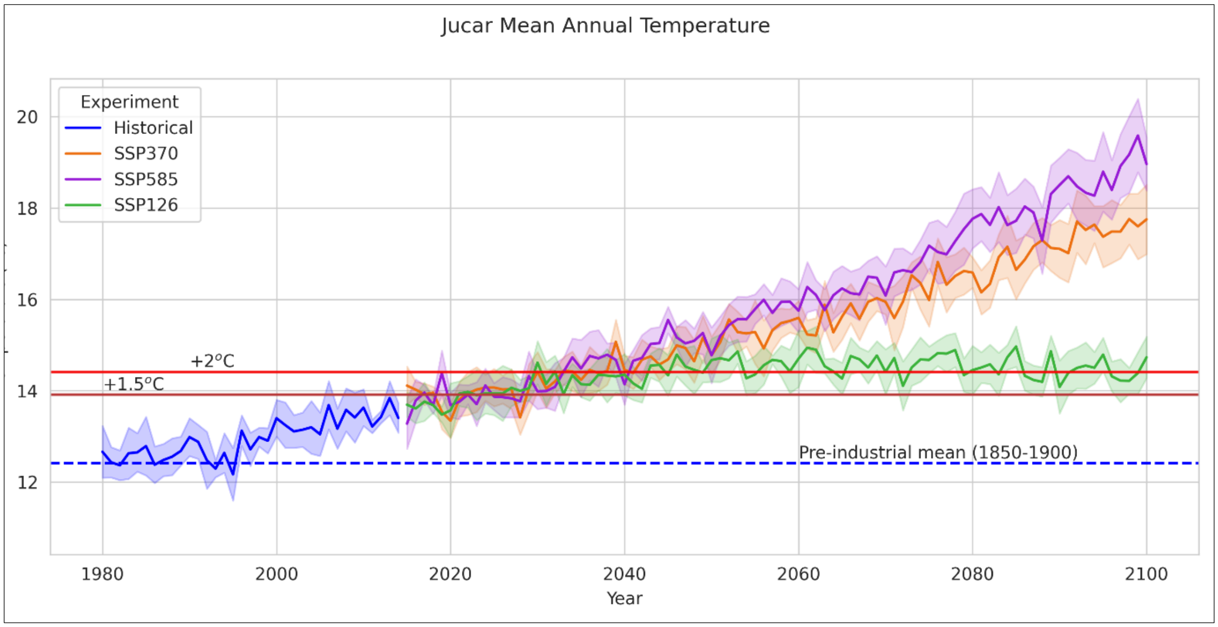


Figure 24 Annual mean temperature in the Jucar basin for the historical period until 2010 and SSP-RCPs. The blue dotted line marks the pre-industrial mean annual temperature, and the two red lines mark the +2o and +1o increase with respect to the pre-industrial level. Data source: Annex I Table 6.

The mean monthly temperatures show a similar pattern to the annual means (Figure 24 and Figure 25). The monthly pattern among trajectories is almost the same before 2050, while it diverges beyond this year. It should be noted that the largest rises in temperature are found during the summer period, in which both energy demands (for cooling) and water demands (for agriculture and tourism) concentrate. This further increase in temperatures would mean increased energy demands and a likely increase of water demands (which would largely depend on the changes of crop behaviour), which might add more pressure to the Jucar water resources.

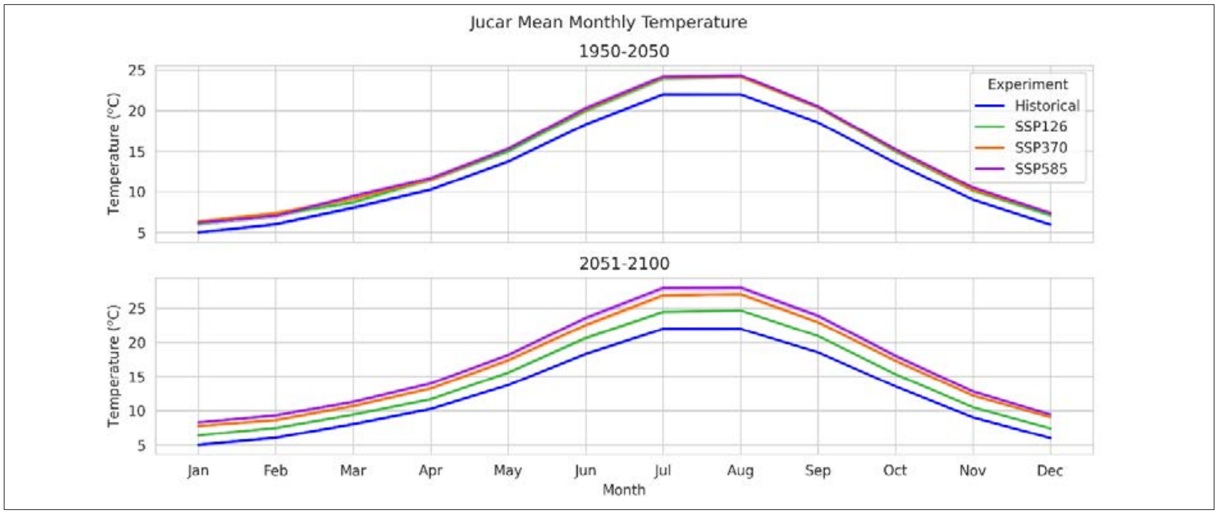


Figure 25 Monthly mean temperature in the Jucar basin for the historical reference 1850-2014 and SSP-RCPs projection divided into 1950-2050 and 2051-2100 periods. Data source: Annex I Table 6.

Precipitation projection from SSP-RCP scenarios

The monthly precipitation pattern evolution estimated by climate change scenarios show some changes compared to the historical period even in the short and medium term (2020-2050), in particular for the SSP5-8.5 scenario, which shows decreases that focus on the months with the highest precipitation nowadays (Figure 26). On the contrary, scenario SSP1-2.26 shows a pattern very close to the historical one. However, beyond 2050 a noticeable decrease in precipitation is found for all scenarios and months, with a direct relationship to how optimistic the scenario is and the changes in precipitation.

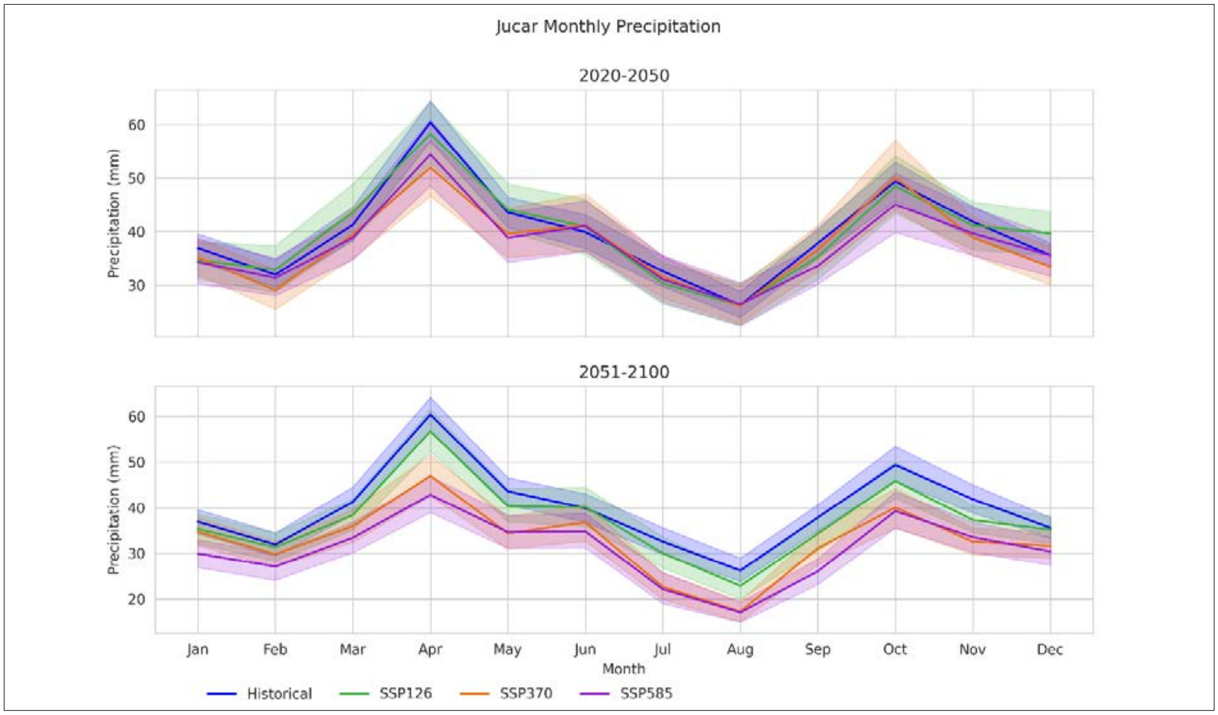


Figure 26 Mean monthly precipitation over the Jucar basin for the historical reference 1850-2014 and SSP-RCPs projection divided into 1950-2050 and 2051-2100 periods. Data source: Annex I Table 6.

The spatiotemporal distribution of the precipitation changes in the Jucar can be seen in more detail in Figure 27. In the short term (2021-2040), winter precipitations could experience a mild increase or no change with respect to the historical ones regardless of the scenario considered, with summer periods showing the steepest decrease (between 5% and 10% in the SSP1-2.6 and SSP3-7.0 scenarios and between 10% and 15% in the SSP5-8.5 scenario).

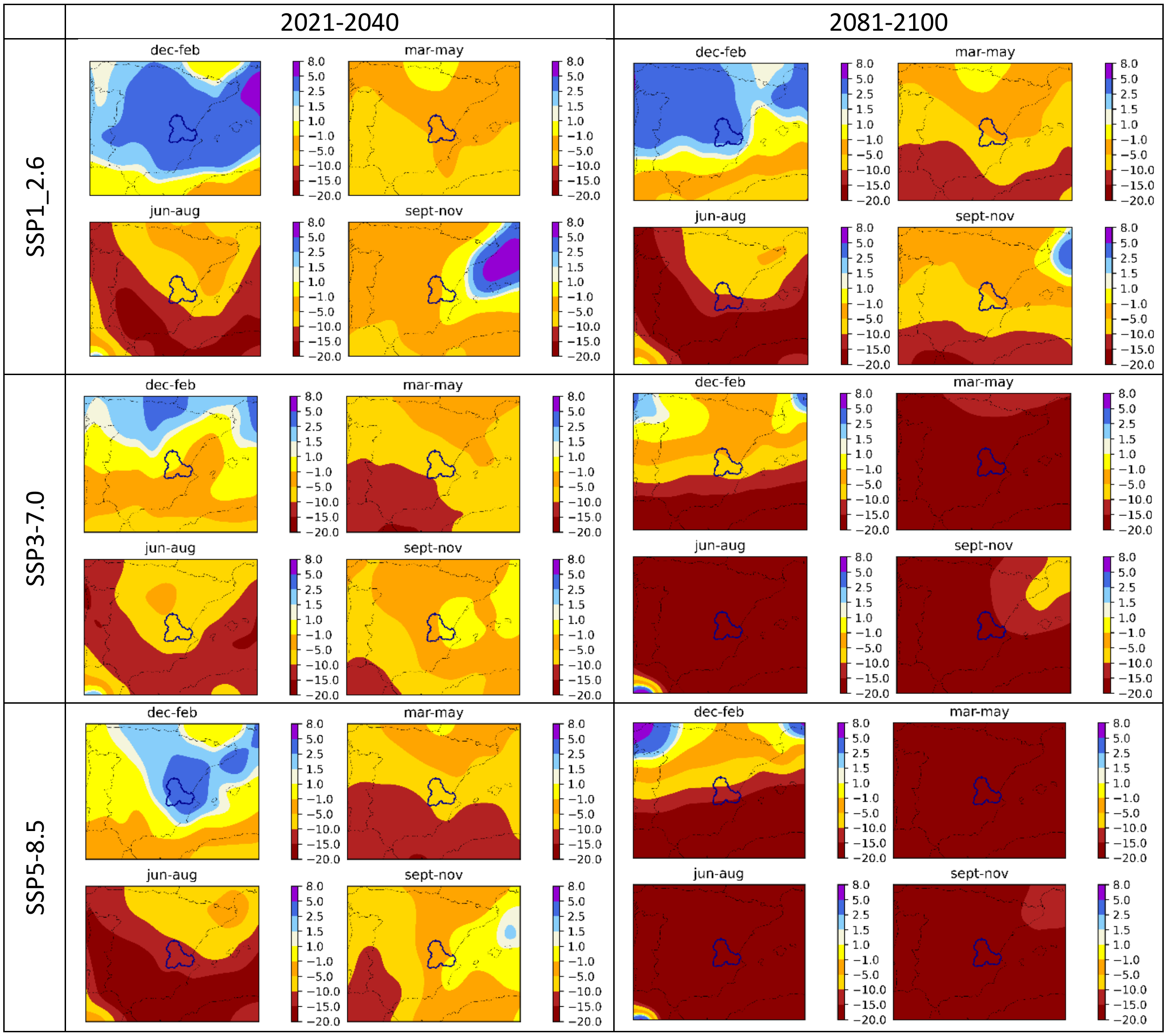


Figure 27 Maps of the mean seasonal precipitation variation projections in the Jucar Basin between 2021 and 2040 compared to the 1981-2010 mean. Data source: Annex I Table 2.

The rest of the seasons could experience decreases up to 5% (SSP1-2.6) or up to 10% (SSP3-7.0 and SSP5-8.5), with a slight tendency to show larger impacts in the inner land areas of the basin. All scenarios show larger and more diverse impacts in the long-term period (2081-2100). The precipitation anomalies worsen in all scenarios but for winter periods and the SSP1-2.6 scenario, which would remain similar to the short-term. In the most optimistic scenario (SSP1-2.6), summer precipitation could decrease between 10% and 15%, while spring and autumn rainfall could decrease up to 10%. The rest of the scenarios show a general decrease of precipitation between 15% and 20% in all seasons except for winter precipitation and SSP3-7.0, whose impacts would be lower (between 5% and 10% decrease).

Socio-economic drivers

The main socioeconomic drivers analysed have been gross domestic product (GDP), population changes and land use. Projections on GDP per capita for the 21st century are shown in Figure 28. The foreseen changes in GDP per capita show a quite diverging trajectory depending on the SSP, being the worst trajectory considering that the lower the GDP is, the worse the trajectory the one depicted by the SSP3, which is considered as the baseline. Both the most optimistic SSP1 and the most pessimistic SSP5 show increases in GDP per capita, although the main drivers behind them would be quite different: while SSP1 would rely on promoting sustainable economic activities, SSP5 would harness resources in a more aggressive way, resulting in a better position in terms of GDP per capita.

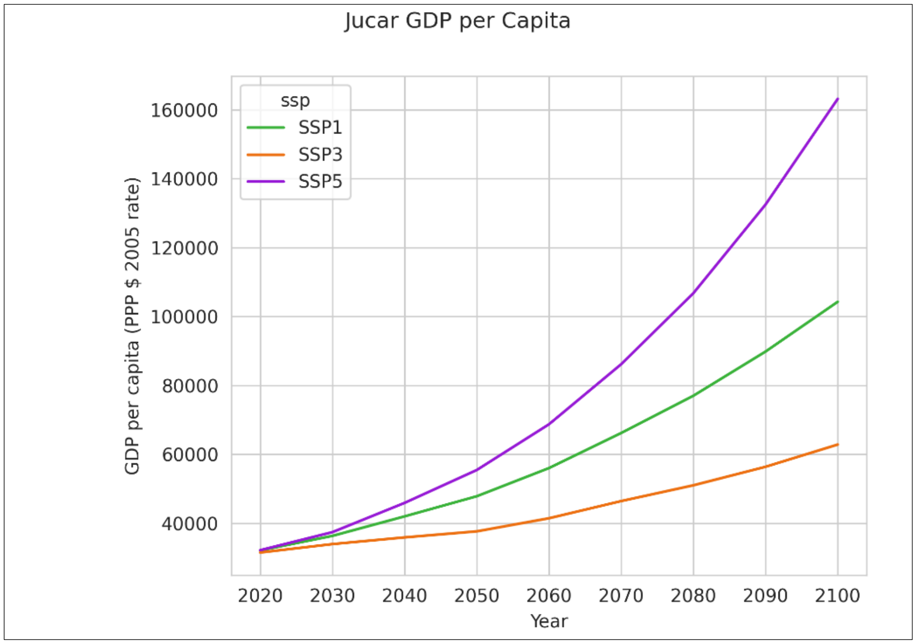


Figure 28 GDP per capita in Purchasing Power Parity (PPP) projections of the three SSPs in the Jucar basin. Data source: Annex I Table 3.

Figure 29 displays the population and the land use evolution per SSP. In the case of population, evolution patterns distinctly vary depending on the type of population (rural or urban) and the SSP. The baseline scenario (SSP3) shows a steady decline in both urban and rural populations, with a similar decrease of people. Although both SSP1 and SSP5 show the same situation in terms of rural population, they differ in urban inhabitants: SSP5 foresees a continuous increase in urban population while SSP1, although following the same pattern as SSP5 up to the middle of the century, experiences a decrease in people living in urban areas.

In terms of land use, SSP3 shows the lower bound for all the main land uses but pasture areas, which in term are distinctly increased in the JRB under this scenario. Conversely, it shows a slight decrease in crops, natural vegetation and urban areas. On the other hand, the most optimistic scenario (SSP1) shows a slight increase in crop areas, natural vegetation and urban areas, contrasted by a decrease in pasture. SSP5, on the other hand, shows a slight increase in urban areas (the highest of all scenarios) but with no significant change in the rest of the categories.

Water availability, water demand and water stress

Similar to the Danube case study, the projections presented here are the results of simulations conducted with the global hydrological model CWatM (Burek et al. 2020). Given that the hydrology of the JRB is challenging to be adequately reproduced by a global model such as CWatM, the following results should be interpreted exclusively considering the trends instead of the exact values provided.

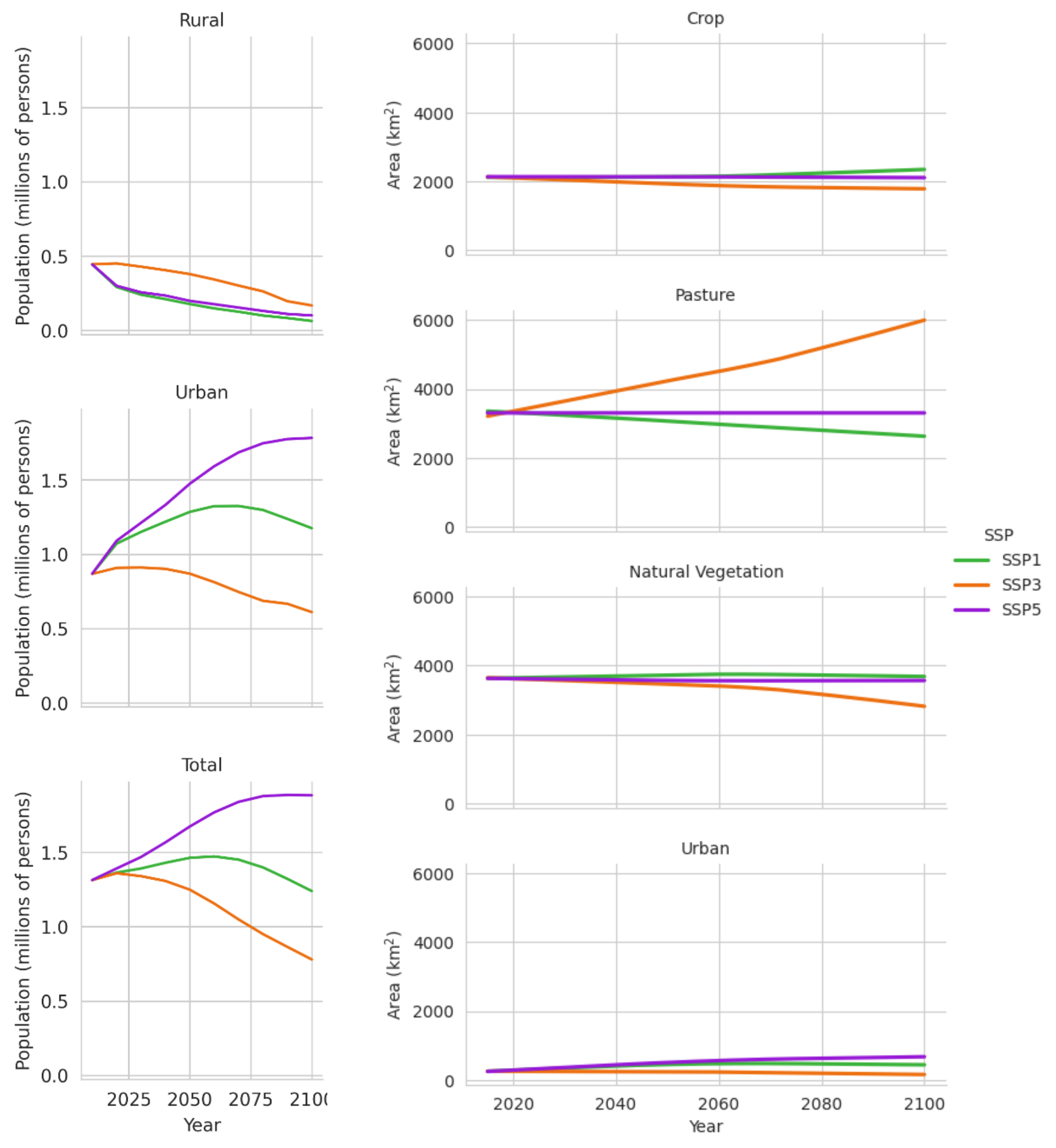


Figure 29 Jucar River Basin population (left) and land use (right) evolution. Source: Annex I Table 5 and Table 3 respectively.

All scenarios predict a decrease in water availability in the Jucar that worsens throughout the 21st century and is directly correlated with the severity of the scenario considered. In the most optimistic scenario, the decrease in water availability would be low, although its variability would increase compared to the historical period, which means that extreme events would be more frequent and require proper planning to confront their impacts.

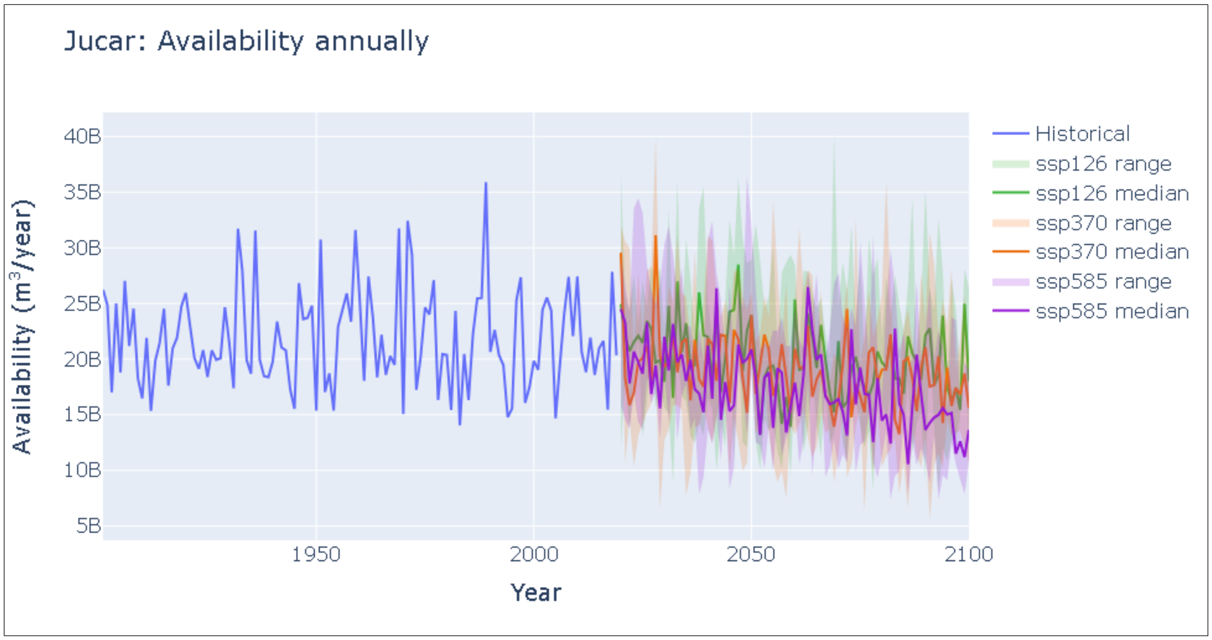


Figure 30 Jucar River basin water availability annual time series (upper) and annual statistics (lower). Source: Burek et al. (2020)

The rest of the scenarios show a significant decrease combined with a wider variability that would distinctly challenge the JRB planning and management operations.st century and is directly correlated with the severity of the scenario considered. In the most optimistic scenario, the decrease in water availability would be low, although its variability would increase compared to the historical period, which means that extreme events would be more frequent and require proper planning to confront their impacts. The rest of the scenarios show a significant decrease combined with a wider variability that would distinctly challenge the JRB planning and management operations.

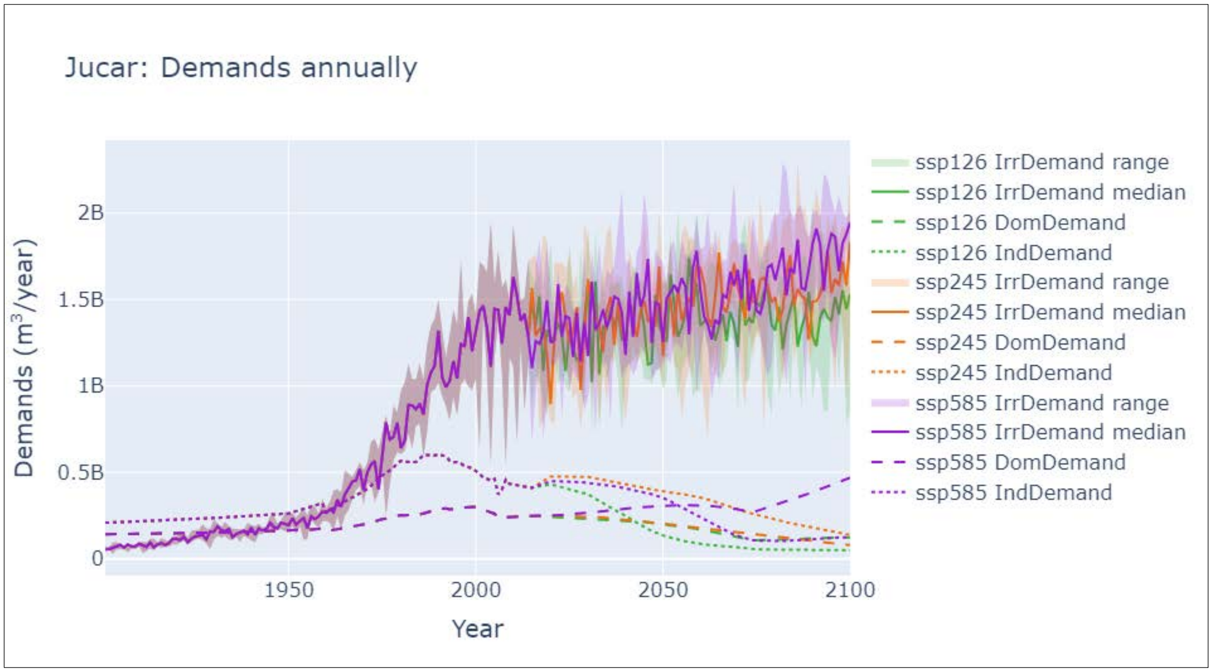


Figure 31 Jucar River Basin water demand evolution. Source: Burek et al. (2020)

Water demand in the JRB would experience, in general, similar trends regardless of the scenario. In particular, irrigation demands would suffer an increase driven by the increase in temperature and decrease in water availability, while industrial water demands are expected to decrease throughout the 21st century. However, while the increase in irrigation demands is linearly correlated with the severity of the scenario, the decrease in industrial demands is larger in the extreme scenarios (the most optimistic SSP1-2.6 and the most pessimistic SSP5-8.5) than in the intermediate one. In case of urban demands, the most pessimistic scenario shows a general trend of increase, while the rest of the scenarios point towards a decrease.

Mekong

The Mekong River Basin (MRB)

The Mekong River stretches nearly 4,800 km, originates in Tibet and flows through 6 countries: China, Myanmar, Laos, Thailand, Cambodia and Vietnam, creating a large delta (among the three largest deltas in the world) before flowing into the East Sea. The Mekong River basin has an area of 795,000 km^2. In particular, the ratio of basin area compared to the national area of Laos is 97%, Cambodia 86%, Thailand 36% (Northeastern region), and Vietnam 20% (of which two main parts are the Central Highlands and Mekong Delta).

The average annual flow of the Mekong River is approximately 475 km3 (475 billion m^3), of which 82% of the total flow is formed from four downstream countries: Laos 35%, Thailand 18%, Cambodia 18%, and Vietnam 11%. The flow contribution from the two upstream countries accounts for about 18% of the total yearly flow. However, this is an important contribution to the dry season flow (about 30%). Water resources per capita are high compared to most other international river basins. The Mekong is the river with the second highest biodiversity in the world after the Amazon and has the world's largest freshwater fishing industry, with about 2.3 million tons/year.

The Mekong River basin is in a tropical climate zone, with high air humidity and copious rain. Rain is the main water source, with an average annual rainfall in the basin of about 1,600 mm, of which the territory of China and Thailand has a low average rainfall of 1,000 to 1,500 mm, the territory of Laos and the Western region. Vietnam's plateau has a relatively high average rainfall of over 1,600 mm, in some places up to 3,000 mm. Cambodia and the Mekong Delta have an average rainfall of 1,500 mm. The rainy season starts in May and ends in November, rain usually starts earlier in the upstream and ends later in the downstream. However, the main rainy period is from May to October, which is defined as the wet season; from November to April is the dry season.

The Mekong has more than 30 main tributaries with a total average annual flow of about 15,000 m^3/s. The average monthly flow changes are relatively large. The flood season from May to November has a peak flood flow of over 50,000 m^3/s, causing flooding of over 6 million hectares, especially in Cambodia and the Mekong Delta. In the dry season, the average flow is relatively low (about 2000-5000 m^3/s), causing potential saltwater intrusion on about 1.6 - 2.2 million hectares of land in the Mekong Delta.

In the years from the 1960s to the present, a large number of hydropower dams have been built, first on tributaries and then on the Mekong itself. By 2013, dams on the Lan Thuong River were nearly completed, with a regulated capacity of about 23 billion m^3. The reservoir system has participated in regulating flow, causing seasonal flow distribution to change greatly, especially in the period after 2012.

The Great Lake on the Tonle Sap River branch in Cambodia has a large storage capacity, regulates the annual cycle, and plays a very important role in both Cambodia and the Mekong Delta. The lake has a capacity of up to 84 billion m^3 (approximately 18% of the total annual flow of the basin), corresponding to a flood level elevation of +11m AMSL and an open surface area of 14,000 km^2. In the dry season, the lake surface area is only about 2,300 km^2 with an elevation of +1.6 m AMSL and a lake capacity of about 1.4 billion m^3.

Mekong Delta of Vietnam (MDV)

The Mekong Delta of Vietnam (MDV) is the last part of the Mekong River Basin, including 13 provinces/cities: Long An, Tien Giang, Dong Thap, Vinh Long, Tra Vinh, Hau Giang, Soc Trang, Ben Tre, An Giang, Kien Giang, Bac Lieu, Ca Mau and Can Tho city, with the total natural area of about 3.96 million ha (not including area of islands), accounting for 79% of the entire Delta, and by 5% of the whole Mekong River Basin.

The Mekong Delta plays an important role in the socioeconomic development strategy of the country. With a huge agricultural potential, the Mekong Delta in recent years has always contributed over 50% of the total national rice production in Vietnam, a decisive contribution to the success of the national strategy for food security and a significant contribution to rice export (more than 90%). Besides, the Mekong Delta also provides about 70% of fruit production and over 75% of the total fishery production in the country.

Due to its geographical location downstream of the Mekong River Basin, the MDV depends greatly on changes occurring upstream. Among these changes, the most impactful will be the development of 11 proposed dams along the Mekong. Additionally, the MDV faces the impacts of climate change. Accordingly, the major drivers of key impacts of upstream development and climate change on the natural, social, and economic systems of the Lower Mekong Basin (LMB) include:

- Changes in the river system flow and LMB flooding patterns, increased irrigation withdrawals, compounded by climate change and sea level rise.
- Changes in sediment flows largely as a result of trapping within the reservoirs and to a smaller extent due to the changes in stream power and flooding patterns.
- Changes in water quality and nutrient flows largely resulting from the combined effect of altered flows and sediment loadings combined with water quality changes resulting from expanded irrigated agriculture and increases in wastewater discharges from urban and industrial centres.
- Potential impacts of mainstream dams on fish migration behaviour and natural fish stocks in the Delta, due to physical fish migration barriers created by the proposed dams.

Major Impacts: In general, hydropower projects alter downstream flow regimes and sediment transport dynamics within riverine systems. In addition, changes could also impact water chemistry, physical habitat, habitat connectivity, and composition, structure, and function of biological communities.

The Mekong Delta Study (2014) identified the following major impacts that are likely to result in the LMB from changes in Mekong River flow regimes and water quality because of mainstream hydropower development:

- Decrease in flood plain and coastal land productivity due to a reduction in flooding, sediment and nutrient flows primarily resulting from increased storage and sediment trapping within the basin.
- Increased risk of bank erosion, which may in part be lessened by reduced wet season flows but aggravated by river regime change as the river system adjusts to new sediment loads.
- Impacts of fluctuating dry season flow depths, compounded by the presence of the proposed new dams on the main channel, on riverine habitats including bank-side and exposed riverbed seasonal gardens and deep pools and the consequential impacts on local livelihoods and on fish refuges and spawning areas.
- Changing in natural nutrients driven by increased sediment trapping and modified by changes in flow patterns (particularly about the Tonle Sap system, but also the Mekong Delta flood plains)

whilst at the same time the likelihood of increased runoff of agricultural input residues due to irrigated agriculture expansion and economic pressures to raise yields.

- Changes in saline intrusion in the Mekong Delta brought about by fluctuations in dry season flows from the increases in storages (especially those in the UMB) and climate change induced sea-level rise.
- Reduction in the extent of wetlands and key habitat areas because of modified flow patterns, the reduction in their productivity due to reduced sediment and nutrient flows and the consequential impact of both on the sustainability of various species, some of which are already endangered by human activity.
- Combined effects of the flow, sediment, and water quality alterations on the basin's rich biodiversity including several key rare, threatened, and unique wildlife.

Hydrometeorological and socio-economic local drivers in the Mekong Delta

Temperature projections from SSP-RCP scenarios

Figure 32 shows the mean monthly temperature in the Mekong basin for historical reference and the three SSP-RCP scenarios. All SSP-RCP combinations show an increasing trend in mean monthly temperature compared to the historical period. SSP-RCP trends indicate that the Mekong Delta Basin is likely to experience warming in the future regardless of the specific development pathway or greenhouse gas emission scenario. However, substantial differences exist among the three SSP-RCP projections. The SSP1-RCP2.6 scenario represents the lowest warming pathway, with a projected increase in temperature of around 1°C to 2°C by the end of the century (2050-2100) compared to the historical baseline. The SSP3-RCP7.0 represents a moderate warming pathway, with a projected increase of 2°C to 3°C by the end of the century. Finally, the highest warming pathway is the SSP5-RCP8.5 scenario, with a projected increase of 3°C to 4°C by the end of the century.

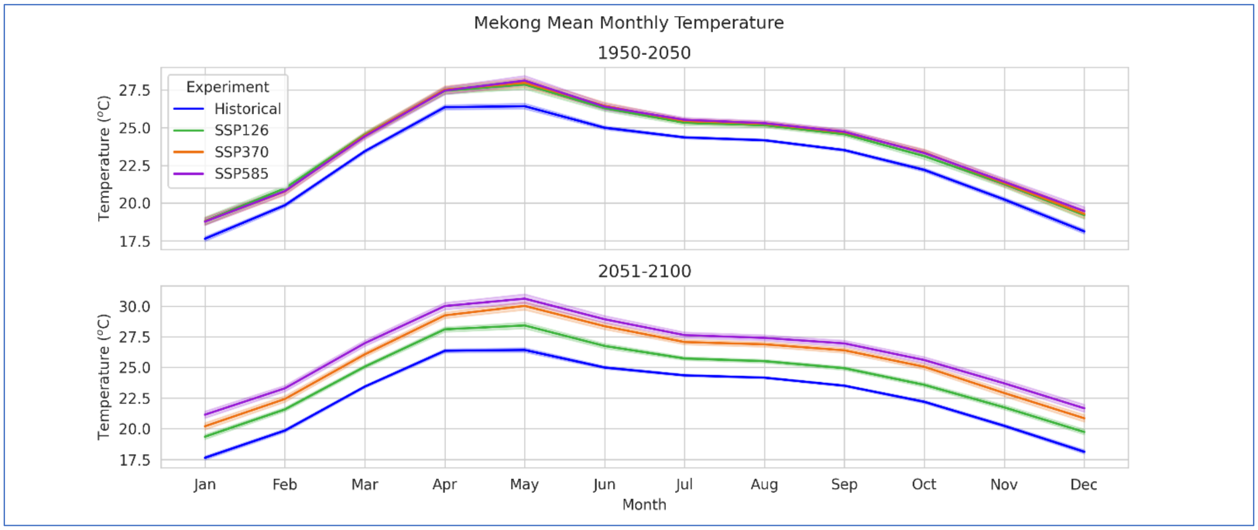


Figure 32 Monthly mean temperature in the Mekong Basin for the historical reference 1850-2014 and SSP-RCPs projection divided into 1950-2050 and 2051-2100 periods. Data source: Annex I Table 6.

The rate of warming is significantly higher in the later months (May to October) compared to the earlier months (November to April) across all scenarios. Warming levels suggest that the Mekong Delta Basin might experience hotter summers in the future. The difference between the low and high warming scenarios (SSP1-RCP2.6 and SSP5-RCP8.5) is around 2°C by the end of the century. Such a large difference highlights the potential impact of different development pathways and greenhouse gas emission levels on future temperatures.

Precipitation projections from SSP-RCP scenarios

Figure 33 depicts the projected changes in mean monthly precipitation for the Mekong Delta Basin under the three SSP-RCPs scenarios of the SOS-Water project. There is a general trend of uncertainty regarding future precipitation patterns in the Mekong Delta Basin across all SSP-RCP combinations, with no clear and consistent increase or decrease projected throughout the year. SSP1-RCP2.6 and SSP3-RCP7.0. These scenarios show similar patterns with potential increases in precipitation during the wet season (May to October) and decreases during the dry season (November to April) compared to the historical baseline. However, the magnitude of these changes is uncertain and varies across the months.

SSP5-RCP8.5: this scenario exhibits a slightly different pattern, with potential increases in precipitation throughout the year compared to the historical baseline. However, similar to other scenarios, the magnitude and consistency of these changes remain uncertain.

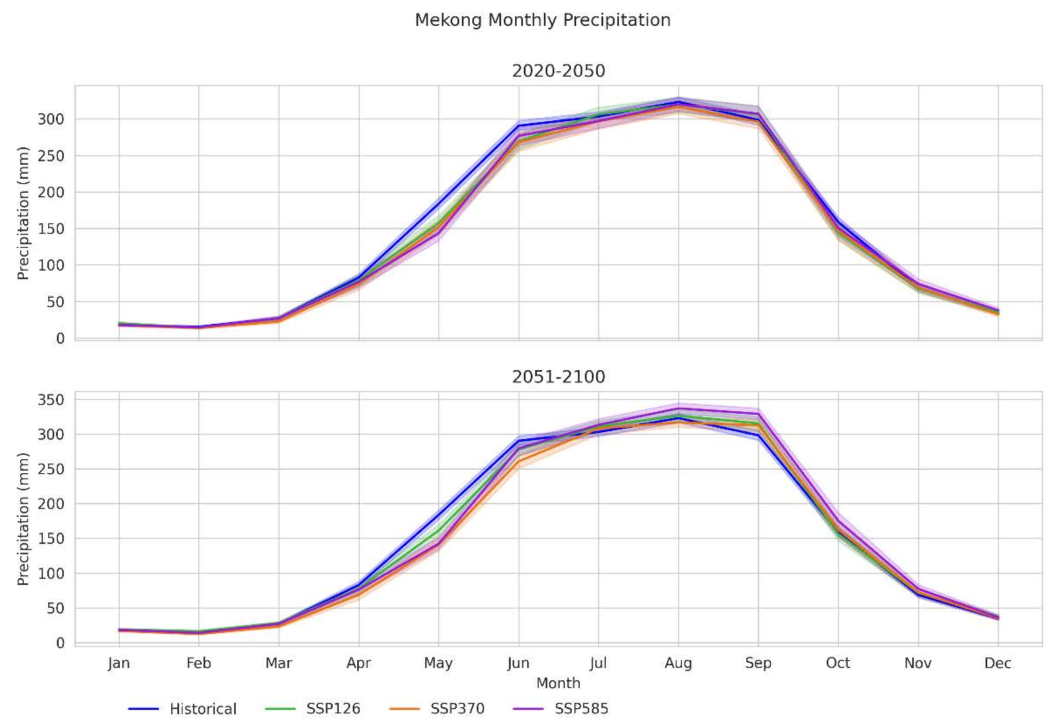


Figure 33 Monthly mean precipitation in the Mekong Basin for the historical reference 1850-2014 and SSP-RCPs projection divided into 1950-2050 and 2051-2100 periods. Data source: Annex I Table 6.

Projections shown in Figure 33 depict a high degree of variability across different months and scenarios, making it difficult to discern a definitive trend in future precipitation. The potential changes in precipitation during the dry season (November to April) are particularly noteworthy as they could significantly impact water availability and agricultural practices in the Mekong Delta Basin. While the specific changes remain uncertain, the projections suggest a potential shift in seasonal precipitation patterns that could have significant consequences for the region's water resources, agriculture, and ecosystems.

Socio-economic drivers

Population evolution trends for the Mekong Delta (Figure 35) show an increase in population for all SSPs until approximately 2040. After this year, the population is expected to decline in SSP1 and SSP5, while remaining steady in SSP3. However, the rates of growth and the distribution between rural and urban areas differ significantly between the scenarios. In SSP1, the total population shows a moderate and steady increase throughout the projection period, while the rural population shows a gradual decline but remains the majority population until 2050. The urban population shows a steady increase, surpassing the rural population around 2035. SSP1 suggests a balanced growth with a gradual shift from rural to urban areas while maintaining a considerable rural population. This scenario might prioritize sustainable development and balanced regional cooperation. In SSP3, the total population shows a moderate increase throughout the projection period, similar to SSP1 but slightly lower.

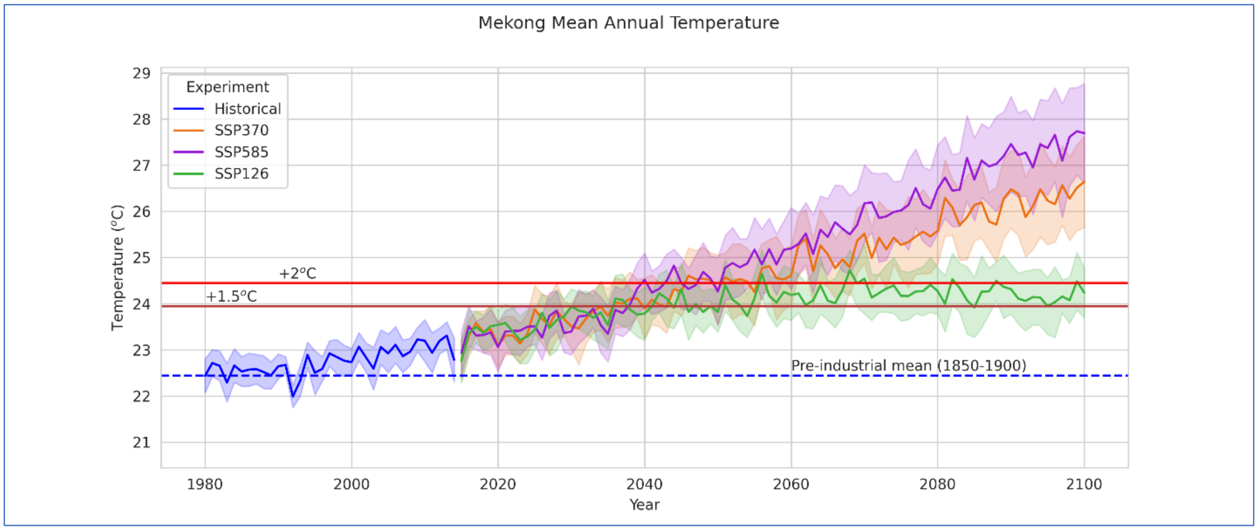


Figure 34 Annual mean temperature in the Mekong Basin for the historical period until 2010 and SSP-RCPs. The blue dotted line marks the pre-industrial mean annual temperature, and the two red lines mark the +2o and +1o increase with respect to the pre-industrial level. Data source: Annex I Table 6.

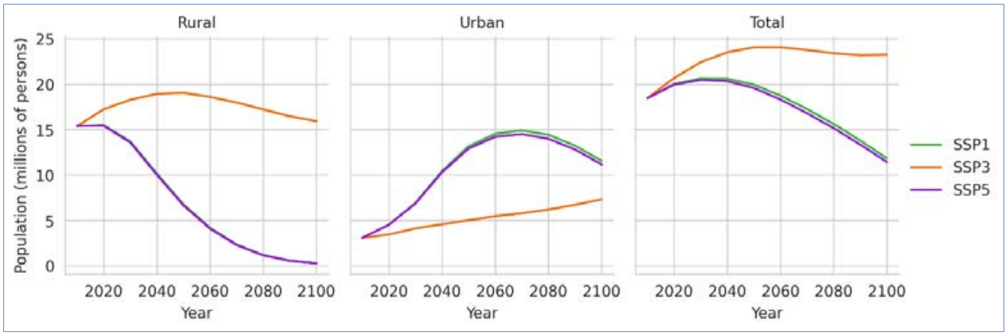


Figure 35 Population projections of the three SSPs in the Mekong delta. Source: Annex I Table 4.

The rural population shows a slower decline compared to SSP1, remaining the majority population for a longer period. The urban population shows a slower increase compared to SSP1, reaching a similar level to the rural population by 2050. SSP3 suggests a slower overall growth with a more gradual transition from rural to urban areas. This scenario might reflect continued challenges in regional cooperation and economic development.

In SSP5, the total population shows the highest increase among the three scenarios, with a sharp rise in the initial decades followed by a slowdown. The rural population shows a rapid decline and will become a minority population by 2025. Finally, the urban population shows the fastest increase, reaching a significantly higher level than the rural population by 2025. SSP5 suggests the fastest overall and urban growth but with a steeper decline in the rural population. This scenario might prioritize rapid economic development potentially at the expense of environmental sustainability and social equity.

The GDP per capita overall trend (Figure 36) in all three SSPs project an increase in the GDP per capita of the Mekong Delta Basin over the next few decades. However, the rates of growth differ significantly between the scenarios. SSP1 shows the steepest and most sustained increase in GDP per capita. Such growth suggests that under conditions of strong international cooperation, investment in sustainable development, and technological advancements, the Mekong Delta Basin could experience rapid economic growth. SSP3 shows a moderate increase in GDP per capita, with a gradual slowdown in growth over time.

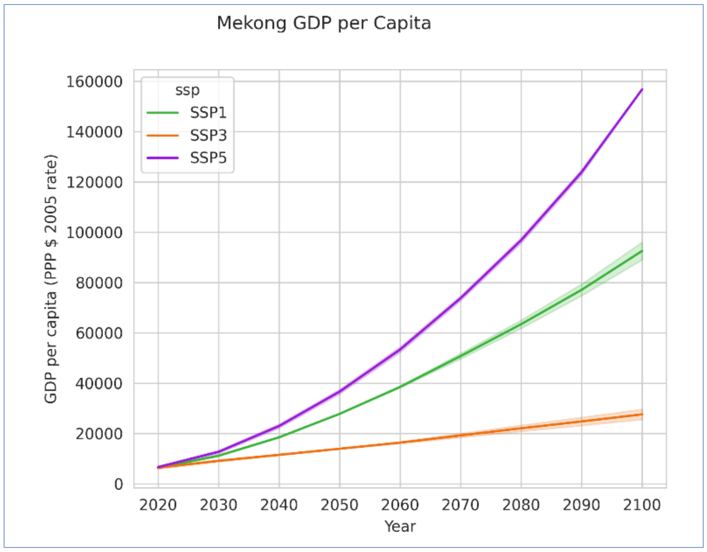


Figure 36 GDP in Purchasing Power Parity (PPP) projections of the three SSPs in the Mekong Delta. Source: Annex I Table 4 and Table 5.

The low growth in SSP3 suggests that under conditions of regional competition, limited international cooperation, and continued reliance on traditional development strategies, economic growth in the Mekong Delta Basin may be slower and less stable. SSP5 shows a somewhat higher increase in GDP per capita compared to SSP3 in the initial decades but with a steeper decline in growth later in the century. This trend suggests that under conditions of prioritizing economic development over environmental sustainability, the Mekong Delta Basin may experience short-term economic gains followed by challenges due to environmental degradation and resource depletion.

Projected land use changes in crop, pasture, natural vegetation, and urban areas for the Mekong Delta are depicted in Figure 37. All scenarios show a gradual increase in cultivated land by 2100. SSP3 and SSP5 show a sharper increase compared to SSP1. The difference suggests that prioritizing economic development under these scenarios might lead to the conversion of other land-use types to agriculture, potentially at the expense of natural habitats. The pasture area in SSP1 shows a stable pasture area throughout the projection period. SSP3 shows a moderate increase, and SSP5 shows the highest increase in pastureland by 2100. The differences suggest that prioritizing economic development, particularly livestock production, might lead to an expansion of pastureland under SSP3 and SSP5 scenarios.

In all scenarios, there is a gradual decrease in natural vegetation cover by 2100. The rate of decrease is slowest under SSP1 and fastest under SSP5. This indicates that prioritizing sustainability in SSP1 might help conserve natural habitats to a greater extent compared to the other scenarios. Finally, in all scenarios, there is a significant increase in urban areas by 2100. The rate of increase is highest under SSP5 (Fossil-fuelled Development), followed by SSP3 (Regional Rivalry) and SSP1 (Sustainability). This suggests that all scenarios anticipate urbanization, but the pace might be faster under development-oriented pathways (SSP3 and SSP5) compared to the sustainability-focused SSP1.

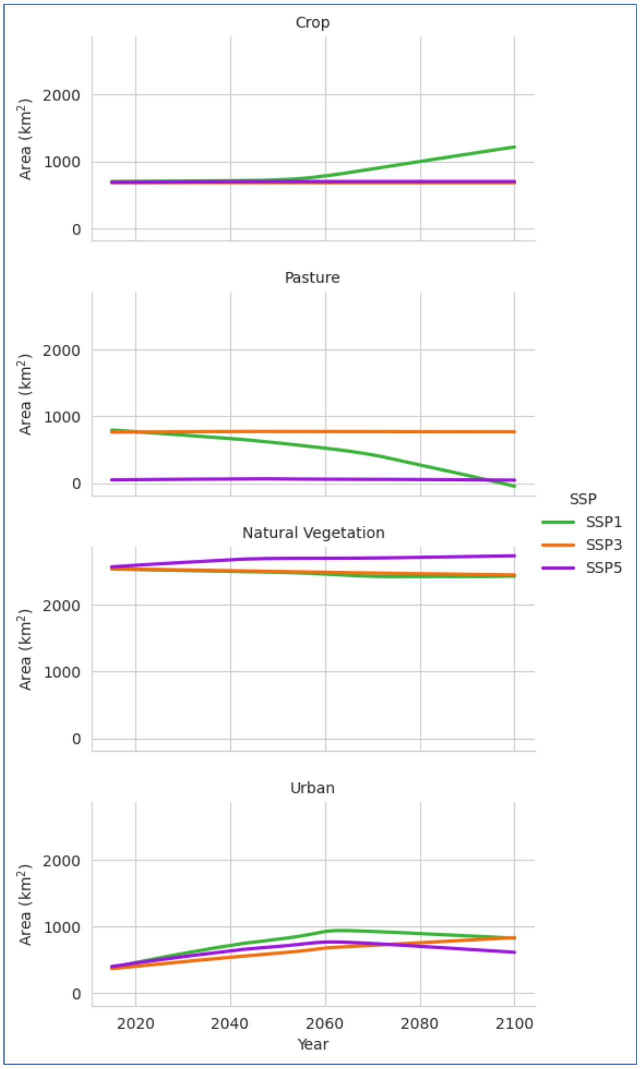


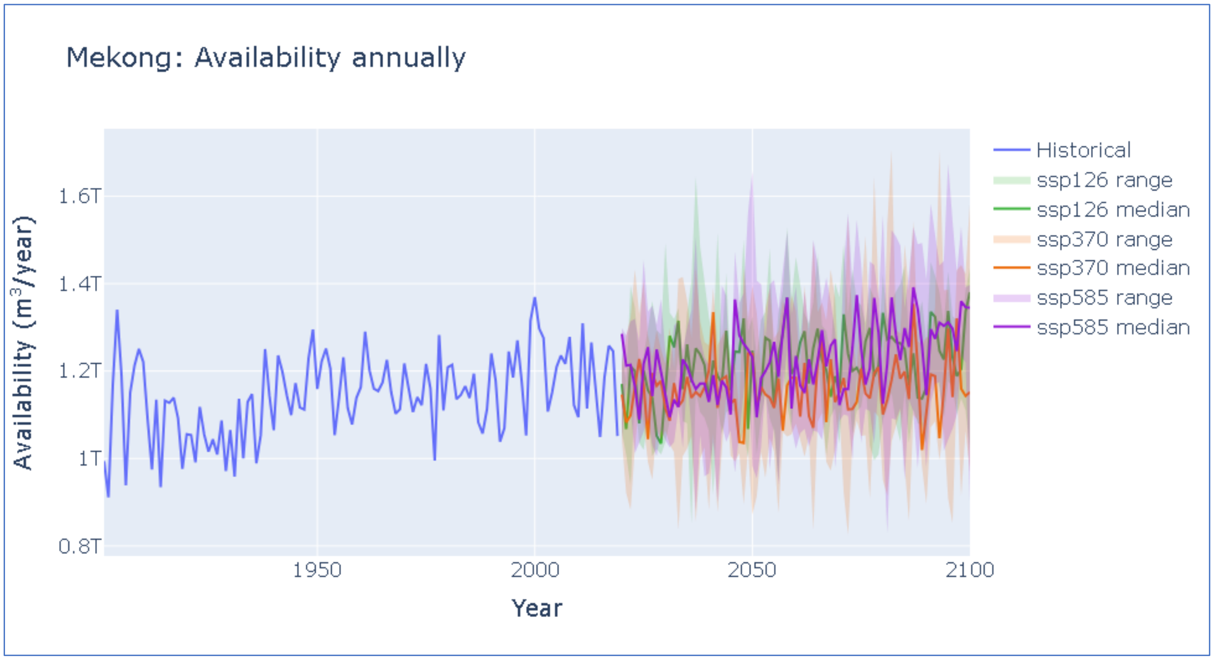
Figure 37 Land use projections for the Mekong Delta. Note: crop area does not include rice paddies (Hurtt et al. 2020). *Source: Annex I Table 5.*

In conclusion, the charts in Figure 37 highlight the potential consequences of different development pathways on land use in the Mekong Delta Basin. While all scenarios project increases in cultivated land, pastureland, and urban areas, the extent of these changes varies depending on the development priorities. Prioritizing sustainability (SSP1) might help conserve natural vegetation and balance land-use changes compared to scenarios emphasizing economic development (SSP3 and SSP5), which might lead to faster land-use conversions. These projections emphasize the importance of considering long-term environmental and social consequences alongside economic development goals when making choices about the future of the Mekong Delta Basin.

Water availability, water demand and water stress

In this section, we provide future projections up to 2050 for some water security indicators, such as water availability and demand, under three climate and socio-economic scenario combinations to provide a range of possibilities. The projections are the results of simulations conducted with the global hydrological models CWatM (Burek et al. 2020). Figure 38 presents a comparative analysis of annual water availability spanning the historical period (1900-2020) and future projections (2020-2100).

Our examination reveals a relatively constant to slightly increasing trend in annual water availability throughout the 21st century. Specifically, the median yearly water availability is projected to experience a 7% increase compared to the 20th century. Moreover, our analysis suggests an elevated frequency of hydrological anomalies in wetter and drier years, with droughts and floods more significant than those experienced in the 20th century.



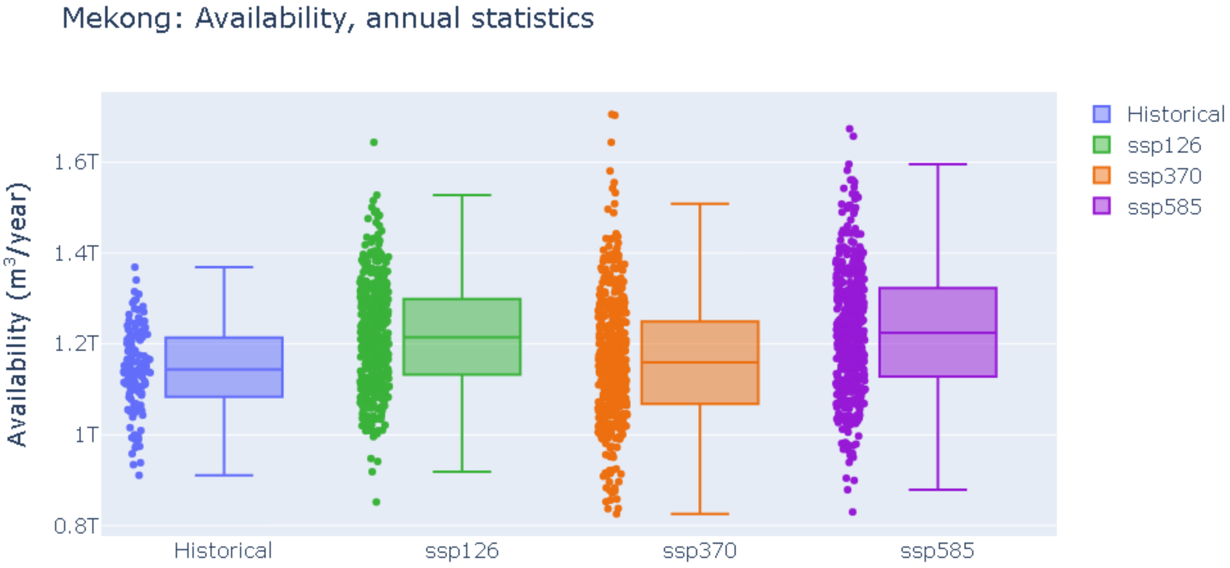


Figure 38 Annual water availability for historical and three future scenarios in the Mekong Basin. Top) Line graphs show the median of the five models for each scenario and the entire range as a shadow. Bottom) Box-whisker plots showing the data variance through quartiles – the quartile divides the data into four relatively equal sizes.

Figure 39 presents the projected total water demand across various sectors. The analysis indicates relatively stable industrial and domestic water demands. Conversely, irrigation demands are projected to rise due to decreasing water availability. In these simulations, water demand projections do not incorporate potential alterations in irrigated areas, which are set in the simulations to remain constant at the 2000 level. The interplay between projected water availability and demand changes produces relatively static water stress, albeit with intermittent periods of extreme water stress potentially exceeding historical levels by up to 25%, as depicted in Figure 40.

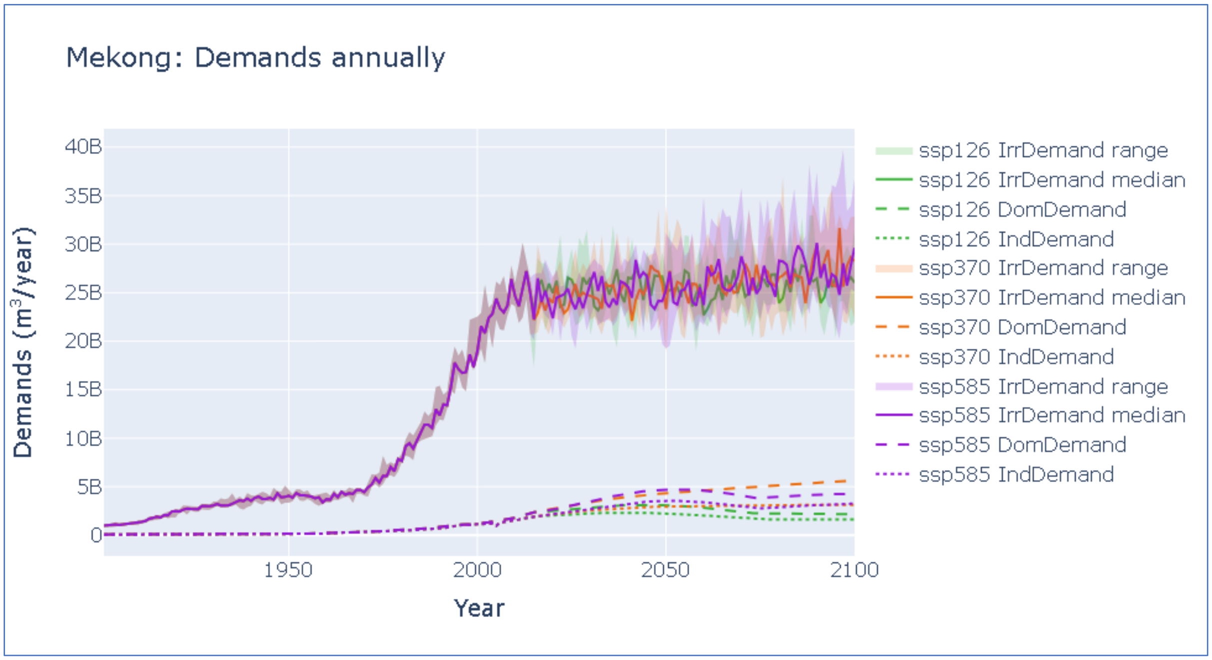


Figure 39: Sectoral demands for historical and future scenarios in the Mekong Basin. Source: Burek et al. (2020).

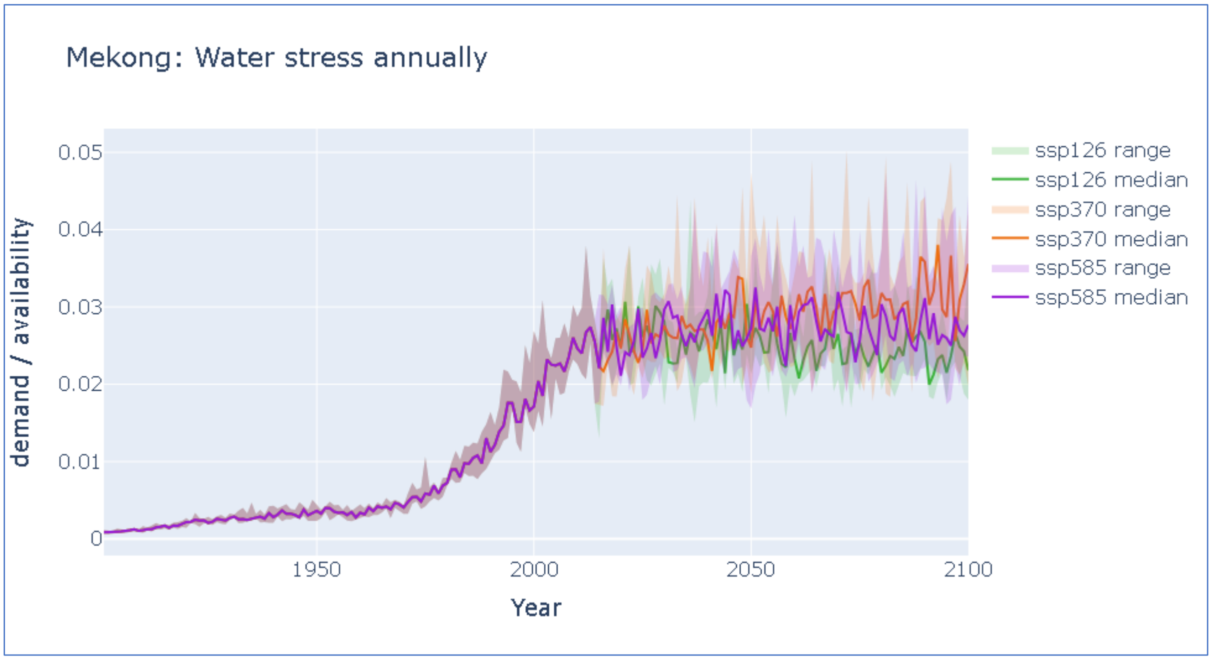


Figure 40 Annual water stress for historical and future scenarios in the Mekong Basin. Source: Burek et al. (2020).

Rhine

The Rhine Basin

The Rhine River, spanning a length of approximately 1,230 km, is a major watercourse in Europe. It has a vast drainage area of around 185,000 km^2, encompassing various sub-basins and tributaries (as shown in Figure 41). The source of the Rhine River is in the Swiss Alps in the canton of Graubünden, from which it flows through diverse landscapes, including mountainous regions, fertile valleys, and urbanised areas. Together with its tributaries, the Rhine forms a diverse range of ecological habitats, including mountain streams, floodplains, wetlands, and estuaries, supporting a rich biodiversity in the region. Moreover, the Rhine plays a crucial role in maintaining ecological connectivity, allowing for the migration and dispersal of species. In addition to serving as an essential navigation route, facilitating trade and commerce within Europe, the Rhine River is also a significant source of water resources, providing drinking water, supporting industrial processes, and facilitating agriculture in the region.

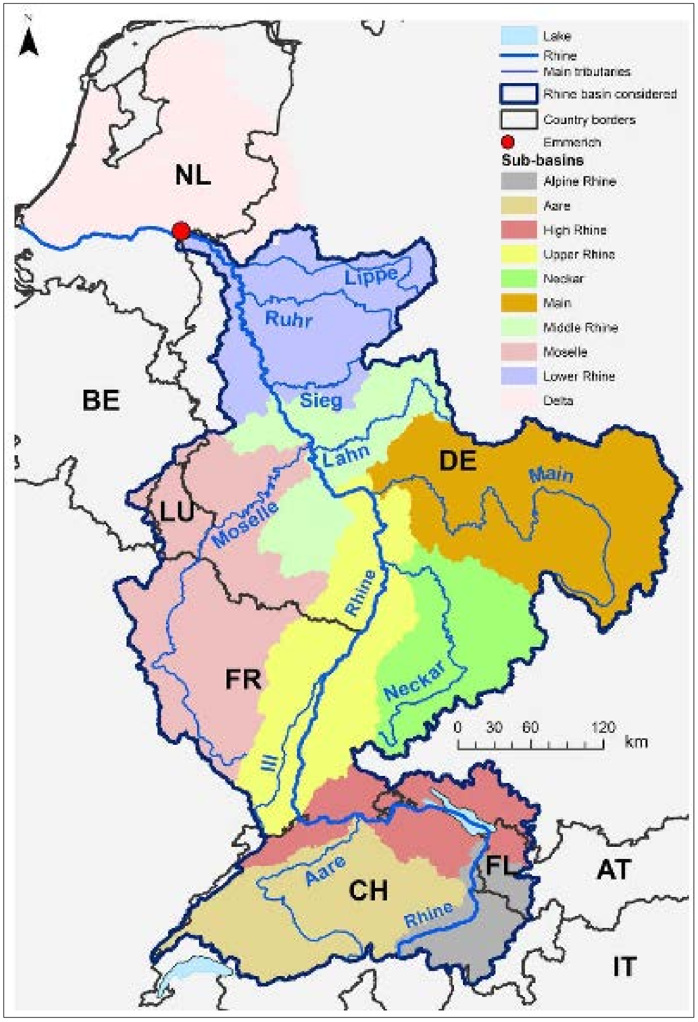


Figure 41 Map of the Rhine catchment obtained from Moser et al. (2018).

The water flow of the upstream parts of the Rhine is regulated through a system of dams and reservoirs to ensure water availability throughout the year. The lower reaches have no man-made obstacles to enable shipping of large volumes of cargo from Germany to the port of Rotterdam and back.

The Rhine-Meuse Delta, also known as the Rhine Delta or the Dutch Delta, is the vast coastal plain formed by the convergence of the Rhine and Meuse rivers in the Netherlands. It extends from the city of Rotterdam to the North Sea and covers an area of approximately 8,000 km^2. The Delta, with its complex network of channels and wetlands, is a dynamic environment influenced by tidal processes, sediment deposition, and human interventions. The diversity of its habitats supports unique flora and fauna, and serves as an important breeding ground for birds, as well as a stopover site for migratory species. The Rhine River and its delta currently face various ecological challenges.

Human activities, including land reclamation, urbanisation, and agriculture, have led to habitat loss, fragmentation, pollution, and a reduced water availability in summer.

The construction of dams and flood defences has altered the natural hydrology of the river, affecting fish migration, sediment transport and water quality. Additionally, climate change poses risks such as sea-level rise increased storm surges, droughts, and changes in precipitation patterns, which can impact the stability and biodiversity of the river basin.

With respect to the future, the Rhine is expected to deal with challenges related to drought and floods. With more hydrological extremes it will be more challenging to balance storage of water to mitigate drought and discharging water to increase potential flood volumes.

The main stakeholders in the Rhine River are the national water authorities of the different countries, they often represent the stakes of the more local stakeholders. Other parties involved include nature, shipping, agriculture, industry, local water authorities, hydropower companies, local communities.

Rhine basin hydrometeorological and socio-economic local drivers

Temperature projections for SSP-RCP scenarios

Figure 42 shows the mean monthly temperature in the Rhine basin for historical reference and the three SSP-RCP scenarios. All SSP-RCP combinations show an increasing trend in mean monthly temperature compared to the historical period. SSP-RCP trends indicate that the Rhine Basin is likely to experience warming in the future regardless of the specific development pathway or greenhouse gas emission scenario. However, substantial differences exist among the three SSP-RCP projections.

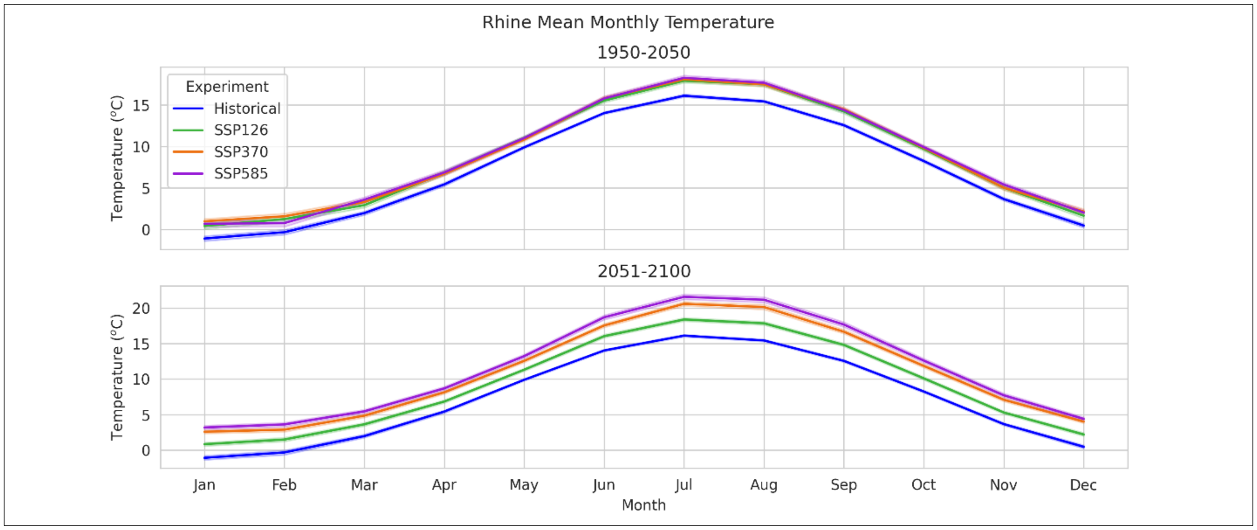


Figure 42 Monthly mean temperature in the Rhine basin for the historical reference 1850-2014 and SSP-RCPs projection divided into 1950-2050 and 2051-2100 periods. Data source: Annex I Table 6.

The SSP1-RCP2.6 scenario represents the lowest warming pathway, with a projected increase in temperature of around 2°C to 3°C by the end of the century (2050-2100) compared to the historical baseline. The SSP3-RCP7.0 represents a moderate warming pathway, with a projected increase of 4°C to 5°C by the end of the century. Finally, the highest warming pathway is the SSP5-RCP8.5 scenario, with a projected increase of 5°C to 6°C by the end of the century. The rate of warming is rather constant throughout the year with slightly higher values in summer than in winter.

Precipitation projections for SSP-RCP scenarios

Figure 44 depicts the projected changes in mean monthly precipitation for the Rhine basin under the three SSP-RCPs scenarios of the SOS-Water project. There is a general trend of more winter precipitation and reduced summer precipitation, especially for the SSP3-RCP7.0 and SSP5-RCP8.5 scenarios. These scenarios show similar patterns with potential increases in precipitation during the wet season (October to April) and decreases during the dry season (May to September) compared to the historical baseline. However, the magnitude of these changes is uncertain and depends on the SSP-RCP combination.

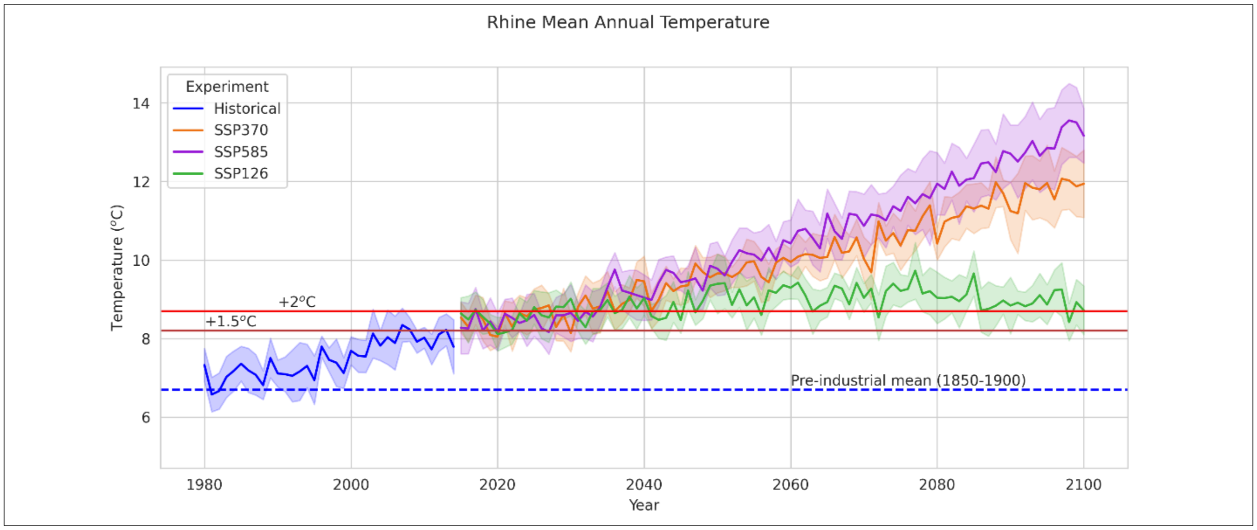


Figure 43 Annual mean temperature in the Rhine basin for the historical period until 2010 and SSP-RCPs. The blue dotted line marks the pre-industrial mean annual temperature, and the two red lines mark the +2o and +1o increase with respect to the pre-industrial.

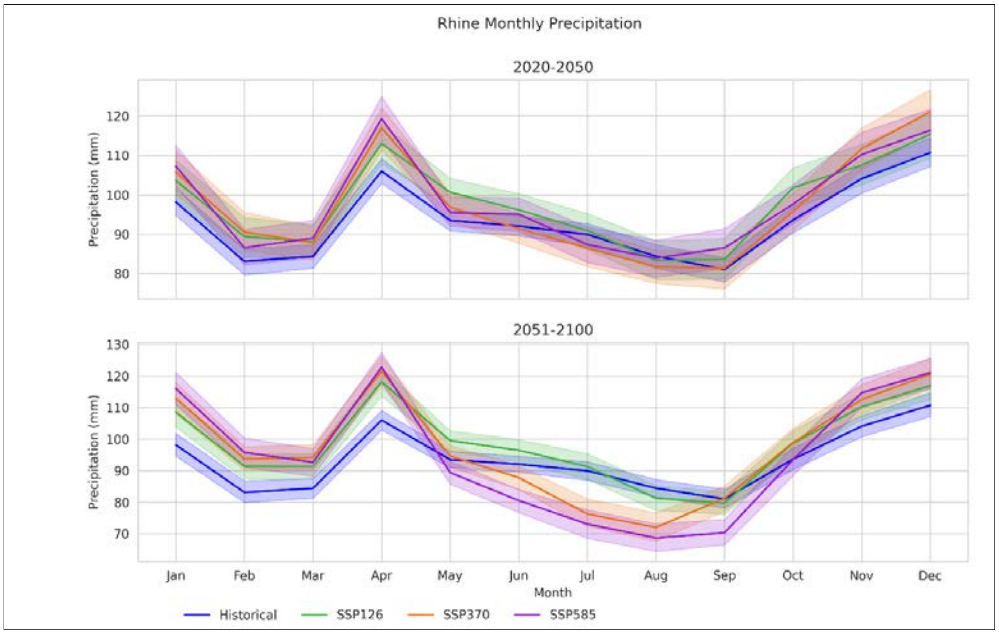


Figure 44 Mean monthly precipitation over the Danube basin for the historical reference 1850-2014 and SSP-RCPs projection divided into 1950-2050 and 2051-2100 periods. Data source: Annex I Table 7.

This pattern combined with the increasing temperatures will lead to more precipitation being discharged in the river in winter, as there is less snow accumulation and more precipitation, and lower discharge values in summer as a result of higher evaporation and reduced precipitation.

Socio-economic drivers

The GDP per capita overall trend (Figure 45) in all three SSPs project an increase in the GDP per capita of the Rhine Basin over the next few decades.

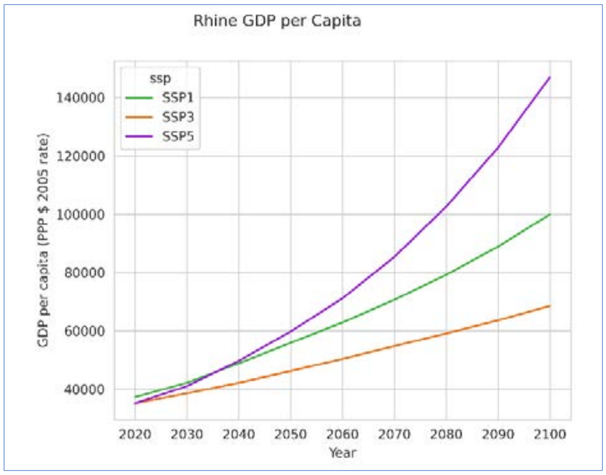


Figure 45 GDP per capita in Purchasing Power Parity (PPP) projections of the three SSPs in the Rhine basin. Data source: Annex I Table 3 and Annex I Table 5.

However, the rates of growth differ significantly between the scenarios. SSP1 shows the steepest and most sustained increase in GDP per capita. Such growth suggests that under conditions of strong international cooperation, investment in sustainable development, and technological advancements, the Rhine Basin could experience rapid economic growth.

Depending on the selected SSP scenario we see either an increase in the population (SSP5), a stabilization in the population (SSP1) or a decrease in the population (SSP3) for the Rhine Basin (Figure 46). Most of these changes occur in the urban areas, while only limited changes are observed in the rural areas.

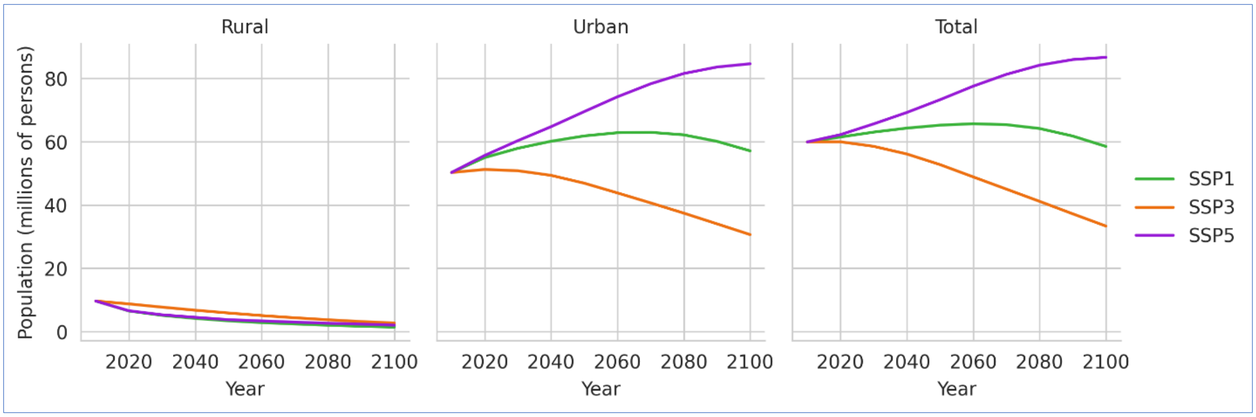


Figure 46 Population projections of the three SSPs in the Rhine Basin. Data source: Annex I Table 5.

The patterns that are observed in population growth are also reflected in the changes in land use, with the biggest changes occurring in the urban area. For SSP3 and SSP 5, only limited changes are observed for the other land use types, with some minor changes in natural vegetation and pasture. Large changes are found for SSP1, where we observe a strong change in the crop land area beyond the year 2050. SSP1 also leads to strong reduction in the pasture and increase in the natural vegetation and almost no changes in the urban area in 2100.

Figure 47 Land use projections for the Rhine Basin. Data source: Annex I Table 4.

Water availability, water demand and water stress

The water availability in the Rhine basin will not exhibit major changes on the annual time scale (Figure 51). Between the different SSP scenarios no significant changes are found in the distribution of the water availability (Figure 52), however seasonal changes can occur due to the changing temperature and precipitation regimes.

A strong reduction in the water demand is observed beyond 2050, for all sectors and SSP scenarios (Figure 49). The decrease in water use levels off towards around 2075 for the different scenarios. Overall, this also results in a decrease in water scarcity for the entire Rhine basin (Figure 50). This decrease is found for all scenarios and levels of around 2075, with SSP1 showing the strongest decrease.

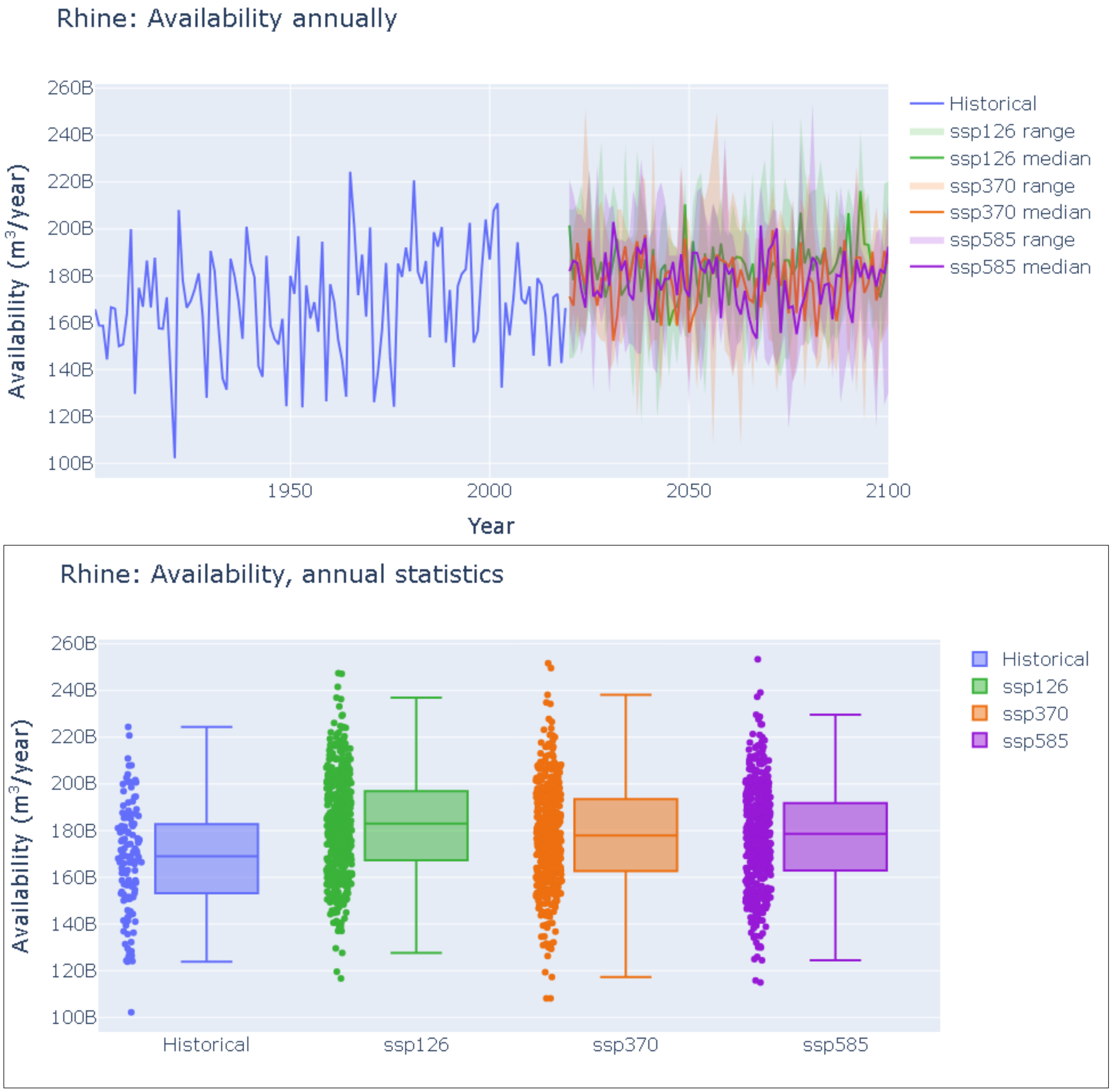


Figure 48 Annual water availability for historical and three future scenarios. Top) Line graphs show the median of the five models for each scenario and the entire range as a shadow. Bottom) Box-whisker plots showing the data variance through quartiles – quartile.

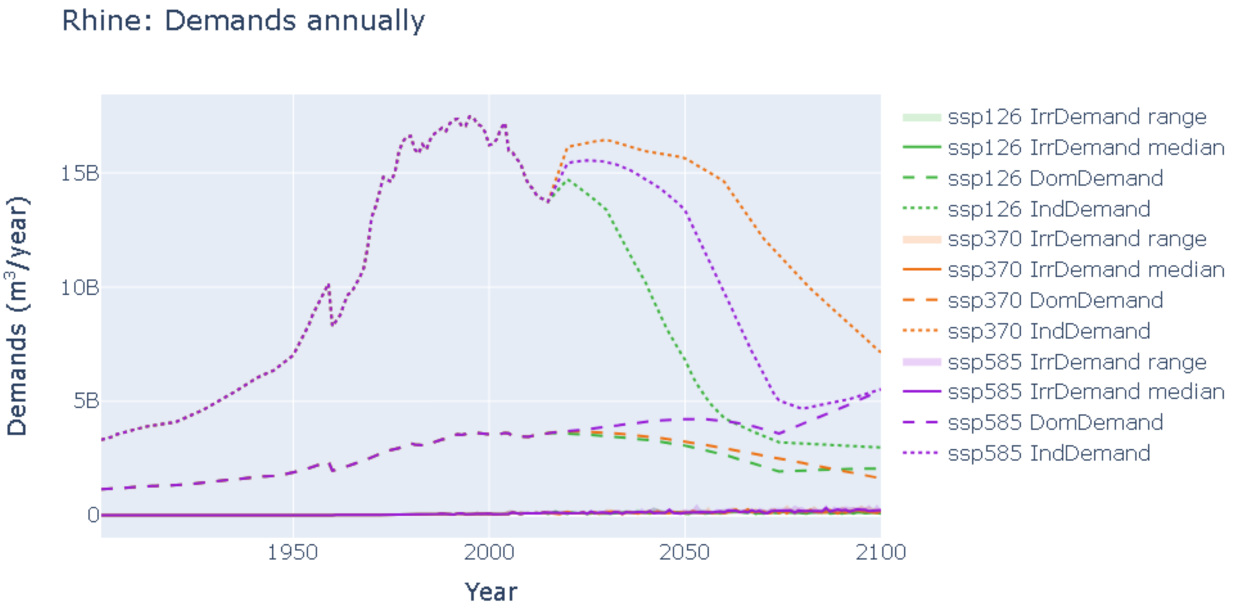


Figure 49 Sectoral demands for historical and future scenarios. Source: Burek et al. (2020).

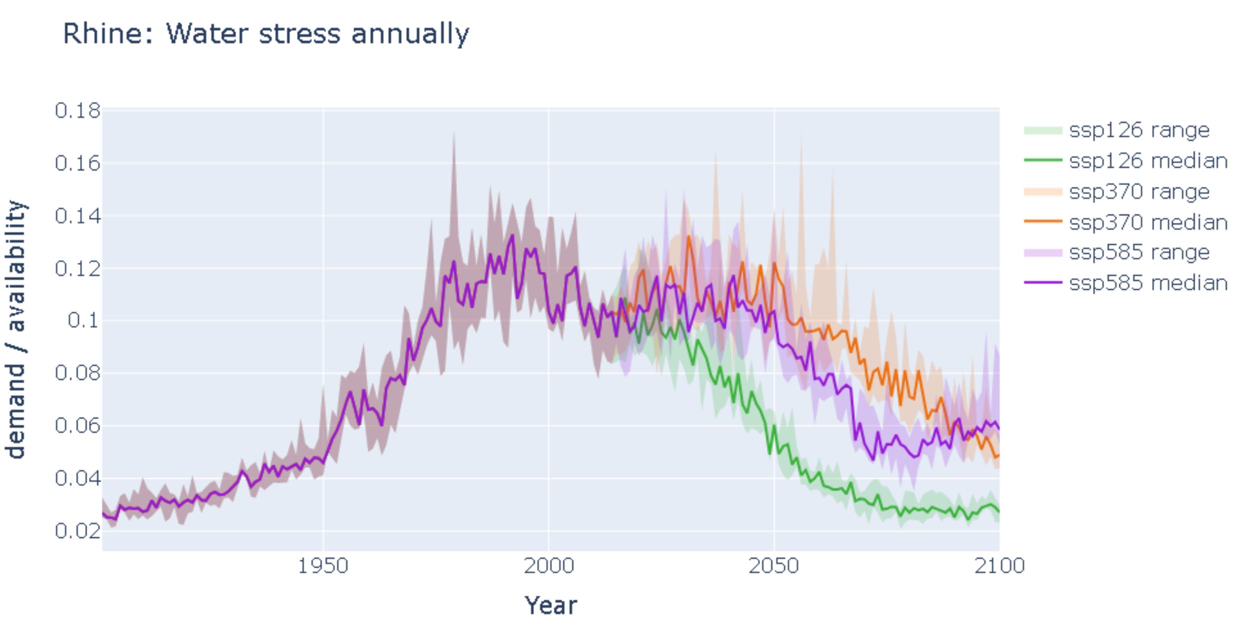


Figure 50 Annual water stress for historical and future scenarios. Source: Burek et al. (2020)

4. Local narratives and pathways development

SSPs' local narratives describe how global SSPs can unfold within a specific geographical area by considering local biophysical attributes, geopolitical context, and existing challenges and opportunities of the subject area. Within the water sector, exploring climate change local narratives can provide insights into how communities are affected by water-related challenges associated with climate change. Understanding these narratives can inform targeted strategies for enhancing water system resilience in specific regions. Local narratives are derived from global SSPs. One can see creating local narratives as downscaling SSPs by adapting their tenets to a local context. Therefore, local narratives must maintain consistency with the SSP from where they are derived. For example, a local narrative extending from SSP3 (regional rivalry) could hardly justify among its tenets the creation of transnational infrastructures to mitigate or adapt to the effects of climate change. Similarly, a local narrative derived from SSP5 (fossil fuelled development) will likely include infrastructure development among the adaptation measures. SSPs also dictate the assumptions underpinning the development of the narrative-dependent scenarios, for example, by providing projections for population growth, which in turn will contribute to determining water demand.

In a nutshell, RCPs' forcings determine local climatic settings, while local SSP narratives describe future social contexts and, thus, how communities will design adaptation measures.

In the context of the SOS-Water project and, therefore, in the remainder of this document, local scenarios built using global drivers and local narratives are addressed as "pathways". The terminology is aimed at clearly distinguishing between global SSP-RCP scenarios and their local implementation, which also includes adaptation measures.

Danube

Local narratives methodology

Creating local narratives for the DB follows an iterative approach involving an exchange between researchers and stakeholders. The role of stakeholders in this project is to provide insight into critical issues and interest groups' objectives, conceptually validate the narratives put forward by researchers and contribute to devising adaptation measures consistent with the narratives. On the other hand, researchers have the role of proposing pathways quantitatively and qualitatively consistent with the global ones, incorporating stakeholders' views and producing projections of climate change impacts and adaptations. The phases and the objectives of the methodology are summarised in Figure 51.

Pathways elements

Basic SSP definitions are built by nine fundamental categories comprising several scenario elements (O'Neill et al., 2014). The scenario elements are a prerequisite for identifying challenges to mitigation and adaptation. However, O'Neill et al. (2014) recognised the need to refine the level of detail of the basic categories and their scenario elements to create extended SSPs for regional or sectoral applications. To create the DB-specific list of pathways elements, the role of stakeholders was acknowledged early on with the goal of co-creating robust, context-specific local narratives and scenarios that contribute to effective research and applied solutions. In the early stages of the co-creation process, the stakeholders' role was to inform scientists about critical issues and identify a hierarchy of objectives for the group they represent. Combining this information with elements drafted from literature (Wada et al. 2016; Alizadeh, Adamowski, and Inam 2022) and further ones we recognised as important drivers of socio-economic development and environmental relevance within the water domain of the DB, the list of categories and scenario elements in Table 5 was created.

Figure 51 Chronological steps and their objectives of the methodology applied to develop local narratives and pathways for the Danube Basin.

The proposed elements in Table 5 encompass quantitative and qualitative variables that will be used to set up the modelling assumptions for the pathways and the socio-economic context of the local narrative. Quantitative elements will be used as inputs for the Integrated Water Modelling System (IWMS) to simulate the pathways. Quantitative elements can be expressed in measurable units (e.g., GDP per capita) or trends (e.g., increased technological efficiency). Qualitative elements are instead expressed with a nominal unit (e.g., high environmental awareness). It has to be noted that at this stage, qualitative values are merely proposed and will be subjected to validation by stakeholders. This is because, while quantitative pathway elements and climate-forcing variables such as temperature or precipitation are the results of models and thus are to be considered objective, qualitative elements are, to some extent, subjective, and so are the descriptions of the local narratives. To render the qualitative elements more robust, DB stakeholders will be consulted for an evaluation to harness their insight into local processes.

The consultation process will be iterative and question the validity of the local narratives concerning the five quality criteria put forward in Kok & van Vliet (2011):

1. Relevance: the scenarios are relevant for the basin and the stakeholders
2. Credibility: the scenarios are deemed plausible
3. Legitimacy: stakeholders' feedback and voice are taken into account
4. Creativity: the scenarios bring new perspectives on future challenges
5. Structure: the scenarios are consistent

The evaluation process will be iterative to ensure that the legitimacy criterion is satisfied and that pathways and simulation results can effectively support the formulation of adaptation measures and policies, as required by the relevance criterion.

Adaptation pathways

Global SSPs are designed to highlight future adaptation and mitigation challenges (Riahi et al., 2017) but, when "downscaled" to the local level, do not explicitly include adaptation measures implemented locally. Therefore, simulations of the DB based solely on the SSP-RCPs assumptions and data represent baseline scenarios. For this case study, the baseline scenarios will be modified with adaptation measures in line with the SSP narrative from where the scenario stems. The creation of adaptation scenarios relies on local SSP narratives and interactions with stakeholders and includes adaptation measures functional to achieve stakeholders' objectives. However, for each SSP, the palette of adaptation options is dictated by the qualitative scenario elements, which limit the possibilities of available measures and policies in each SSP.

Defining the adaptation measures for each scenario will rely on the expected climate change impacts found by previous studies on the DB (ICPDR, 2018; Bisselink et al., 2018; Pistocchi et al., 2020). These studies found the types and classes of impacts reported in Table 6.

To draft the adaptations to be associated with each impact, local narratives' qualitative elements become relevant, for they represent intangible societal elements (e.g., environmental awareness) that, although not quantifiable, embody the public sentiment that steers policy and decision-making. In other words, these elements, e.g., the level of environmental awareness, orient the type of adaptations a future society will adopt.

The Danube "climate change adaptation strategy" (ICPDR 2018) provides a comprehensive set of possible adaptations, classified into five categories built on EEA (2015) and UNECE (2009) classifications. The five categories are:

1. Preparation measures
2. Ecosystem-based measures
3. Behavioural and managerial measures
4. Technological measures
5. Policy approaches

As an illustrative example, we report in Table 7 a set of measures suggested to address the "reduced water availability" impact. The measures are adapted from the adaptation measures toolbox for the Danube (ICPDR, https://www.icpdr.org/tasks-topics/tasks/climate-change-adaptation/climate-change-adaptation-measures-toolbox) and assigned to an SSP considering the sentiment expressed by each narrative. From this hypothetical example, "preparation measures" have been left out because those proposed in the ICPDR list cannot be modelled, which is an essential prerequisite for inclusion in an adaptation scenario.

The list of adaptation measures in response to the challenges of SSPs will undergo further interaction with the stakeholders, following a similar process as in the section "Pathways elements" to ensure the relevance, credibility, legitimacy, creativity and structure of the pathways.

Danube local narratives

The following paragraphs describe the broad socio-economic context of the proposed local narratives. The global SSP-RCP code name composes the title of the local narratives, followed by the title of a classical music piece in line with the narrative's mood, and that will be used to refer to the narrative itself nominally. The scope of these narratives is to provide a descriptive picture of possible futures, thus conveying the qualitative elements of the local SSPs in verbal form. They have been derived from the global SSP narratives, adapting some of their tenets to the DB context.

SSP1-2.6: An der schönen blauen Donau

The international context favours the reduction of economic and capacity disparities between the upper and lower basin countries. The cooperation results in water management's shared vision and goals centred around sustainability. Goals are pursued by deploying environmentally sound practices that spread their benefits equally among all communities. In the beginning, wealthier countries sustain higher financial burdens to restore river functionality. Later on, the socio-economical levelling of the Danube nations allows for an even financial commitment. The shifts toward environmentally conscious habits, low population growth, and technological development drive the market demand toward sustainable agricultural production. The high education level and effective institutions allow for planning for large-scale infrastructures coordinated among countries. At the same time, high education levels also allow for complex local infrastructures to be planned, deployed, and operated at the local level. The environmentally aware society drives the demand for interventions required for reducing environmental impacts (e.g., wastewater treatment plants), efficient use of resources (e.g. efficient irrigation), and increased aesthetic value and biodiversity enhancement (e.g. river revitalisation). Interventions prefer green infrastructures over grey ones and natural-based solutions over strictly engineering works. Energy production transitions towards renewable sources, possibly also driving the increase of hydropower while energy demand becomes more efficient. Technological development is high and driven by widespread high education levels and knowledge sharing among institutions of the different Danube countries.

SSP3-7.0: Dies Irae (day of wrath)

Socio-economic disparities remain and possibly increase between the lower and upper basin countries. Scarce cooperation among countries leads to poor basin management shared vision and goals. Investments are focused on local benefits, possibly leading to conflicts between the countries, mainly due to excessive water withdrawal from upstream. The level of conflict increases downstream as more and more countries withdraw water. High withdrawals are required to cope with poor technological development and limited resources dedicated to efficiency improvements. A lack of financial resources limits the scale of infrastructures, and when significant works are implemented, they are designed to yield benefits only to the implementing country. A possible driver for large-scale infrastructures is the enhancement of water security, even if perpetrated at the expense of other countries. The type of interventions is mainly oriented toward grey infrastructure and significant engineering works with little regard for environmental goals dictated by the urgency of supplying water. Tailored, local-scale interventions are very limited in countries with lower incomes. At the same time, wealthier ones put in place local interventions only to enhance competition (e.g., supporting local agriculture or tourism). The low level of education also reflects negatively on the technical complexity and efficiency of the interventions and on the overall capacity to operate and maintain complex structures.

The rise of two contraposing blocks between the wealthier countries of the upper basin and the less resourceful ones of the lower basin is possible.

SSP5-8.5: Der Radetzky-Marsch

The cooperation among states is strong, mainly to promote development, although in a technologically savvy way. The focus on technology and integration encourages the basin's capacity building and socio-economic development. Basin management is shared yet subject to growth-oriented agendas. Thus, large-scale projects are implemented to promote the exchange and production of goods. Still, smaller-scale interventions are also carried out primarily to protect assets from extremes such as floods or droughts. Environmentally oriented interventions are carried out only if they do not limit growth or are functional for development, e.g., tourism development. Environmental impacts and adaptation measures rely on technology, possibly using grey infrastructure to ensure growth if deemed more convenient and suitable.

*Table 5 Danube SSPs pathways elements. Adapted and extended from (O'Neill et al., 2014). * quantitative data available else, qualitative. Percentages are meant as annual increases.*

Category	Scenario element	SSP1	SSP3	SSP5
Demographics	Population*	Figure 35	Figure 35	Figure 35
	Urbanisation (rural vs. urban population) *	Figure 35	Figure 35	Figure 35
Human development	Environmental awareness	High	Low	Med
	Societal participation	High	High	Med
Economy & lifestyle economic model	GDP*	Figure 14	Figure 14	Figure 14
	Trade liberalisation	Med	Low	High
	Intervention mode	Green, large, and small infrastructures	Grey local infrastructures	Large green and grey infrastructures
Consumption and demand	Cultivated area, irrigation share and crop type	Figure 16	Figure 16	Figure 16
	Domestic and industrial demand	Figure 35 and Figure 14	Figure 35 and Figure 14	Figure 35 and Figure 14
	Energy production and consumption	Figure 35 and Figure 14	Figure 35 and Figure 14	Figure 35 and Figure 14
Cost and prices	Potential operational cost in the agricultural sector	High	Low	Med
	Relative prices for agricultural products	High	Med	Low
	Relative prices for natural resources (e.g., water, fertilisers)	High	Med	Low
Policies and institutions	Political stability	High	Low	High
	Multilevel cooperation	High	Low	High
	Institutional participation	High	Low	Low
	Socio-environmental focus of agricultural policies	High	Low	Low
	Implementation of adaptation measures	Med	Low	High
	Decision-making context (i.e., transnational cooperation)	Cooperative	Non-cooperative	Cooperative
Technology	Technology development (incl. agriculture) *	1.1%	0.6%	1.3%
	Energy sector technological change *	1.1%	0.6%	1.3%
	Energy sector structural change *	40 years	None	30 years
	Manufacturing sector technological change *	1.1%	0.6%	1.3%
	Manufacturing sector structural change *	Yes	Yes	Yes
	Domestic sector technological change *	1.1%	0.6%	1.3%
	Domestic sector structural change *	20% until 2050	None	30% until 2050
Environment & natural resources	Depletion of resources	Low	High	Med
	Efficiency of resources use	High	Low	High
	Land use change	Strong regulation	Deforestation allowed	Some regulation
	Protected areas	Fully enforced	Limited enforcement	Fair enforcement
	Protection of ecosystem functionality	High	Low	Med

Table 6 Climate change expected impacts (adapted from ICPDR, 2018*).*

Impact type	**Impact class**	**Impact**
Climatic		Air temperature
		Precipitation
		Extreme weather events
Water-related	Extremes	Droughts, low flow and water scarcity
		Flood
		Flash flood
	Water availability	Runoff
		Snow and ice storage
		Groundwater
		Evaporation
	Water quality	Water temperature
		Water quality
	Water and land use	Water supply
		Water demand
		Agriculture
		Irrigation
		Navigation
		Hydropower
		Thermal electricity production
		Forestry
	Ecology	Biodiversity
		Ecosystems
		Soil and erosion
		Limnology
		Marine coastal zones

Table 7 Example of impact, adaptation class and differentiation of adaptation measures depending on SSP. Adapted from: ICPDR, (2018*)*

Impact	Adaptation	SSP1 measures	SSP3 measures	SSP5 measures
Reduced water availability	Ecosystem-based	• Increase water retention by restoring wetlands and bogs/swamps. • Limit activities in the floodplain. • Renaturation of riparian areas and wetlands.		• Building of multipurpose large reservoirs.
	Behavioural and management	• Use of grey water. • Use of purified wastewater. • Implementation of highly efficient irrigation schemas.	• Implementation of low-efficiency irrigation schemas.	• Inter-basin water transfers. • Use of grey water. • Use of purified wastewater. • Implementation of efficient irrigation schemas.
	Technological	• Prevent water loss in distribution networks. • Collection of rainwater. • Efficient cooling of power stations. • Infrastructure upgrade.	• Building and use of existing dams and reservoirs to redistribute precipitation, snow, and ice melt between seasons by water storage	• Artificially recharge the groundwater. • Efficient cooling of power stations. • Infrastructure upgrade.
	Policy	• Strong restrictions on developing activities in water shortage areas. • Strong environmental limits on extraction.		• Restrictions on developing activities in water shortage areas. • Limits on extraction.

Jucar

The development of local narratives for the JRB relies on the activities done by the ADAPTAMED project (https://www.iiama.upv.es/adaptamed/sobre-adaptamed/) funded by the Ministry of Science and Innovation of the Spanish Government, which in turn was a continuation of the IMPADAPT project, funded by the same entity.

Local narratives methodology

The development of local narratives for the Jucar was done using a bottom-up approach, in particular through scenario building workshops based on the methodology developed by Rinaudo et al (2013), which was adapted to the JRB by Ortega-Reig et al (2018). The methodology followed relied on three pillars (Marcos-Garcia et al, 2023):

1. Expert interviews: round of interviews to identify the main drivers and trends of change in the agricultural sector at basin scale, as well as the associated uncertainty. In the case of the Jucar, eighteen semi-structured interviews were developed with experts in agriculture economics, irrigation technologies, environmental aspects and so on. These interviews were selected to balance the representation from the main agricultural zones of the Jucar.
2. Storytelling design: the main elements of the SSPs are adapted to the local context based on the responses to the interviews. For the Jucar, four storylines were developed: two for the Mancha Oriental (aligned with SSP3 and SSP5) and two for the lower Jucar (aligned with SSP3 and SSP5). These storylines are transformed into fictional news in local newspapers with future dates
3. Participative workshops involving local stakeholders: in the Jucar, as for the storytelling design, workshops need to take into account the different setups of the Mancha Oriental and the lower basin. During each workshop, the participants are divided into groups and each group works on a different storytelling to discuss on how plausible it is, to debate on their potential consequences at the local scale and to draw a cause-effect map on the identified aspects. Afterwards, both subgroups gather together and share their results and points of view.

La Tribuna
ALBACETE

Una agricultura competitiva frente a la escasez de agua

La ausencia de subvenciones ha obligado a reestructurar el patrón de cultivos
Preservar el nivel del acuífero es una premisa fundamental para los agricultores
La tecnología está ofreciendo soluciones ante los retos climáticos

Albacete, EFE. El calentamiento global está incrementando la presión sobre los recursos hídricos en el sistema Júcar, en línea con las previsiones pesimistas establecidas hace dos décadas. Sin duda alguna, la agricultura es el sector económico más severamente afectado por estos procesos climáticos.

En los últimos 20 años la región ha experimentado un aumento de 2° de las temperaturas medias estivales, que ha incrementado notablemente las necesidades hídricas de los cultivos. Las lluvias se han reducido un 20% y las entradas en Alarcón en un 40%, mientras que el acuífero de la Mancha Oriental ha disminuido su recarga notablemente. Sin embargo, los mecanismos de control de las superficies y cultivos regados establecidos por los usuarios y la administración han logrado mantener un equilibrio en los niveles del acuífero de la Mancha Oriental. Esta eficaz gestión colectiva de las aguas subterráneas ha beneficiado a los cultivos de menor exigencia hídrica, pero ha limitado la entrada de otros que podrían beneficiarse de la disminución de las heladas.

La liberalización de los mercados y el calentamiento global determinan la evolución de la agricultura

El papel desempeñado por la Directiva Marco del Agua ha sido clave en la última década, al imponer la preminencia de los usos ambientales sobre los aprovechamientos agrarios. La trasposición de la normativa ha condicionado la gestión del acuífero manchego, que ha superado las restricciones ambientales merced a la incorporación de tecnologías de ahorro.

En este sentido, el crecimiento de la inversión en I+D agrario está dando sus frutos en el campo manchego, y hace posible que muchas empresas superen los retos impuestos por el cambio climático con inversiones en tecnologías de ahorro y control del recurso en parcela, así como mediante las mejoras de las variedades.

El control del riego mediante drones se ha generalizado en la Mancha para ajustar las dosis en parcela.

Debido al éxito económico de las economías industrializadas y emergentes, hay cada vez más fe en los mercados competitivos, la innovación y la participación social como camino hacia el desarrollo sostenible. Los mercados globales están cada vez más integrados, con intervenciones centradas en el mantenimiento de la competencia y la eliminación de las barreras. Estas políticas de liberalización de los mercados agrarios y la profundización de la PAC postproductivista –enfocada en la defensa del medio natural y el desarrollo rural– han hecho desaparecer las subvenciones a los cultivos. Tan sólo persisten algunas ayudas, bastante limitadas, a explotaciones en espacios naturales protegidos y al mantenimiento de determinados hábitats y especies. Las explotaciones de mayores dimensiones y más tecnificadas son las que mejor se han adaptado a este contexto de libre mercado.

Levante
EL MERCANTIL VALENCIANO
Viernes, 21 de Octubre de 2030

Aumenta la rentabilidad agrícola en la cuenca del Júcar
por tercer año consecutivo

La clave del éxito se asienta en la reducción en el cultivo de frutales tradicionales, como los cítricos y caquis

Los grandes damnificados han sido las pequeñas explotaciones, que sobreviven gracias a las ayudas vinculadas a la protección del medio ambiente

21. Octubre 2030. Albalat de la Ribera

Por tercer año consecutivo, y a pesar de la persistente sequía, la cuenca del Júcar aumenta su rentabilidad agrícola gracias a la presencia de sus principales productos en el mercado internacional.

Tras una década de reformas estructurales para favorecer la liberalización del comercio, las empresas valencianas confirman el incremento de las exportaciones de almendra, granada y aguacate.

El sector ha sabido restructurarse a nivel local, y las pequeñas explotaciones en crisis durante la década de los años 2010-2020, han dado lugar a grandes empresas, como Valencia Almond, líder nacional en la producción de almendras, así como cooperativas de medianos y grandes agricultores competitivas a nivel internacional. Del mismo modo, cultivos tropicales antes exóticos, como el aguacate, presentan buenas perspectivas de futuro gracias a su fuerte valor añadido.

El calentamiento global determina la evolución de la agricultura

El calentamiento global, con un incremento de 2ºC en la temperatura, ha incidido en una mayor demanda de riego, que se ha visto a su vez afectada por la disminución de las lluvias en torno a 20%.

Por este motivo, se redujo el cultivo de frutales vinculados históricamente a la agricultura valenciana, como los cítricos y caquis, que también se vieron afectados durante la última década por la disminución de horas frío.

"Arròs de València", marca de calidad

La denominación de origen 'Arròs de València' se encuentra bien posicionada en el mercado gracias a su singular homogeneidad y calidad apreciada en el mercado nacional. Además, este cultivo disfruta de las pocas ayudas que aún existen, y que se justifican por el carácter medioambiental en el entorno de l'Albufera.

La alta competitividad, la innovación y la participación social han promovido un desarrollo rápido de la tecnología y de la trasferencia de la tecnología al sector agrario.

Este factor, unido a la reorganización del sector, ha permitido disminuir los costes de producción para equipararse al mercado exterior.

Almendros en la Acequia Real del Júcar en Alberic.

Estas estrategias adoptadas han tenido sus damnificado
explotaciones que aún sobreviven gracias a las ayudas, cad
a la protección del medio ambiente y diversificación de la

Nuevos retos

Con la actual sequía y los caudales de entrada a Alarcón
reducciones de alrededor de un 40%, el futuro de la agric
desafíos. A pesar de los avances en el ámbito biotecnoló
como el progreso en la tecnología e ingeniería a
organizaciones se sigue denunciando a destaca la ausenci
los problemas ambientales globales.

Figure 52 Fictional press news developed for the Jucar River participative workshops. Source: Ortega-Reig et al (2018)

Baseline scenarios (SO)

Two baseline scenarios were developed based on SSP3 and SSP5, labelled as ”protectionism” and “globalization” respectively. Their main drivers, both in the Mancha Oriental and the lower Jucar, are shown in Table 8. Their consideration of baseline scenario refers to the absence of any intervention from the CHJ apart from the measures already in place (e.g. use of remote sensing to control groundwater use in the Mancha Oriental area, irrigation modernization in the lower basin).

Table 8 Main drivers of socioeconomic scenarios for the Jucar River Basin. Source: Marcos-Garcia et al (2023)

		Protectionism (SSP3)		**Globalization (SSP5)**	
		Mancha Oriental	Lower Jucar	Mancha Oriental	Lower Jucar
Crop patterns	General trend	Promotion of seasonal and local products and introduction of new varieties	Diversification and, when possible, use of less water-demanding varieties among each crop type	Crops that benefit from higher temperatures and CO2 concentrations	No distinct changes on the current crops, area of each crop could vary
	Expected decrease	Cereal, corn	Citrus, fruits	Cereal, corn	Rice (outside of protected areas)
	Expected increase	Green vegetables, agro-industrial and high-value woody crops	Kaki, almond, avocado, pomegrenade and other tropical crops	Less water-demanding crops (short cycle crops, woody crops), eco-friendly agriculture (subsidized)	Kaki, citrus trees and other high-value crops
Technological development		Smart agriculture, humidity control, remote sensing support, leaf phenology	Correction of negative impacts of drip irrigation	Rising control of water demands, use of renewable energy for pumping	Technification of production systems
Consequences		Increase of water conflicts, costs and land property concentration	Increase of water conflicts, changes in the agricultural sector	Increase of water conflicts due to water scarcity, increase or decrease of groundwater use depending on the interface between control and cheaper pumping due to solar energy	Potential aquifer overexploitation, poorer groundwater quality, rise of water costs, land abandonment and increase of social and territorial conflicts

Development of adaptation pathways

Given that the JRB is already in a tight equilibrium between resources and demands, options to improve its sustainability have been already put on the table by the JRBMP. These options would not essentially differ from the ones required to adapt to climate change impacts, although their particular setup might need to be adapted (e.g. wastewater reuse would need to be higher than the one anticipated in the JRBMP or would need to be combined with other measures). During the scenario building workshops celebrated by the ADAPTAMED and IMPADAPT projects, stakeholders were asked about their evaluation of the impact (Figure 53) and suitability (Figure 54) of several adaptation options.

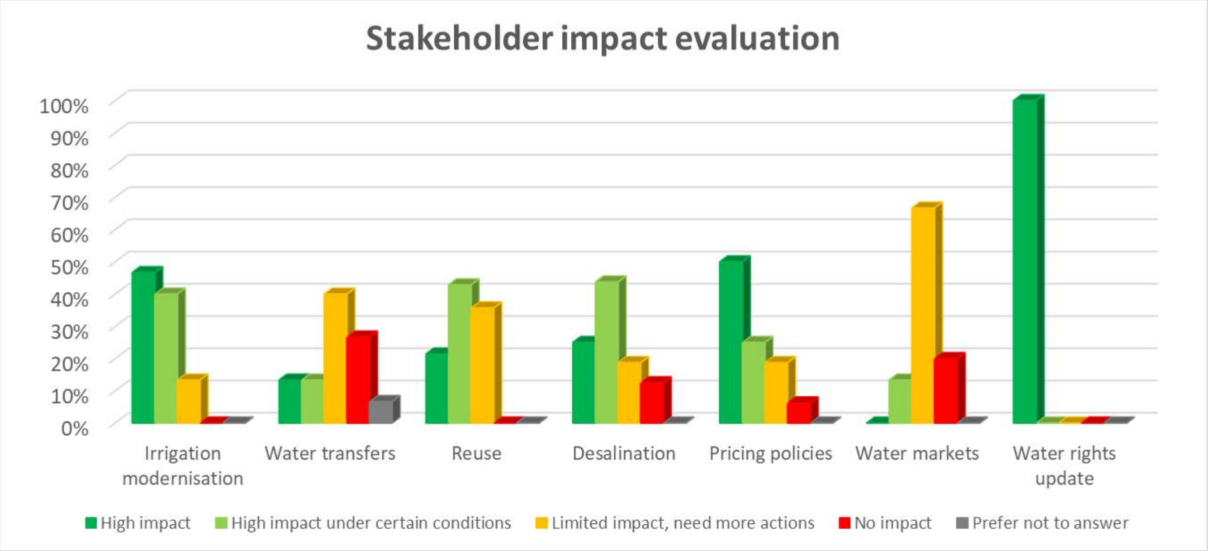


Figure 53 Stakeholder impact evaluation on adaptation measures in the Jucar River Basin. Source: Modified from Marcos-Garcia et al (2023)

The adaptation option considered as the one with the highest impact against climate change would be an update of the water rights, which control how much water resources can each user access, followed by the irrigation modernisation and the adoption of pricing policies. Both wastewater reuse and desalination were evaluated similarly but below the previous ones, with water transfers and water markets being considered the ones with the lowest impact. It should be pointed out that this evaluation was made solely in terms of how impactful each measure would be, without considering how easy or difficult its implementation would be.

The suitability of these measures asked stakeholders to rank how adequate would they be from their point of view, combining both their impact with the difficulties of its practical implementation. The ranking among options varied, with irrigation modernization and water rights considered as the most suitable option, followed by pricing policies, wastewater reuse and desalination. Both water transfers and water markets were given marks below 5 (on a scale from 0 to 10).

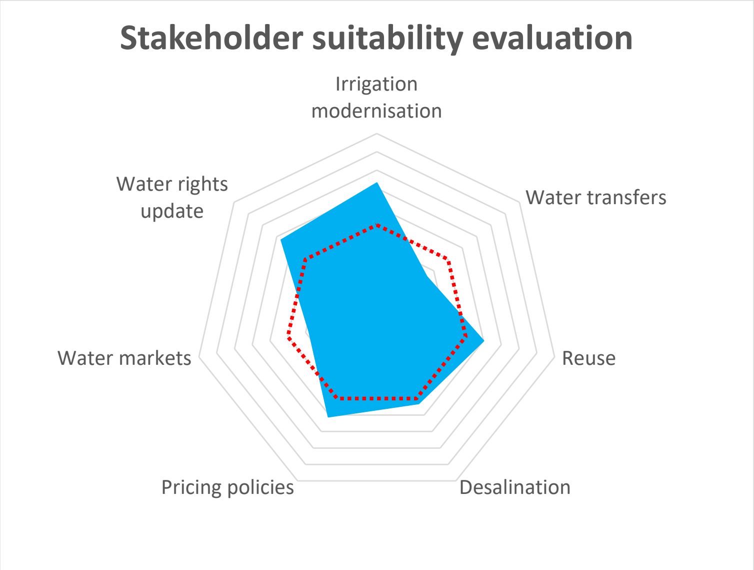


Figure 54 Stakeholder suitability evaluation on adaptation measures in the Jucar River Basin. Source: Modified from Marcos-Garcia et al (2023)

These adaptation measures would not be tailored to a specific SSP by definition, although their features might depend on them. For example, desalination might have a quite different cost depending on the cost of energy and possibility of using solar panels, which would be refer to certain SSP(s).

Jucar river local narratives

These narratives have been extracted from Ortega-Reig et al (2018) and refer to the drivers of Table 8.

Mancha Oriental: protectionism (SSP3)

This scenario has a high degree of confidence in the adaptive capacity of farmers, without expecting catastrophic situations. Its impact on productions would be limited, and a future pattern of high-value crops would be expected such as horticultural, agro-industrial or woody crops; disappearing corn and other extensive crops. The trend would be to produce seasonal and local products, and biotechnological advances will allow new adapted varieties to be cultivated.

Improvements in water use efficiency would continue to occur in the future. The use of new technologies would be essential, including precision agriculture, humidity control in the plot, remote sensing combined with the study of foliar phenology and agriculture of conservation. An increase in production costs would be expected due to an increase in fertilizers (phosphorus), safety problems within the agricultural sector (which will make surveillance necessary) and the appearance of new pests. This increase would be closely conditioned by the evolution that may occur on energy policy and prices. However, cost rises could be compensated if liberalization of the energy market occurs or self-consumption of photovoltaic energy grows. In this scenario, a concentration of ownership might occur favouring large agri-food corporations, and a growing difficulty for the viability of small farms, which must improve their size and use services of specialized companies to reduce production costs. A worsening of territorial conflicts over water would be expected.

Mancha Oriental: globalization (SSP5)

This scenario will see crops with lower water requirements, facilitated by the high technification of agriculture in the zone, and crops that would adapt better to the new climate conditions that would be expected. Adaptation to water scarcity would be carried out through the cultivation of crops with a very short cycle (vegetables) or long cycle (woody plants), despite the fact that the introduction of woody crops is discouraged by its long unproductive initial period. Cultivated areas of cereals are expected to decrease and corn is expected to disappear. Research would be essential to provide new crop varieties and enable deficit irrigation. Environmental subsidies and organic farming would grow under this scenario.

The increasing control over water demands of users, favoured by the use of new technologies, would reduce groundwater pumping. However, the existence of renewable energies with zero marginal cost could favour extractions. The importance of the Common Agricultural Policy (CAP) would be crucial to sustain the sector in the future. With or without the CAP, a reduction in the number of small farmers would be expected, associated with the depopulation of rural centres, which would force the employment of more foreign labour to cover unskilled agricultural work. Likewise, social conflicts (interregional) would increase due to water scarcity and the use of surface water in the lower basin.

Lower basin: protectionism (SSP3)

In this scenario, climate change would produce greater diversification of crops and the introduction of varieties with lower water requirements. A decline in orange and stone fruit trees is foreseeable, but a notable increase in the persimmon area would be expected due to the fact that it is grouped in a designation of origin, and because it adequately withstands climatic fluctuations. In addition, moderate increases would be found in almond cultivation, and slight increases in the area of pomegranate and avocado; together with the appearance of new tropical crops such as papaya.

The development of water-saving technologies, such as drip irrigation, would be essential to adapt to water scarcity. Drip irrigation, despite its drawbacks, would prosper because it provides comfort to farmers, and it is advantageous when water costs are high. However, this technology would have a negative impact on l'Albufera, because the potential savings generated by drip irrigation would reduce the infiltration and runoff of irrigation surpluses, decreasing the inflow to this protected wetland. Production costs would increase due to rising fees, greater use of groundwater, new pests and diseases, and the increase in salinity of the soils. This increase in irrigation and production costs would make many farms unprofitable and force its owners to abandon them. This would cause a progressive concentration of ownership of land and water and changes in the structure of the marketing channels for the productions, which will focus on a few hands. These changes in the structure of the sector, together with the growth demographic and the scarcity of resources, are facts that would stimulate an increase in conflicts over water use.

Lower basin: globalization (SSP5)

In this scenario, rice cultivation would be challenging due to the shifts in expected water availability. However, since its surface is protected by environmental legislation, only rice crops outside the protected areas (less than 20% of the total) would be at risk of disappearance. Persimmon would continue to grow and present an important surface area. The orientation of productions would shift towards quality or gourmet markets. However, this scenario would lead to greater diversification, favouring crops more tolerant to scarcity such as lemon or pomegranate. Research would be a key factor for providing support in crop changes and the provision of less water-demanding varieties. The decrease in available resources would promote an increase in water use efficiency, which would lead to more technical systems. On the other hand, the overexploitation of aquifers would increase, having negative effects on water quality, and chloride buildup could create problems in persimmon and orange crops.

Increases in water and production costs would cause an accentuation of the current problems of land abandonment. This would promote the concentration of ownership, something that has already begun to happen. The future viability of funding policies of drip irrigation technologies would be challenged. In this scenario, changes would also occur in the structure of the marketing channels, favouring multinational companies. However, crop prices would be higher than today, because there would be a more specialized market for a quality product. Finally, scarcity and worsening water quality would cause a rebound of social and territorial conflicts over water.

Mekong

Local narratives methodology

Scenarios for MDV are inherited from regional planning studies. The scenarios are evaluated to qualitatively present their specific benefits in realizing the vision and set goals compared to future expectations when implementing investment projects. A panel of stakeholders and experts scored these scenarios, based on expected benefits across 29 development criteria presented in Table 9, Table 10 and Table 11. Note that, based on the assessment and perception of stakeholders and experts about their relative importance, these 29 criteria are reformulated into 18 development goals in the regional planning.

Baseline scenarios (SO)

The Mekong Delta is basically a purely agricultural region. The agricultural structure is relatively similar in all regions, favouring rice cultivation to ensure food security. Areas less favourable for rice growing, such as coastal areas, use large irrigation projects to create conditions for rice growing. Recently there has been a large-scale shift towards reducing rice and increasing aquaculture, fruits and vegetables, but mainly due to local initiatives, based on calculations of immediate and local benefits.

The region is divided into 13 provinces and cities, each province has a fairly similar program, so competition, which province surrounds the centre of that province, rarely creates regional linkage strategies.

This scenario focuses on economic growth - "Optimizing GDP growth, mainly based on the current economic activity structure, growth but at the expense of natural capital, investment in the environment and society such as previous period, therefore the negative impacts of environmental pollution, ecological degradation, resource depletion, etc. continue to increase".

Development of adaptation scenarios

The development scenario focuses on minimizing the limitations of the S0 scenario with regional integration strategies. In particular, the development plan in the Mekong Delta region's infrastructure plan aims to build an autonomous region, prioritizing agricultural development based on 6 ecological regions and a system of centralized agricultural centres. The Mekong Delta region has enhanced international connectivity through the Trans-Asia transport corridor with Cambodia. For intra-regional links, Ca Mau - Can Tho – City, Ho Chi Minh City is the axis of regional development and has a regional centre located in the city Can Tho. For urban and rural systems, the development structure remains unchanged, continuing to encourage population accumulation in the central region and dispersed development of small urban areas in coastal and border areas. For the technical infrastructure system, the planning orients the integration of the water-road transportation system and offshore construction of deep-water airports/ports on artificial islands. The direction of environmental protection to prevent and combat natural disasters and respond to climate change is integrated with solutions such as planning surface water areas to serve flood drainage and drought prevention to enhance the resilience of the entire region. preventing saltwater intrusion, living with floods, changing crop and livestock structure (combining rice and shrimp farming), strengthening natural disaster warning capacity, meteorological and climate forecasting.

Table 9: Description of natural resources and environmental sector criteria used in evaluating DAs (according to the integrated master plan for the Mekong Delta region, 2022)

(i)	**Natural resources and environment (NR) sector**
NR 1	Water resources management and irrigation infrastructure have the ability to adapt to the impacts of climate change, interventions in the upstream of the basin affect flow regime and sediment load and interventions in the Mekong Delta cause subsidence and landslides. mudslide. Adaptation is based on the motto "Living with fresh, brackish and salt water" and "Respecting natural laws".
NR 2	View water as a scarce resource: determine priorities for functions, based on policies on effective use of freshwater resources for urban and industrial purposes. Limit groundwater use in agriculture and aquaculture through alternative sustainable practices (see previous criteria section).
NR 3	Create freshwater storage/retention areas for the dry season and maintain wetlands for emergency water storage if extreme floods occur. Reduce the level of risk of infrastructure, communities, people's assets and businesses from post-extreme weather events such as storms, floods, sea level rise due to storms, drought, and saltwater intrusion.
NR 4	Issue regulations to prevent excessive sand exploitation; Find affordable solutions to meet the needs of the industrial, construction and landfill sectors.
NR 5	Limit conversion of land use purposes to prevent the use of fertile land for functions other than agriculture, for example: urban areas and industrial parks.
NR 6	With the increasingly attractive economic benefits of renewable energy sources, adjusting policies to limit coal power plants in the Mekong Delta towards a "Development roadmap based on renewable energy". Support the construction of onshore and offshore wind power plants (nearshore and offshore) and large-scale solar power plants in suitable locations, connected to transmission lines and small-scale systems distributed throughout the region, through demonstrating financially feasible models and training local officials.
NR 7	Promote natural flow regimes and connect wetlands to surface waters without creating any barriers that impede nutrient circulation and animal movement. Waste management causes environmental pollution and affects human health. Develop an integrated coastal management program, linking water resources management, responding to natural disaster risks, and protecting the coast (especially mangrove forests to promote biodiversity conservation with businesses). industry (inland and coastal areas) and local people, to encourage optimization of financial and natural resources.
NR 8	Increase awareness about environmental pollution, plastic waste and ecological imbalance. Minimize and control solid waste and wastewater before being discharged into the environment by installing waste treatment plants and strictly handling polluting facilities.
NR 9	Consolidate and strengthen cross-border coordination in biodiversity conservation, natural resource management and environmental pollution through the Mekong River Commission. Establish ecological corridors and protected areas, conserve and enhance terrestrial and aquatic ecosystems and consider these areas as valuable assets in conserving biodiversity, protecting coasts and mitigate the impacts of climate change, changes in flow regimes and rising sea levels, especially mangrove forests, melaleuca forests and special-use forests that are being degraded in wetlands throughout the delta.
NR 10	Apply the green growth model by prioritizing investment in projects that emit little greenhouse gases and do not harm or pollute the environment.

Particularly in the fields of natural disaster prevention and irrigation, scenarios related to water infrastructure development, water resources and climate change have been developed.

Mekong Delta local narratives

Local narratives are established as the basis for building and selecting priority development scenarios. Three development alternatives (DAs) have been developed, each focusing mainly on one of three pillars: economic ('profit'), natural resources nature ('earth') or social development ('people') with the remaining two pillars remaining at acceptable minimum levels. Based on the analysis of strengths, weaknesses, opportunities, and expected challenges that may occur if one of those three directions is implemented, consult with relevant stakeholders (for example, 13 provinces/city in the Mekong Delta and relevant Ministries/agencies) through the process of jointly scoring each of the 29 development criteria, a priority scenario was selected.

Table 10 Description of social development sector criteria used in evaluating DAs (according to the integrated master plan for the Mekong Delta region, 2022)

(ii)	**Social development sector**
SC 1	Promote equality and inclusion through appropriate policy solutions for ethnic minorities and people with disabilities in health and education services.
SC 2	Reducing the gender gap through bold action in education and training, and leadership in the public sector. Targeting vulnerable groups (e.g., the elderly, the homeless, informal workers in urban areas) with specific supports and through the creation of demanding employment opportunities low skills, targeting the poor.
SC 3	Create safety and adaptability for people living in the Mekong Delta region. Ready to adapt in coastal areas: forecasting and adapting to inevitable trends such as sea level rise, climate change and the impact of development activities in the upper Mekong River. Develop rural residential areas, especially in coastal areas and buffer zones, into small towns to ensure safety and increase adaptation to climate change, and develop evacuation plans when natural disasters occur.
SC 4	Preserve the rich landscape and cultural values of the region.
SC 5	Characteristics of the sub-region, including green growth.
SC 6	Minimize urban fragmentation, develop inter-urban linkages, enhance urban quality and resilience, and increase economic density to increase land use efficiency (for example, in industrial zones) and promoting specialization in the provision of business services and promoting equity in access to services, as well as labor market development.
SC 7	Enhance connectivity between cities and transport networks and service delivery points and plan urbanization strategically rather than relying on centralized finance.
SC 8	Enhance connectivity between urban areas and rural residential areas

DA1: Priority on economic development

DA1 focuses on both speed and quality of economic growth - Maximizing GDP growth, mainly based on taking advantage of immediate opportunities: making more use of natural resources and human resources. Regarding agriculture, continuing to increase crops, adding fertilizers, chemicals, pesticides, and super-intensive farming. Regarding service tourism, exploiting landscapes and natural areas into tourism. Regarding industry, taking advantage of spillover effects from the city area. Ho Chi Minh City for rapid economic development, but low value due to lack of preparation in technology, human resources, and location. Accepting investment projects that do not ensure sustainable quality such as thermal power, heavy industry with old technology, etc. Sociocultural issues ensure a minimum level of social service provision. Regarding environmental ecology, controlling polluting activities and sanction violations, keeping damage levels as low as possible. This orientation may lead to continued growth, even faster in the short term, which is the planning period, but will certainly lead to long-term consequences, in all three aspects of ecology, culture, and economics.

Table 11 Description of the economic sector criteria used in evaluating DAs (according to the integrated master plan for the Mekong Delta region, 2022)

(iii)	**Economic sector: (Developing a sustainable & modern agricultural economic structure, modern industry, logistic & service)**
E 1	Increase modern agricultural production areas with high-value crops; Priority order (aquaculture - fruit trees - rice) based on suitable hydrological and agro-ecological zones; At the same time, the rice growing area by 2030 will decrease. Practical experience in sustainable development in agriculture, especially in biosecurity, multi-cropping in aquaculture, as well as organic agriculture and ecological agriculture (combining agriculture with tourism).
E 2	Promote fisheries and aquaculture in suitable areas, including suitable soil/water conditions, sustainability and market access.
E 3	Domestic, regional and global integrated value chain for agricultural products (rice, fruits, vegetables) and seafood, providing high quality, safe and certified/branded goods, Based on high-quality key agricultural products and exploiting logistics, marketing, research and in-depth training capabilities.
E 4	Increase the rate of domestic value addition in existing light industries (especially assembly) through more efficient services, easier access to capital, reducing the role of state-owned enterprises and reforming improve logistics services.
E 5	Increase access to information, input materials (fertilizers and other materials), high technology and mechanized farming practices, increase vertical integration, land consolidation and land transfer. Close connection with processing facilities and markets (links with industry, logistics centers, certifications, trade). Prepare to realize digital opportunities in areas such as e-commerce, AI, life sciences and social analytics.
E 6	Enhance connectivity between cities and markets and between urban and rural areas through reducing transport times and logistics costs.
E 7	Integrate integrated logistics and transportation platforms across all modes and geographies, with an emphasis on major road and highway corridors to reduce the burden of road transport costs.
E 8	Support the development of value chains along regional centers and reduce logistics costs (concentration of goods) and create economic density with economic corridors associated with regional centers, industrial clusters and inner regions. agricultural geography.
E 9	Enhance trade with neighboring regions (Cambodia and Ho Chi Minh City) through investment in logistics hubs, brands and industry associations. Develop capacity to support financial, ICT and other services – including in the logistics, trade and finance sectors – in key regional hubs (e.g., Can Tho and other cities) to increase income and increase consumption.
E 10	Develop diverse land and sea tourism destinations (for example, Phu Quoc, Con Dao and other areas) in a sustainable manner, based on strict management of natural landscapes, associated with the community local communities, creating employment opportunities for the poor and protecting social and cultural heritage.
E 11	Strengthen education and professional training for both public and private sectors in provinces, districts, and cities.

DA2: Priority on environment and natural resources protection

The main concern of DA2 is to protect natural resources and the environment by developing the economy in a green direction, increasing investment in environmental protection, and investing in restoring natural resources and ecology. This ultimately leads to increasing prices value based on a sustainable foundation. Identifying the Mekong Delta as a national ecological garden, restoring a rich biosphere at international level with high value in landscape, ecology and environment. The most important criterion for choosing development activities is to ensure environmental sustainability. This orientation is of course more long-term in nature, however, it will be difficult to implement in the short term, when the people as well as the government are not aware enough and want to pursue immediate benefits.

DA3: Priority on local social development

DA3 focuses on social development - Optimizing social development and economic development towards fairness in the long term by investing in human resources and social culture. Promoting the diversity of local identities and socio-cultural strengths. Accepting that economic growth may be below average, but people have happy lives, less suffering from injustice and polluted environment. The most important criterion for choosing development activities is the benefits/impacts to people in the region. This is also a long-term orientation, however in the short term it will be difficult to be feasible if only focusing on this one orientation.

In reality, there will never be an absolute orientation towards any plan, but instead there will be a combination of solutions in all three areas of economics, social culture, and environment. The three aforementioned options only show what the consequences will be if one were to focus significantly on investing in one of the three directions. After analysing the three options, the consultant determines which development criteria are the core if you want to promote development in each pillar, summarizing 29 main criteria or solutions that can be implemented to promote development of the 3 pillars in the MDV.

At the consultation workshop in the Mekong Delta, relevant parties were also consulted on 3 development options, with 29 specific public development criteria and scoring of the criteria. The consultation results are displayed in Figure 55.

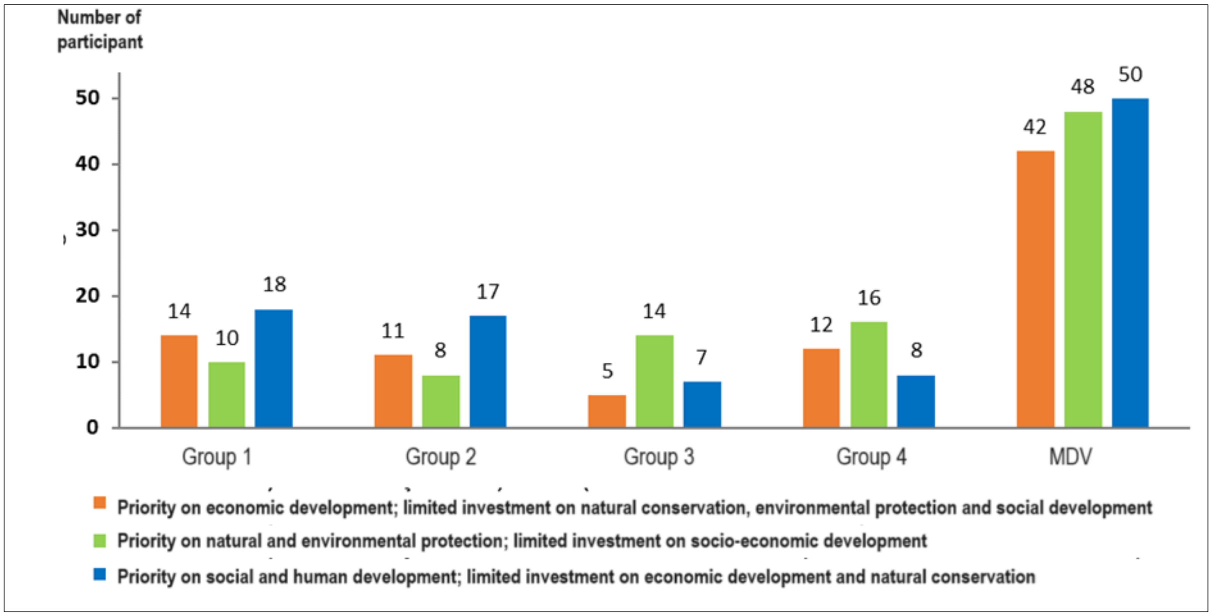


Figure 55 Priority is given to development orientation among stakeholders' groups.

The three Mekong Delta narratives are not explicitly based on global SSPs and are therefore named differently. The choice originates from the higher relevance these narratives bear for the local MDV communities. Despite this, many elements of the MDV narratives resonate with the elements of the global ones, therefore the following correspondences can be loosely compared.

- DA1-Priority on economic development and SSP5
- DA2- Priority on environment and natural resources protection and SSP1

- DA3- Priority on local social development and SSP3

For each local narrative a corresponding development pathway is designed, implementing adaptation measures aligned with the SSP from where the local narrative stems. These adaptation pathways will be created based on stakeholder consultations, ensuring that the chosen measures effectively address stakeholders' objectives. The set of actions that can be implemented is defined through an ongoing iterative process involving exchanges between researchers and stakeholders. These actions encompass the entire Mekong Basin since upstream interventions can significantly impact the Delta region. The proposed interventions are utilized to establish the modelling inputs and assumptions required for evaluating the SOS under the scenario of the local narrative considered. The measures are adapted considering what the models are capable of simulating and their relevance in achieving stakeholders' goals. These interventions are then assigned to specific SSPs based on the scale of the intervention, ensuring alignment between the local narratives they generate and the corresponding global SSPs from which they should be derived.

For the Mekong River Basin case study, these measures are summarized in Table 12, detailing their applicability to either the Delta or Upper region of the river, their association with specific local narratives, and their alignment with corresponding global SSPs.

It is important to note that the list of adaptation measures is still evolving and will undergo further refinement through stakeholder engagement. This process aims to validate the significance of these measures in relation to stakeholders' interests and to identify new measures that may impact the final evaluation of the SOS.

Table 12 Examples of considered adaptation measures in the Mekong River Basin

Measures	Area of Interest	Local Narrative	Global SSP
Enhancing cooperation among different countries and implementing shared water and sediment release policies	Upper Mekong	DA2-DA3	SSP1
Considering different dam development portfolios	Upper Mekong	DA1-DA2-DA3	SSP3 - SSP5
Equipping future dams with specific infrastructures for sediment and fish passages	Upper Mekong	DA2 – DA3	SSP1
Retrofitting existing dams with dedicated equipment for sediment and fish passages	Upper Mekong	DA2 – DA3	SSP5
Demolishing obsolete and highly impactful dams to restore natural flow regime	Upper Mekong	DA2	SSP5
Implementing different irrigation schemes	Upper Mekong - Mekong Delta	DA3	SSP3
Upgrading 26 existing irrigation systems **to enhance water management efficiency**	Mekong Delta	DA3-DA1	SSP3
Construction of additional gates on the main river channels **to regulate water flow and manage salinity intrusion**	Mekong Delta	DA1-DA3	SSP3-SSP5

Rhine

Local narratives methodology

The following paragraphs describe the broad socio-economic context of the proposed local narratives. The global SSP-RCP code name composes the title of the local narratives, where names are derived from the Dutch Delta Scenarios (Wolters et al. 2018) that have outlined different future pathways. The scope of these narratives is to provide a descriptive picture of possible futures, thus conveying the qualitative elements of the local SSPs in verbal form. They have been derived from the global SSP narratives, adapting some of their tenets to the Rhine context.

We have based the local narratives on the Dutch Delta Scenarios that comprises of four different pathways, named “Pressure”, “Steam”, “Rest”, “Warm” (Figure 56). These pathways are the result of stakeholder engagement and expert knowledge in the Netherlands and with the international partners. They aim to combine local knowledge in different disciplines with the expected climate change along two axis. The socio-economic development levels and the climatic change impact.

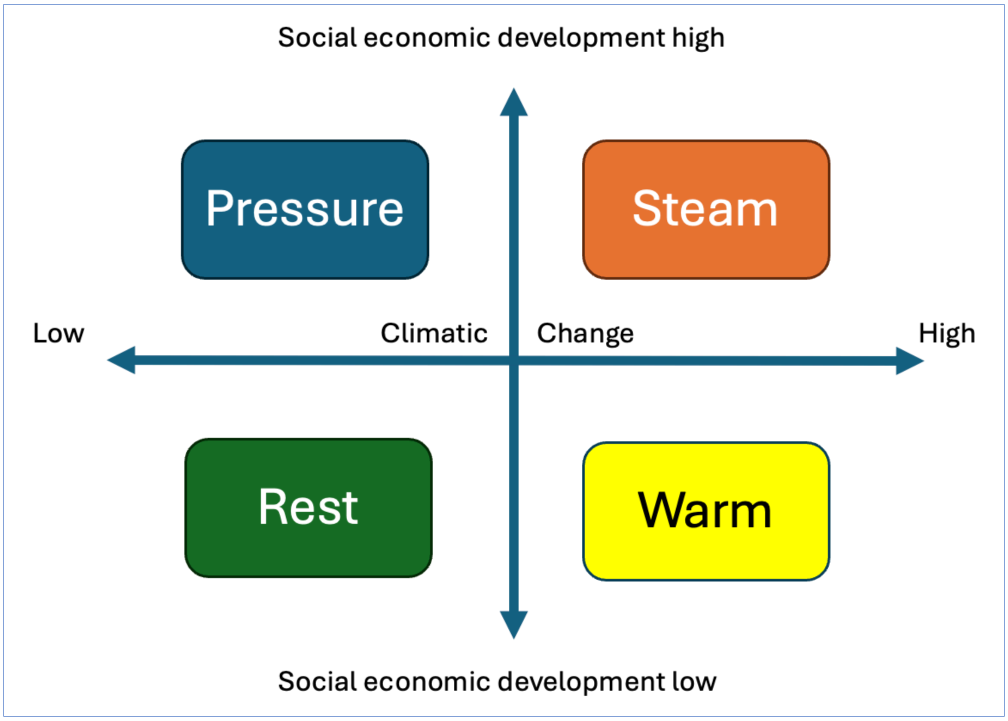


Figure 56 Dutch Delta Scenarios future pathways.

These local narratives can also be linked to the global narratives and SSP-RCP framework, where we link SSP1- “Rest”, SSP3-“Warm”, SSP5-“Steam”, to make this connection.

The Rest pathway (SSP1)

In the Rest pathway, modest economic growth and a slight decline in the number of inhabitants go hand in hand with slow climate change. The low economic growth entails relatively limited greenhouse gas emissions. Because the additional efforts that need to be made are limited, it is relatively easy to make and comply with global climate agreements. These trends promote the development of new innovations focused on energy and climate technology, which in turn enables transitions to sustainable regional economies. As a result, the temperature increase in this scenario remains limited.

Table 13 Examples of adaptation measures for the Rhine basin consistent with the local pathways.

Impact	Adaptation	SSP1 measures	SSP3 measures	SSP5 measures
Reduced water availability	Ecosystem-based	• Increase water retention by restoring wetlands and bogs/swamps. • Limit activities in the floodplain.		• Limit activities in the floodplain.
	Behavioural and management	• Reuse of treated waste water • Increase irrigation efficiency • Optimalization of reservoir operation • Limits on groundwater abstractions • Reduction in drinking water demand	• Large-scale implementation of low-efficiency irrigation schemas. • Optimalization of reservoir operation	• Reuse of waste water • Implementation of efficient irrigation schemas. • Optimalization of reservoir operation
	Technological	• Artificially recharge the groundwater. • Collection of rainwater. • Infrastructure upgrade.	• Building and use of existing dams and reservoirs to redistribute precipitation, snow, and ice melt between seasons by water storage	• Artificially recharge the groundwater. • Infrastructure upgrade.
	Policy	• Strong restrictions on developing activities in water shortage areas. • Strong environmental limits on extraction.		• Restrictions on developing activities in water shortage areas. • Limits on extraction.

The Warm pathway (SSP3)

In the Warm scenario, modest economic growth and a decline in population size go hand in hand with high global population growth and rapid climate change. No global climate agreements are being made and little is being invested in new energy technology worldwide. As a result, fossil fuels continue to play a dominant role and no CO2 is captured and stored, so CO2 emissions are high. The Warm pathway also leads to a limited focus on (nature-based) solutions to reduce increasing water demand and mostly focusses on increasing (unsustainable) water use.

The Steam pathway (SSP5)

In the Steam pathway, high global economic growth and strong population growth go hand in hand with strong and rapid climate change. The economy and population size are also growing rapidly in the Rhine River Basin. This puts additional pressures on the basin and will lead to strong socio-economic changes as well as climate change impacts. In the Steam pathway there is more focus on sustainable solutions to reduce the water demand.

From the different pathways different adaptation strategies have been identified and provided in Table 13. They are closely linked to the challenges the Rhine basin will face with climate change and the level of socio-economic development that goes hand in hand with the different pathways.

5. Combining global scenarios and local narratives

This chapter explains how scenario-narratives' climate change impacts, adaptation and mitigation measures of the different pathways will be modelled.

Danube

The pathways hydrological simulations for the DB will be generated using the Community Water Model (CWatM), a process-based, state-of-the-art large-scale rainfall-runoff and channel routing water resources model (Burek et al. 2020). CWatM operates on a regular grid, with daily time steps (with sub-daily time steps for soil and river routing). CWatM is implemented as an open-source modular structured Python program and requires daily meteorological input encompassing precipitation, surface air temperature, relative humidity, wind speed, surface air pressure, and incoming longwave and shortwave radiation. This set of data is the output of Global Circulation Models (GCMs) used to compute the RCP scenarios. In the DB case study, the latest CMIP6 dataset (O'Neill et al., 2016) will be used. Out of the 50 GCMs ensemble used in the CMIP6, for the DB, the outputs of the following five will be used:

1. MRI-ESM2-0
2. GFDL-ESM4
3. UKESM1-0-LL
4. MPI-ESM1-2-LR
5. IPSL-CM6A-LR

Each local scenario will be run using its dataset of scenario elements with adaptations and once for each of the five GCM meteorological datasets. Therefore, for each local scenario, there will be five simulations, thus also allowing the estimation of uncertainty of results.

Besides the meteorological inputs, CWatM also requires data to quantify water supply and human water demand from different sectors (industry, domestic, and agriculture).

Explaining in detail all the processes replicated by CWatM goes beyond the scope of this document. It suffices to say that water demand is driven by quantitative pathways elements such as population, agricultural areas, crop types and GDP (see Table 14 for the full list). For example, population growth and distribution directly drive domestic water demand, while economic development influences industrial water demand. Similarly, the extent of crops and the share of irrigation shape the water demand for agriculture while also playing a role in the water cycle with crops' evapotranspiration.

In CWatM, the intensity of the water demand for agriculture, industry and civil consumption can be changed over time to reflect the technological changes. This feature is crucial in simulations aimed at climate change studies based on SSP-RCPs because the rates of technological change reflect the capacity of society to innovate and implement adaptation measures. These capacities vary depending on the SSP narrative; for example, the SSP5-8.5 "der Radetzky-Marsch" technological development will be fast while SSP3-7 "Dies Irae" will slow (see Table 5). Progression in technology leads to more efficient water use and, ultimately, lower water consumption.

Besides naturally occurring water stores and flows, such as rain, runoff, or lakes, CWatM also simulates artificial storage and water-transferring infrastructures, including reservoirs, groundwater pumping and irrigation canals. This capacity to mimic infrastructures and their efficiency is a key element in simulating adaptation measures for the scenarios, for example, by including more reservoirs or recycling grey water (see Table 7). By acting on water routing inputs such as channel sinuosity and planform topography, in CWatM, it is also possible to simulate natural water retention measures such as wetlands, a typical green solution contributing to water-reducing flood peaks and increasing low floods (Burek P. et al. 2012).

Table 14 Water demand pathways elements used in CWatM.

Water demand component	Pathway element
Industrial and civil (incl. livestock)	Population
	Urbanisation (rural vs. urban population)
	GDP
	Technological development
	Domestic and industrial demand (incl. livestock)
	Manufacturing sector technological change
	Manufacturing sector structural change
	Domestic sector technological change
	Domestic sector structural change
Agriculture (excl. livestock)	Cultivated area, irrigation share and crop type
	Technological development
	Potential operational costs in the agricultural sector
	Relative prices
	Agricultural technological development
	Agricultural structural change
	Land use change
	Protected areas
	Relative prices for natural resources (e.g., water, fertilisers etc.)

The complete workflow of the DB modelling exercise is summarised in Figure 57. Global SSP-RCP scenarios serve as the foundation for meteorological inputs, providing the basis for future climate scenarios. SSP scenarios downscaled to the local scale provide socio-economic scenario elements (Table 5), while SSP narratives provide decision-making context and social attitudes. Combining scenario elements and context enables the creation of draft local scenarios and narratives that are consistent with the broader global SSP framework. Stakeholder engagement plays a crucial role in this workflow.

Their insights on basin-specific peculiarities validate local narratives and SSP assumptions, ensuring consistency with the cultural context of the basin. Additionally, stakeholder feedback helps validate the adaptation measures associated with each pathway. Finally, model runs based on these pathway provide quantitative information on how the specific water system will evolve under future climate conditions, considering the potential effectiveness of various water system adaptations.

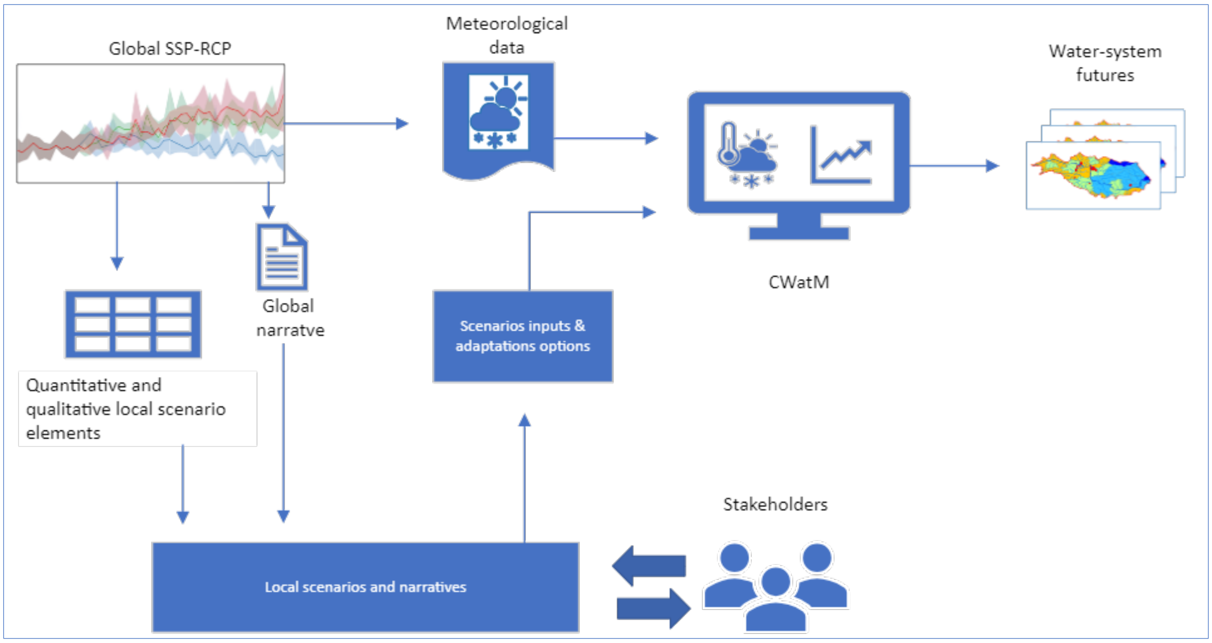


Figure 57 Local narratives and modelling workflow for the Danube Basin case study.

Jucar

The combination of global scenarios and local narratives will be achieved by applying a top-down meets bottom-up strategy (Girard et al, 2015; Marcos-Garcia et al, 2023). This methodology combines a traditional top-down approach, relying on a chain of models that transform CMIP6 climate projections into hydrological projections; with a participatory bottom-up approach in which global narratives are adapted to the local scale as described in previous sections for the Jucar. Both hydrological projections and local narratives will be used as inputs for a water resource management model, in this case a hydro-economic model trained and validated for the Jucar River system (see Macian-Sorribes, 2017) that reproduces the current Jucar River system operating policies to obtain the associated water fluxes and the economic benefits and costs achieved by the Jucar river system users.

Hydrological scenarios for the hydro-economic model are built using a simple conceptual model: the Temez model (Temez, 1977). This model intricately balances water fluxes among distinct processes within the hydrological system throughout various stages of the hydrological cycle (Figure 58). Falling under the category of lumped hydrological models, it globally assesses each sub-basin without factoring in the spatial distribution of variables and parameters involved in calculations, instead opting for average values. In spite of its lumped features and its conceptually simple setup, it has been proven as a suitable model for Mediterranean rivers and has been extensively and successfully applied over Spain. In case of the Jucar, the division in sub-basins is shown in Figure 21.

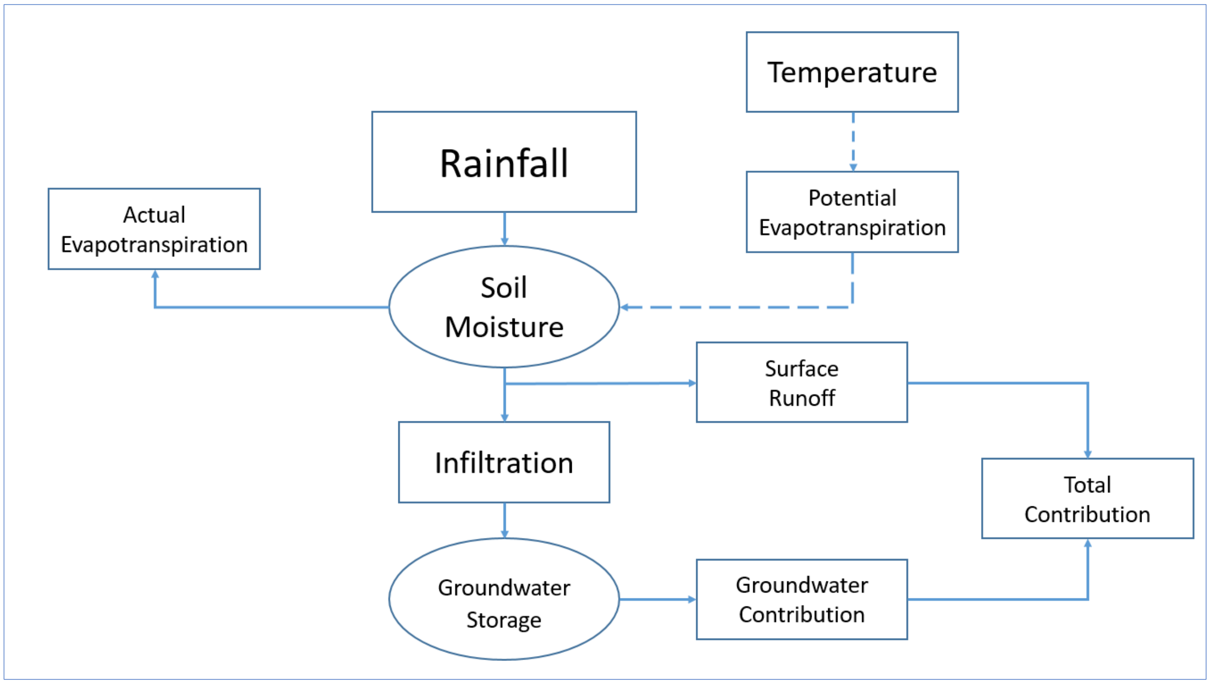


Figure 58 Schematic of the processes modelled by the Temez hydrological model.

Hydro-economic model

The hydro-economic model representing the Jucar River Basin was constructed using the Explicit Stocastic Programming Advanced Tool (ESPAT) developed by Macian-Sorribes et al. (2017). Operating on a monthly time scale, this model employs a simulation approach that reproduces the current water resource management in the Jucar River system. The Jucar River system is represented by 27 nodes, 8 surface reservoirs, 5 groundwater bodies modelled using the Embedded Multireservoir Model (Pulido-Velazquez et al., 2005), 7 sub-basins, 18 consumptive demands, 9 hydropower plants and 6 minimum environmental flows (as described in the hydrological plan). The representation of the system for this model is presented in Figure 59.

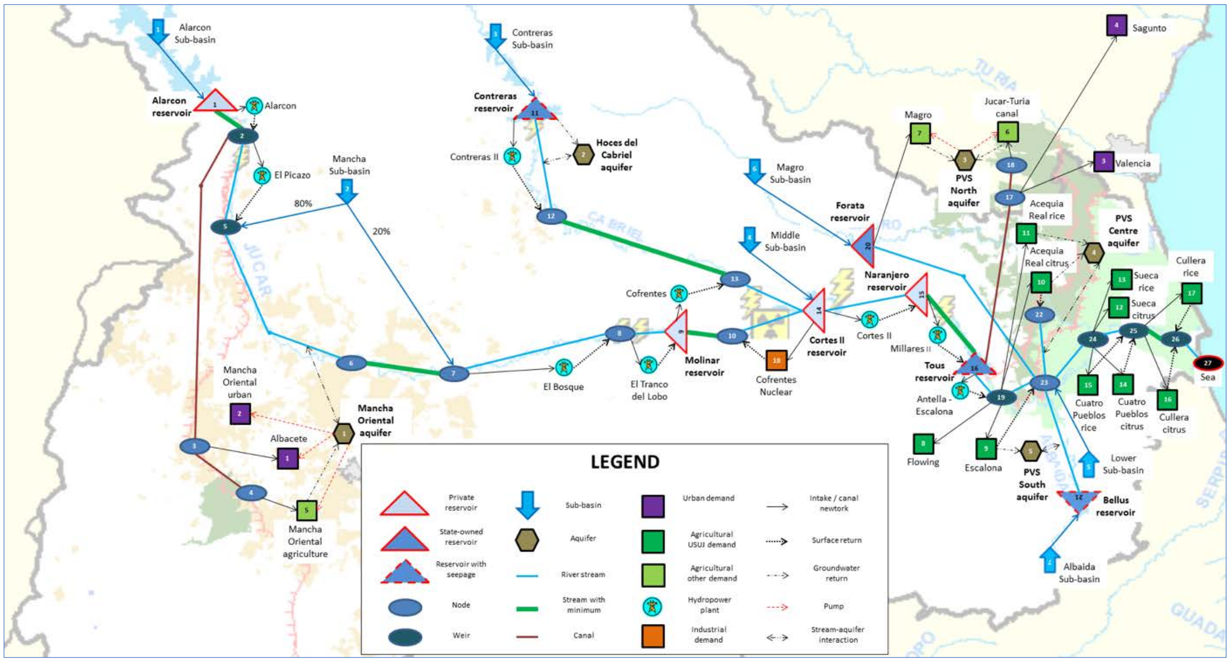


Figure 59 Hydro-economic model schematic for the Júcar River Basin

The model's physical attributes - hydrological sub-basins, reservoir features (capacity, minimum level, storage-head, and storage-surface curves), groundwater dynamics, river reach and canal capacities, prescribed minimum streamflow, water demands, returns, and fish habitat details - were gathered from the CHJ. Economic aspects related to water usage, like urban water needs, energy prices, and pumping expenses, were first taken from the JRBMP (CHJ, 2021) and past studies (Pulido-Velázquez et al., 2006) within the DMA rollout in the Jucar, part of the EU AQUAMONEY project. These economic factors were compared with other similar models (Kahil et al., 2016). Urban water demand was characterized using demand functions that establish a connection between water supply levels and the marginal utility of water for consumers.

On the other hand, agricultural water demand linked to citrus, orchards, and perennial crops was modelled through an adapted approach to crop yield calculations derived from FAO66 methodologies (FAO, 2012). This method calculates yearly crop yields based on supply-demand ratios and historical data, then estimates total food production from this yield and crop prices. Rice cultivation significantly contributes to maintaining l'Albufera Lake, a vital protected area in the region, and its water supply has been treated as a constraint.

The only industrial water demand from surface water comes from the Cofrentes Nuclear Power Plant. Its benefits per unit of water consumption were assessed employing the alternative cost approach, which factors in the cost of generating equivalent energy via gas minus the operational expenses of the plant, as detailed in Pereira-Cardenal et al. (2014).

The impact of temperature fluctuations on irrigation requirements was assessed by establishing a correlation between the potential evapotranspiration for a specific month and the average evapotranspiration for that month during the historical period. This approach results in increased irrigation demands during warmer months and decreased demands during colder months compared to the historical baseline. It is important to note that this methodology operates under the assumption that there will be no significant changes to the fields' composition (or at least none that would significantly affect the simulation period).

The top-down meets bottom-up analysis would be done, at first, without applying any adaptation measure in order to determine if the particular combination of scenarios tested is sustainable or not. If a situation is found not to be sustainable, then adaptation measures and their combination (programmes of measures) would be introduced into the model and the performance of the Jucar River system would be analysed with this new configuration. Finally, results before and after adaptation measures would be compared per scenario to establish the performance level and applicability range of these measures and programmes of measures.

Figure 60 Top-down meets bottom-up methodology flowchart. Source: Marcos-Garcia et al, 2023

Mekong

Despite the fact that the primary focus of the SOS-Water project is the evaluation of different adaptation measures in response to climate change and socio-economic impacts in the Mekong Delta, it is necessary to also model the upstream portion of the Mekong River. This is crucial because various upstream adaptation measures can have different impacts on the natural resources of the Delta. Therefore, the modelling of scenario-narratives' climate change impacts, and adaptation and mitigation measures will be carried out using two different integrated modelling systems. The firsts (VICRes-CASCADE) will simulate the upstream portion of the Mekong, providing outputs such as the amount of water and sediment reaching the model's outlet section under different local pathways and global scenarios. The latter (VRSAP/Mike 11) will utilize the outputs of the upstream models as boundary conditions and simulate the performances of the Mekong Delta Water System under the respective local pathways and global scenarios.

However, in both modelling systems, we integrate global scenarios and local narratives using a combination of top-down methodology and bottom-up strategy. Global SSP-RCP scenarios form the basis for the models’ meteorological inputs, establishing future climate scenarios (top-down). Through joint efforts of stakeholders and researchers, local pathways for adaptation and mitigation measures are developed, aligning with the broader global SSP framework (bottom-up). Stakeholder engagement helps validate local narratives, SSP assumptions, and associated adaptation measures for each scenario. Subsequently, the integrated modelling systems, forced with the climate-meteorological inputs from global SSP-RCP scenarios, are run based on these local pathways, providing quantitative insights into how the specific water system will evolve under future climate conditions, considering the potential effectiveness of different local interventions.

Upstream Mekong

The core of the integrated water modelling system for the upstream Mekong consists of a hydrological-water management model, VICRes, coupled with D-CASCADE, a basin-scale dynamic sediment connectivity model, which quantifies spatiotemporal sediment transport in river networks.

D-CASCADE offers the ability to analyse the spatiotemporal evolution of sediment supply and delivery across a basin (Tangi et al., 2022). It relies on river discharges for multiple reaches of the network, simulating the daily amount of sediments mobilized, deposited, and transported. Additionally, it can model the presence of reservoirs along the river network, simulating their sediment trap efficiency and sediment deposition within the impoundments.

VICRes is a large-scale hydrological model that integrates water storage representation within its routing module (Dang et al., 2020). It consists of two modules: the VIC module simulates water and energy fluxes governing the terrestrial water cycle (Liang et al., 1994). It calculates evapotranspiration, infiltration, runoff, and baseflow for each cell of the domain at a daily time step. To execute this module, along with other inputs, climate forcings for each cell of the spatial domain are necessary. These forcings include precipitation, minimum and maximum temperatures, and wind speed, which will be derived from the output of Global Circulation Models used to compute the RCP scenarios. The second module, the routing model, utilizes the baseflow and runoff outputs of VIC to simulate river discharges along the Mekong River network (Lohmann et al., 1998). It also allows for the representation of water reservoirs and their operations within the routing process. To achieve this, it is required to model the positions of dams and their associated water impoundments, specifying their water and sediment release policies, as well as irrigation water extractions.

Both models share the same daily time step and spatial domain (with a spatial resolution of 0.0625°), extending from the upstream part of the Mekong to Stung Treng, located about 500 km upstream of the Delta. The integration of D-CASCADE and VICRes facilitates ongoing communication between the two models at every time step, allowing for continuous feedback exchange. VICRes provides the daily flow data required by D-CASCADE to simulate sediment transport and changes in river morphology. Conversely, D-CASCADE supplies VICRes with daily data on sediment deposition in each reservoir. This information, in turn, influences subsequent reservoir releases and consequently affects flows at the next time step.

While different global climate change scenarios determine the inputs of climate-meteorological forcings, local adaptation pathways define the potential interventions, such as different reservoir water and sediment releases, water extractions for irrigation purposes, and dam locations or development portfolios. Together, these global scenarios and local pathways will affect how the specific water system will evolve. The integrated framework produces outputs including river discharge along the network, sediment amount reaching the outlet section, hydroelectric energy generated by reservoirs, and water quantity extracted for irrigation purposes. These outputs can serve as inputs or boundary conditions for other models in the region, such as energy system models, irrigation models, and biodiversity models, expanding the analysis of implemented program of measures to other socio-economic sectors.

VRSAP and Mike 11: Hydrodynamic Models for the Mekong River Basin

The Vietnamese River System Analysis Program (VRSAP), established in 1978 and the Danish Hydraulic Institute's Mike 11 (2005) are popular hydrodynamic models extensively used for water resource management in the Mekong River Basin. These models have supported various planning and development initiatives, including:

- Water balance assessments: VRSAP played a crucial role in evaluating the water balance for sustainable development in the Mekong River (2002).
- Flood risk management: Both models have been instrumental in flood planning for the Cuu Long basin in Vietnam, notably in 2000 and 2020.
- Integrated basin planning: They have also been employed in the integrated planning of the Cuu Long basin (2005) and the development of the master plan for the basin's adaptation to climate change and sea level rise (2012).
- National water management strategies: VRSAP recently contributed to the development of the national irrigation and risk reduction plan in Vietnam (2022).

The models cover a vast geographical extent, encompassing the Mekong River from Kratie in Cambodia to the sea, including the Delta, the Great Lake, and the Vietnamese Cuu Long Basin. The model considers various inputs, including upstream flow data at Kratie, water level data from 11 coastal tidal stations, and rainfall data from multiple stations. The VRSAP model network is comprised of 7002 river sections, 4279 junction nodes, and 5578 floodplain cells.

For robust decision-making, model validation is crucial. Both VRSAP and Mike 11 have undergone calibration and verification processes. Calibration involved using observed data from flood events in 2011 and salinity observations from 2016. The models were subsequently verified using data from the 2020 flood event and 2023 salinity measurements. This continuous validation ensures the models' accuracy and reliability in supporting water resource management in the Mekong River Basin.

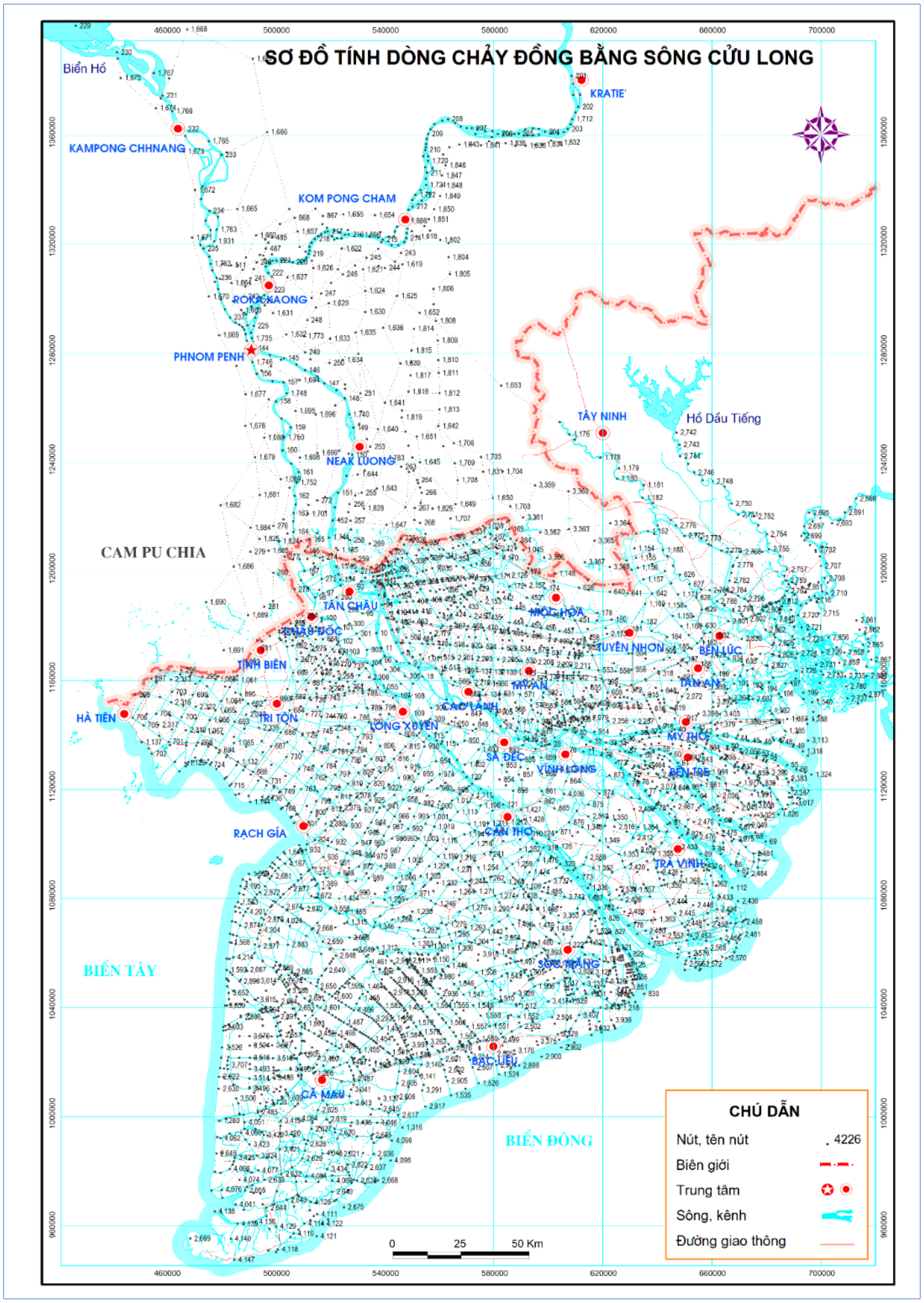


Figure 61 Water model network for the Mekong delta.

Mekong delta interventions

This section outlines the diverse water management approaches adopted in different ecological zones of the Mekong Delta, considering the region's unique challenges.

Zonal Strategies:

- **Upper Area (Flood-Prone):** The focus lies on **flood control** through improved floodgates, canals, dikes, and dedicated floodways. Additionally, internal **irrigation systems and transportation networks** are upgraded to enhance agricultural productivity and connectivity.
- **Middle Area (Fresh-Brackish Water):** This zone prioritizes **fresh-brackish water control and freshwater diversion** strategies. **Flood proofing measures** are vital, coupled with continual improvement of internal irrigation and transportation systems.
- **Coastal Area (Brackish-Salt Water):** Managing **salt and brackish water intrusion** becomes paramount in this zone. **Coastal protection measures** safeguard infrastructure and communities. **Fresh water collection, storage, and diversion** strategies ensure resource availability.

Structural Measures: Two primary options are considered (Figure 62):

- **Option 1:** This option focuses on **upgrading 26 existing irrigation systems** to enhance water management efficiency.
- **Option 2:** This option proposes the construction of **additional gates on the main river channels** to regulate water flow and manage salinity intrusion.

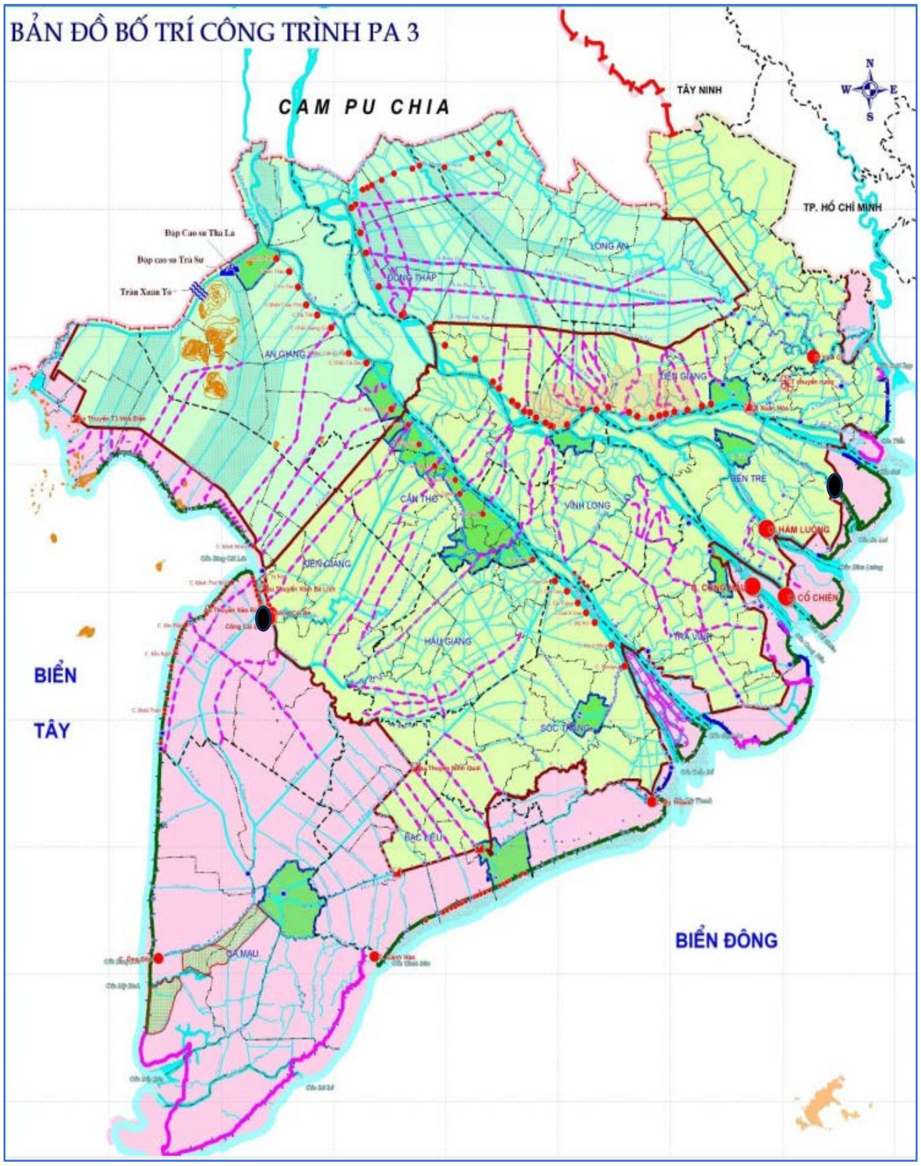


Figure 62 Map of main water structure intervention in the Mekong delta.

Boundary Conditions:

- **Upstream flow:** Data from Kratie is used, considering **Mekong water assessment scenarios** under climate change impacts and the influence of upstream reservoir and irrigation development.
- **Sea tide level:** This factor is incorporated with a **sea level rise scenario** to assess future coastal dynamics.
- **Local rainfall patterns:** These are integrated to accurately represent precipitation variations across the basin.
- **Water demand from all users:** This data is crucial for optimizing water allocation and ensuring efficient use across various sectors.

By employing diverse management strategies, structural measures, and incorporating relevant boundary conditions, the models provide a comprehensive framework for sustainable water resource management in the Mekong Delta.

Rhine

For the Rhine River basin we will primarily rely on the hydrological model PCR-GLOBWB2.0 (Sutanudjaja et al 2018). This model solves the water balance at a spatial resolution of 1 to 50km spatial resolution at a daily temporal timestep. This integrated water model has been applied extensively globally in many regions and has shown good performance to generate key hydrological variable like soil moisture, groundwater stores and river discharges. One of the advantages of PCR-GLOBWB is that it incorporates the interaction between human water management and the natural water system. This also leads to dynamic interactions where the human and natural water system affect each other.

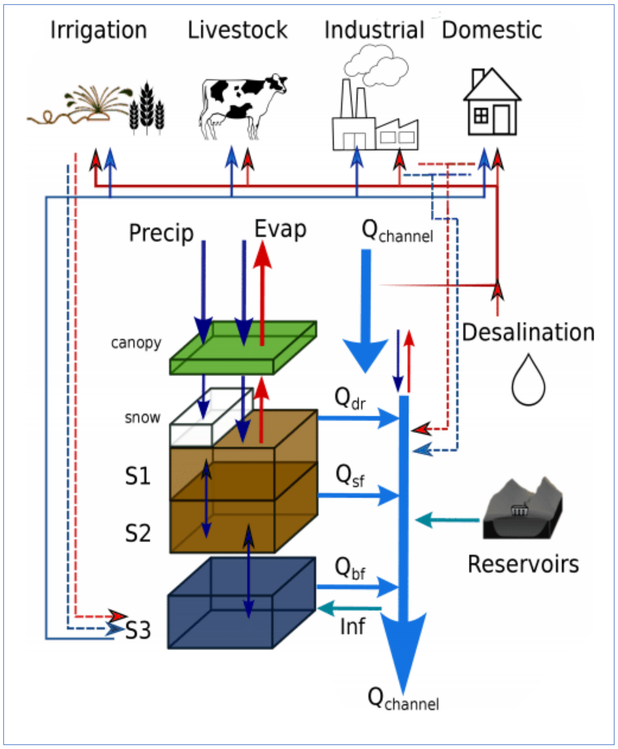


Figure 63 Schematic representation of the global hydrological model PCR-GLOBWB

Using the same global climate models and scenarios as available for the Danube (see paragraph Danube in this chapter), we obtain the local changes in meteorology and human water management needed to get a realistic estimate of the future water availability in the Rhine basin. SSP-RCP information is typically included into PCR-GLOBWB by change the meteorological forcing of temperature, precipitation, and evaporation, as well as the human affected component of land use and water demands. By changing these components we can mimic the changes that occur when different SSP or RCP scenario unfold.

In most assessments, the human water management (e.g. irrigation, reservoir operations) are assumed to not change in the future. However, for the SOS-Water project we aim to also make change in irrigation and reservoir schemes to mimic adaptation strategies that aim to increase the water local water availability and reduce local water scarcity.

6. Conclusions

General remarks

Accounting for socio-economical constraints in pathways development

The capacity of national and transnational entities to put in place adaptations to climate change and, more generally, solutions to cope with environmental issues depends on each nation's income, strong governance, economic readiness (Sarkodie et al. 2022) and technological level. Moreover, as societies evolve in terms of socioeconomic development, scientific advancement and policy integration progress, their capacity for adaptation evolves accordingly (Theokritoff et al., 2023). Nevertheless, accounting for socioeconomic constraints when projecting adaptation scenarios is still a scientific challenge (see IPCC 2023, chapter 16).

Within the SOS-Water project's context, such constraints have been considered by seeking the support of high-level stakeholders. The adaptations making up each pathway have either been proposed or will be validated by stakeholders with in-depth knowledge and long experience of the basins they operate in. At the same time, the palette of possible proposed adaptations will be constrained by taking into account the SSP narrative (e.g. international cooperation level) and scenario (e.g. GDP) underpinning the local narrative and pathways.

Stakeholders bias

Water and water management is a transversal subject. It encompasses environmental requirements, primary and secondary production, services and human consumption. Considering the spirit of intergenerational, infragenerational and interspecies justice that inspires the SOS framework (Rockström et al., 2023), it is paramount that stakeholders' consultation includes an audience representative of all relevant water dimensions of the basin. If such a requirement is not met, important considerations might be neglected if stakeholders focus only on information that aligns with their values while other interest groups are excluded.

To enforce this principle, in the case studies that directly engaged the stakeholders, relevant representatives were carefully mapped to make sure to include all different perspectives. In the Rhine case study, indirect engagement relies on a nationwide consultation that is done within the Delta program, a collaborative initiative led by the Dutch government. Both approaches reached out to a balanced representation of NGOs and nonprofit organisations engaged in environment protection, academia representatives to provide independently neutral advice, industry and farming representatives and international financial institutions strongly engaged in supporting regional development.

The variety of involved organisations and the relative numerical balance among them ensures the minimisation of bias and wide representation of interests.

Danube

The DB is the most international basin of the world, draining across 19 countries. Thus, the international decision-making context (i.e. international cooperation level) is very relevant for the Danube future. Disparities within the basin complicate the development of local narratives for the DB. Although many countries are within the EU, and those that are not in the process of entering or are already candidate states, substantial economic and social disparities still exist within the DB as the heritage of the 20th-century West-East block division. Such division translates into heterogenous abilities of coping with climate change adaptation measures both for lack of resources and capacities. Consequently, limited international cooperation assumed in SSP3 could strongly hamper the capacity of non-EU countries to cope with climate change. Moreover, non-EU countries are located in the lower part of the basin, where relative temperatures are expected to rise more than the upper part. In contrast, precipitations are expected to decrease, thus increasing the hazard levels for these countries (Pistocchi, Bontoux, and Rafael Rodrigues Vieira de Almeida 2020).

A challenging aspect of developing local narratives consistent with the global ones resides in applying global tenets that clearly contrast with the local cultural context. An example of this challenge is reported in in Lehtonen et al. (2021), where local communities pointed out that the strong environmental awareness engraved in their culture will unlikely fade as postulated in SSP3. Similarly, within the DB, there are examples of countries with strong environment-oriented policies dictated by social pressure, and stakeholders clearly manifested their willingness and necessity to cooperate. Moreover, within this basin, the history of cooperation among states has deep historical roots and has continued even during the height of the Cold War. However, in those times, cooperation focused on exploiting the river for economic purposes, while nowadays, cooperative management strongly focuses on integrated management for sustainable development. Nevertheless, in the post-cold-war years, Danube states have demonstrated that the region can reach high levels of tension and conflict among states, exacerbating the challenge between the centralised authority required to manage an international basin and the decentralised national independence (Linnerooth-Bayer and Murcott 1996; Linnerooth 1990). At the same time, in the very last decades, several programs successfully developed cooperation and cohesion among Danube countries (e.g. https://danube-region.eu/about/the-danube-region/). The strength of the European Union and the will of adherence of the DB states to its principles will presumably be key factors to ensure the cooperation among basin states will continue.

Jucar

With a tight balance between resources and demands, a Mediterranean hydrology, conflicts between middle and lower basin water users and the threat of climate change driving increased water demands and decreased water resources, the JRB requires careful and well-informed decision-making from both the planning and the management side. Climate change scenarios suggest a challenging situation, although the severity and consequent adaptation needs might vary significantly depending on the scenario.

All the features of the JRB have driven significant infrastructure development and a detailed and careful water planning process, including the definition of measures to achieve a sustainable water use in the basin. With these adequate foundations, climate change is still challenged by possible water conflicts, and the expected need that further significant changes in its water management and planning would be required. Narratives development for the Jucar is clearly dominated by large-scale markets, with the importance of agricultural products that are exported abroad and the key role played by tourism in coastal areas. However, local factors can play a significant role in shaping future scenarios and should be accounted for. The development of scenarios at the local scale benefits distinctly from the interaction with stakeholders. Furthermore, its combination with climate change models through a top-down meets bottom-up strategy is a suitable way to reconcile both scales in the river basin, and acknowledge and manage the interaction between global and local driving forces.

Mekong

In the dynamic landscape of the Mekong Delta, the pursuit of development alternatives is crucial to meet the demands of rapid and diverse agricultural expansion, recent advancements in aquaculture, and the urgent need for water supply. Notably, strides have been made in the successful improvement of acid sulphate soils, enhancing agricultural productivity. The region has also witnessed effective measures in reducing risks associated with drought, salinity intrusion, and flooding. However, the current strategies, while meeting the maximum water requirement, come with a higher cost of investment in construction, operation, and management. It is evident that every intervention in the basin and delta introduces more uncertainty, difficulty, and potential hazards. Furthermore, the existing design criteria fall short in addressing the most extreme events and fail to tackle issues such as land subsidence, river morphology, and biodiversity. To address these challenges comprehensively, there is a pressing need for water modelling that accurately incorporates upstream water change scenarios under the influence of climate change and water regulation.

Rhine

The strong international character of the Rhine and its importance for countries like Germany and the Netherlands make that this river has been heavily managed in the past decades. Functioning as one of Europe’s major water ways also makes it important for economic activities. At the same time the Rhine faces challenges when it comes to flood, droughts, habitat functioning and water quality. This has resulted in a strong collaboration between the Rhine countries to ensure that the water quantity and quality of the Rhine will not be affected too much by human activities. It is, however, clear that the Rhine will face more droughts in summer, more floods in winter. The current global projections predict that this has a positive impact on water scarcity, that will be reduced as a result of an overall increase in water demand. To get a better understanding of where water resources will be under pressure, we need to quantify the available water resources using integrated water resource models that can capture the interactions between the natural and the human water system. Combined with local pathways to deal with these upcoming pressures we can identify the effectiveness of different types of measures.

7. References

Alizadeh, M. R., Adamowski, J., & Inam, A. (2022). Integrated assessment of localized SSP–RCP narratives for climate change adaptation in coupled human-water systems. Science of the Total Environment, 823. https://doi.org/10.1016/j.scitotenv.2022.153660

Bisselink, B., Bernhard, J., Gelati, E., Jacobs, C., Adamovic, M., Mentaschi, L., Lavalle, C., & De Roo, A. (2018). Impact of climate change on future water resources of the Danube River Basin – A model simulation study. Publications Office. https://doi.org/10.2760/561327

Burek P., Mubareka S., Rojas Mujica R., De Roo A., Bianchi A., Baranzelli C., Lavalle C., & Vandecasteele I. (2012). Evaluation of the effectiveness of Natural Water Retention Measures - Support to the EU Blueprint to Safeguard Europe’s Waters. Publications Office. https://doi.org/10.2788/5528

Burek, P., Satoh, Y., Kahil, T., Tang, T., Greve, P., Smilovic, M., Guillaumot, L., Zhao, F., & Wada, Y. (2020). Development of the Community Water Model (CWatM v1.04) - A high-resolution hydrological model for global and regional assessment of integrated water resources management. Geoscientific Model Development, 13(7). https://doi.org/10.5194/gmd-13-3267-2020

Calvin, K., Bond-Lamberty, B., Clarke, L., Edmonds, J., Eom, J., Hartin, C., Kim, S., Kyle, P., Link, R., Moss, R., McJeon, H., Patel, P., Smith, S., Waldhoff, S., & Wise, M. (2017). The SSP4: A world of deepening inequality. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2016.06.010

CHJ - Confederación Hidrográfica del Júcar (Spanish Government). (2021). Plan Hidrológico de la demarcación hidrográfica del Júcar. Ciclo de planificación hidrológica 2022-2027. Memoria.

Confederación Hidrográfica del Júcar (Spanish Government) (2020). Esquema de Temas Importantes de la Demarcación Hidrográfica del Júcar. Tercer ciclo de Planificación Hidrológica (in Spanish).

Confederación Hidrográfica del Júcar (Spanish Government) (2023). Plan Hidrológico de la demarcación hidrográfica del Júcar. Ciclo de planificación hidrológica 2022-2027. Memoria (in Spanish).

Copernicus Climate Change Service. (2024). CMIP6 climate projections. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). In Climate Data Store. Accessed on 20-February-2023.

Crespo Cuaresma, J. (2017). Income projections for climate change research: A framework based on human capital dynamics. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2015.02.012

Dang, T. D., Vu D. T., Chowdhury A. F. M. K., & Galelli, S. (2020). A software package for the representation and optimization of water reservoir operations in the vic hydrologic model. Environmental Modelling Software, 126. https://doi.org/10.1016/j.envsoft.2020.104673

Dellink, R., Chateau, J., Lanzi, E., & Magné, B. (2017). Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2015.06.004

DHI, 2013, Study of the Impact of Mainstream Hydropower on the Mekong River, Draft Inception Report, Model set up and simulation using Mike;

EEA. (2015). The European Environment-State and Outlook 2015: synthesis.

FAO (2012) Crop yield response to water. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i2800e/i2800e.pdf

Fricko, O., Havlik, P., Rogelj, J., Klimont, Z., Gusti, M., Johnson, N., Kolp, P., Strubegger, M., Valin, H., Amann, M., Ermolieva, T., Forsell, N., Herrero, M., Heyes, C., Kindermann, G., Krey, V., McCollum, D. L., Obersteiner, M., Pachauri, S., … Riahi, K. (2017). The marker quantification of the Shared Socioeconomic Pathway 2: A middle-of-the-road scenario for the 21st century. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2016.06.004

Fujimori, S., Hasegawa, T., Masui, T., Takahashi, K., Herran, D. S., Dai, H., Hijioka, Y., & Kainuma, M. (2017). SSP3: AIM implementation of Shared Socioeconomic Pathways. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2016.06.009

Girard, C., Pulido-Velazquez, M., Rinaudo, J. D., Page, C., & Caballero, Y. (2015). Integrating top–down and bottom–up approaches to design global change adaptation at the river basin scale. Global Environmental Change, 34:132–146. https://doi.org/10.1016/j.gloenvcha.2015.07.002

Haskoning, D. H. V. (2022). MDV integrated regional master plan for period 2021-2030, vision to 2050 (in Vietnamese).

Hurtt, G. C., Chini, L., Sahajpal, R., Frolking, S., Bodirsky, B. L., Calvin, K., Doelman, J. C., Fisk, J., Fujimori, S., Goldewijk, K. K., Hasegawa, T., Havlik, P., Heinimann, A., Humpenöder, F., Jungclaus, J., Kaplan, J. O., Kennedy, J., Krisztin, T., Lawrence, D., … Zhang, X. (2020). Harmonization of global land use change and management for the period 850-2100 (LUH2) for CMIP6. Geoscientific Model Development, 13(11). https://doi.org/10.5194/gmd-13-5425-2020

ICPDR. (2018). Climate Change Adaptation Strategy. https://www.icpdr.org/sites/default/files/nodes/documents/icpdr_climate_change_adaptation_strategy_web.pdf

ICPDR-International Commission for the Protection of the Danube River. (2021). Danube River Basin Management Plan-Update 2021.

Intergovernmental Panel on Climate Change (IPCC). (2021). IPCC: Summary for Policymakers. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change (IPCC). "Key Risks across Sectors and Regions." Chapter. In Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2411–2538. Cambridge: Cambridge University Press, 2023.

IWRP-SIWRP. (2022). National irigation and risk reduction masterplan for period 2021-2030, vision to 2050;

Jiang, L., & O'Neill, B. C. (2017). Global urbanization projections for the Shared Socioeconomic Pathways. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2015.03.008

Kahil, M. T., Ward, F. A., Albiac, J., Eggleston, J., & Sanz, D. (2016). Hydro-economic modeling with aquifer-river interactions to guide sustainable basin management. Journal of Hydrology, 539. https://doi.org/10.1016/j.jhydrol.2016.05.057

KC, S., & Lutz, W. (2017). The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2014.06.004

Kok, K., & van Vliet, M. (2011). Using a participatory scenario development toolbox: Added values and impact on quality of scenarios. Journal of Water and Climate Change, 2(2–3). https://doi.org/10.2166/wcc.2011.032

Kriegler, E., Bauer, N., Popp, A., Humpenöder, F., Leimbach, M., Strefler, J., Baumstark, L., Bodirsky, B. L., Hilaire, J., Klein, D., Mouratiadou, I., Weindl, I., Bertram, C., Dietrich, J. P., Luderer, G., Pehl, M., Pietzcker, R., Piontek, F., Lotze-Campen, H., … Edenhofer, O. (2017). Fossil-fueled development (SSP5): An energy and resource intensive scenario for the 21st century. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2016.05.015

Lehtonen, H. S., Aakkula, J., Fronzek, S., Helin, J., Hildén, M., Huttunen, S., Kaljonen, M., Niemi, J., Palosuo, T., Pirttioja, N., Rikkonen, P., Varho, V., & Carter, T. R. (2021). Shared socioeconomic pathways for climate change research in Finland: co-developing extended SSP narratives for agriculture. Regional Environmental Change, 21(1). https://doi.org/10.1007/s10113-020-01734-2

Leimbach, M., Kriegler, E., Roming, N., & Schwanitz, J. (2017). Future growth patterns of world regions – A GDP scenario approach. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2015.02.005

Liang, X., Lettenmaier, D. P., Wood, E. F., & Burges, S. J. (1994). A simple hydrologically based model of land surface water and energy fluxes for general circulation models. JGR Atmospheres, 99: 14415–14428. https://doi.org/10.1029/94jd00483

Linnerooth, J. (1990). The Danube River Basin: Negotiating Settlements to Transboundary Environmental Issues. Natural Resources Journal, 30, 629. https://digitalrepository.unm.edu/nrj/vol30/iss3/10

Linnerooth-Bayer, J., & Murcott, S. (1996). The Danube River Basin: International Cooperation or Sustainable Development. Natural Resources Journal, 36(3), 521–547. https://www.jstor.org/stable/24885861

Lohmann, D., Raschke, E., Nijssen, B., & Lettenmaier, D. P. (1998). Regional scale hydrology: I. formulation of the vic-2l model coupled to a routing model. Hydrological Sciences—Journal—des Sciences Hydrologiques, 43(1):131–141. https://doi.org/10.1080/02626669809492107

Macian-Sorribes, H. (2017). Design of optimal reservoir operating rules in large water resources systems combining stochastic programming, fuzzy logic and expert criteria. Universitat Politècnica de València. Retrieved 8 June 2017 from https://doi.org/10.4995/THESIS/10251/82554.

Marcos-Garcia, P., Pulido-Velazquez, M., Sanchis-Ibor, C., García-Mollá, M., Ortega-Reig, M., Garcia-Prats, A. & Girard, C.. (2023). From local knowledge to decision making in climate change adaptation at basin scale. Application to the Jucar River Basin, Spain. Climatic Change 176, 38. https://doi.org/10.1007/s10584-023-03501-8.

Meinshausen, M., Raper, S. C. B., & Wigley, T. M. L. (2011). Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 - Part 1: Model description and calibration. Atmospheric Chemistry and Physics, 11(4). https://doi.org/10.5194/acp-11-1417-2011

Meinshausen, M., Wigley, T. M. L., & Raper, S. C. B. (2011). Emulating atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 - Part 2: Applications. Atmospheric Chemistry and Physics, 11(4). https://doi.org/10.5194/acp-11-1457-2011

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., van Vuuren, D. P., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J., Stouffer, R. J., Thomson, A. M., Weyant, J. P., & Wilbanks, T. J. (2010). The next generation of scenarios for climate change research and assessment. Nature, 463(7282), 747–756. https://doi.org/10.1038/nature08823

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grubler, A., Jung, T. Y., Kram, T., Lebre La Rovere, E., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., … Dadi, Z. (2000). Special Report of Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. In Special Report of Emissions Scenarios (SRES), A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. https://doi.org/10.1017/CBO9781107415324.004

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2015.01.004

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., Mathur, R., & van Vuuren, D. P. (2014). A new scenario framework for climate change research: The concept of shared socioeconomic pathways. Climatic Change, 122(3). https://doi.org/10.1007/s10584-013-0905-2

O'Neill, B. C., Tebaldi, C., Van Vuuren, D. P., Eyring, V., Friedlingstein, P., Hurtt, G., Knutti, R., Kriegler, E., Lamarque, J. F., Lowe, J., Meehl, G. A., Moss, R., Riahi, K., & Sanderson, B. M. (2016). The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. Geoscientific Model Development, 9(9). https://doi.org/10.5194/gmd-9-3461-2016

Ortega-Reig, M., Garcia-Molla, M., Sanchis-Ibor, C., Pulido-Velazquez, M., Girard, C., Marcos, P., Ruiz-Rodriguez, M., Garcia-Prats, A. (2018). Adaptacion de la agricultura a escenarios de cambio global. Aplicacion de metodos participativos en la cuenca del rio Jucar (Espana). Economia Agraria y Recursos Naturales 18 (2) 29–51. https:// doi. org/ 10. 7201/ earn. 2018. 02. 02 (In Spanish).

Pereira-Cardenal, S. J., Madsen, H., Arnbjerg-Nielsen, K., Riegels, N., Jensen, R., Mo, B., Wangensteen, I., & Bauer-Gottwein, P. (2014). Assessing climate change impacts on the Iberian power system using a coupled water-power model. Climatic Change, 126(3–4), 351–364.

Pistocchi, A., Bontoux, L., & Rafael Rodrigues Vieira de Almeida, S. (2020). Water scenarios for the Danube River Basin: future challenges and preparedness. https://doi.org/10.2760/134358

Pulido-Velazquez, M. A., Sahuquillo-Herraiz, A., Ochoa-Rivera, J. C., & Pulido-Velazquez, D. (2005). Modeling of stream-aquifer interaction: The embedded multireservoir model. Journal of Hydrology, 313(3–4). https://doi.org/10.1016/j.jhydrol.2005.02.026

Pulido-Velázquez, M., Andreu, J., & Sahuquillo, A. (2006). Economic Optimization of Conjunctive Use of Surface Water and Groundwater at the Basin Scale. Journal of Water Resources Planning and Management, 132(6). https://doi.org/10.1061/(asce)0733-9496(2006)132:6(454)

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., … Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Rinaudo, J. D., Maton, L., Terrason, I., Chazot, S., Richard-Ferroudji, A., & Caballero, Y. (2013). Combining scenario workshops with modeling to assess future irrigation water demands. Agricultural Water Management, Elsevier, 130(C):103-112. https://doi.org/10.1016/j.agwat.2013.08.016

Rockström, J., Gupta, J., Qin, D., Lade, S. J., Abrams, J. F., Andersen, L. S., Armstrong McKay, D. I., Bai, X., Bala, G., Bunn, S. E., Ciobanu, D., DeClerck, F., Ebi, K., Gifford, L., Gordon, C., Hasan, S., Kanie, N., Lenton, T. M., Loriani, S., … Zhang, X. (2023). Safe and just Earth system boundaries. Nature. https://doi.org/10.1038/s41586-023-06083-8

SIWRP. (2002). National research study KC.08-14 on 'Comprehensive research on flood identification, forecasting, control and drainage to serve the requirements of living with floods in the Mekong Delta'- Flood modelling report using VRSAP;

SIWRP. (2005). Mekong delta integrated master plan;

SIWRP. (2012). Master plan on irrgation and risk reduction in adaptation to climate change for MDV, Summary Report, Main report, Hydraulic modelling report using VRSAP (in Vietnamese).

Sutanudjaja, E. H., van Beek, R., Wanders, N., Wada, Y., Bosmans, J. H. C., Drost, N., van der Ent, R. J., de Graaf, I. E. M., Hoch, J. M., de Jong, K., Karssenberg, D., López López, P., Peßenteiner, S., Schmitz, O., Straatsma, M. W., Vannametee, E., Wisser, D., and Bierkens, M. F. P. (2018). PCR-GLOBWB 2: a 5 arcmin global hydrological and water resources model, Geosci. Model Dev., 11, 2429–2453, https://doi.org/10.5194/gmd-11-2429-2018.

Tangi, M., Bizzi, S., Fryirs, K., & Castelletti, A. (2022). A dynamic, network scale sediment (dis)connectivity model to reconstruct historical sediment transfer and river reach sediment budgets. Water Resources Research, 58. https://doi.org/10.1029/2021WR030784

Témez, J. R. (1977). Modelo Matemático de transformación "precipitación-escorrentía". Asociación de Investigación Industrial Eléctrica. ASINEL. Madrid 39 pp.

Theokritoff, E., van Maanen, N., Andrijevic, M., Thomas, A., Lissner, T., & Schleussner, C. F. (2023). Adaptation constraints in scenarios of socioeconomic development. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-46931-1

UNECE. (2009). Guidance on water and adaptation to climate change.

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J. F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., & Rose, S. K. (2011). The representative concentration pathways: An overview. Climatic Change, 109(1), 5–31. https://doi.org/10.1007/s10584-011-0148-z

van Vuuren, D. P., Stehfest, E., Gernaat, D. E. H. J., Doelman, J. C., van den Berg, M., Harmsen, M., de Boer, H. S., Bouwman, L. F., Daioglou, V., Edelenbosch, O. Y., Girod, B., Kram, T., Lassaletta, L., Lucas, P. L., van Meijl, H., Müller, C., van Ruijven, B. J., van der Sluis, S., & Tabeau, A. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. Global Environmental Change, 42. https://doi.org/10.1016/j.gloenvcha.2016.05.008

Wada, Y., Flörke, M., Hanasaki, N., Eisner, S., Fischer, G., Tramberend, S., Satoh, Y., Van Vliet, M. T. H., Yillia, P., Ringler, C., Burek, P., & Wiberg, D. (2016). Modeling global water use for the 21st century: The Water Futures and Solutions (WFaS) initiative and its approaches. Geoscientific Model Development, 9(1). https://doi.org/10.5194/gmd-9-175-2016

Wolters, H.A., Hunink, J., Delsman, J., de Lange, G., van den Born, G.J., Reinhard, S. (2018). Delta scenario’s voor de 21e eeuw, actualisering 2017, Achtergrondinformatie over gebruiksfuncties en sectoren, Deltares, Utrecht (In Dutch). Accessible online at: https://media.deltares.nl/deltascenarios/Deltascenarios_actualisering2017_achtergrondrapport.pdf

WRD (MONRE). (2021). National water resources master plan for period 2021-2030, vision to 2050 (in Vietnamese).

Appendix I – Data sources references

Annex I Table 1 Temperature anomalies.

Variable:	Temperature anomalies		
Dataset download link:	https://interactive-atlas.ipcc.ch/		
Dataset			
Time range	Time step	Format	Unit of measure
2021-2040, 2041-2100	Periods average	Geo tiff, 1x1°	°C
Reference:	Iturbide, M., Fernández, J., Gutiérrez, J.M., Bedia, J., Cimadevilla, E., Díez-Sierra, J., Manzanas, R., Casanueva, A., Baño-Medina, J., Milovac, J., Herrera, S., Cofiño, A.S., San Martín, D., García-Díez, M., Hauser, M., Huard, D., Yelekci, Ö. (2021) Repository supporting the implementation of FAIR principles in the IPCC-WG1 Atlas. Zenodo, DOI: 10.5281/zenodo.3691645. Available from: https://github.com/IPCC-WG1/Atlas		
Short description			
CMIP6 – Global mean temperature (T) Change °C averaged from several models between 28 and 34 GCM. Data has been downloaded for the periods 2021-2040 and 2041-2100 using 1981-2010 as a reference. Data has been downloaded with annual and seasonal aggregations (dec-feb, mar-may, jun-aug, sep-nov).			
Model (if relevant)			
SSP1	SSP3	SSP5	
Processing			
Downloaded data have been clipped and displayed for each basin.			

Annex I Table 2 Precipitation anomalies.

Variable:	Precipitations anomalies		
Dataset download link:	https://interactive-atlas.ipcc.ch/		
Dataset			
Time range	Time step	Format	Unit of measure
2021-2040, 2041-2100	Periods average	Geo tiff, 1x1°	Total precipitation % change
Reference:	Iturbide, M., Fernández, J., Gutiérrez, J.M., Bedia, J., Cimadevilla, E., Díez-Sierra, J., Manzanas, R., Casanueva, A., Baño-Medina, J., Milovac, J., Herrera, S., Cofiño, A.S., San Martín, D., García-Díez, M., Hauser, M., Huard, D., Yelekci, Ö. (2021) Repository supporting the implementation of FAIR principles in the IPCC-WG1 Atlas. Zenodo, DOI: 10.5281/zenodo.3691645. Available from: https://github.com/IPCC-WG1/Atlas		
Short description			
CMIP6 – Global total precipitation averaged from several models between 28 and 34 GCM. Data has been downloaded for the periods 2021-2040 and 2041-2100 using 1981-2010 as a reference. Data has been downloaded with annual and seasonal aggregations (dec-feb, mar-may, jun-aug, sep-nov).			
Model (if relevant)			
SSP1	SSP3	SSP5	
Processing			
Downloaded data have been clipped and displayed for each basin.			

Annex I Table 3 Gridded global GDP.

Variable:	GDP		
Dataset download link:	https://gcp-tsukuba.github.io/SSP-downscale/		
Dataset			
Time range	Time step	Format	Unit of measure
1850-2100	10 years	Geo tiff 0.08x0.08 °	Purchase PP in Million USD-2005 rate
Reference:	Murakami, D., Yoshida, T. & Yamagata, Y. (2021). Gridded GDP projections compatible with the five SSPS (shared socioeconomic pathways). *Front. Built Environ.* **7**, 760306. https://doi.org/10.3389/fbuil.2021.760306.		
Short description			
Estimated global GDPs between 1850—2100 by 10-year intervals. In the estimation, national GDP data (past data until 2010; future projection under SSPs after 2020) is downscaled considering spatial and economic interactions among cities, urban growth patterns compatible with SSPs, and other auxiliary geographic data (land cover, road network, etc.).			
Model (if relevant)			
SSP1	SSP3	SSP5	
Processing			
Data from the year 2020 have been clipped by each basin and the cells of the resulting raster summed up to compute the cumulative GDP of the basin.			

Annex I Table 4 Gridded global land use.

Variable:	Land use		
Dataset download link:	https://luh.umd.edu/data.shtml		
Dataset			
Time range	Time step	Format	Unit of measure
2015-2100	1 Year	Netcdf 0.25x0.25°	% of occupied by each land cover
Reference:	Hurtt, G. C., Chini, L., Sahajpal, R., Frolking, S., Bodirsky, B. L., Calvin, K., Doelman, J. C., Fisk, J., Fujimori, S., Goldewijk, K. K., Hasegawa, T., Havlik, P., Heinimann, A., Humpenöder, F., Jungclaus, J., Kaplan, J. O., Kennedy, J., Krisztin, T., Lawrence, D., … Zhang, X. (2020). Harmonisation of global land use change and management for the period 850-2100 (LUH2) for CMIP6. Geoscientific Model Development, 13(11). https://doi.org/10.5194/gmd-13-5425-2020		
Short description:			
As part of the World Climate Research Program Coupled Model Intercomparison Project (CMIP6), the international community is developing the next generation of advanced Earth System Models. The goal of the Land-Use Harmonization (LUH2) project is to prepare a harmonised set of land-use scenarios that smoothly connects the historical reconstructions of land-use with the future projections in the format required for ESMs. The land-use harmonisation strategy estimates the fractional land-use patterns, underlying land-use transitions, and key agricultural management information, annually for the time period 850-2100 at 0.25 x 0.25 resolution, while minimising the differences at the transition between the historical reconstruction ending conditions and IAM initial conditions, and working to preserve changes depicted by the IAMs in the future. Land use classes:			
• forested primary land • non-forested primary land • potentially forested secondary land • potentially non-forested secondary land • urban land • C3 annual crops • C4 annual crops • C3 perennial crops • C4 perennial crops • C3 nitrogen-fixing crops • managed pasture • rangeland			
Model (if relevant)			
SSP1	SSP3	SSP5	
IMAGE	AIM	REMIND-MAGPIE	
Processing			
Each land use class for each year in the NetCDF files have been converted to Geo tiff, reprojected to a coordinate reference system (epsg 3857), and multiplied by the cell size in meters to obtain the meters squared occupied by each land use class in each grid cell. These rasters have then been clipped by each basin shapefile and the sum of the area of each land use class in each year recorded in a table. For the plotting, the dataset classes have been aggregated using the following criteria:			
• forested primary land->natural vegetation • urban land->urban • C3 annual crops->crop • C4 annual crops->crop			

- non-forested primary land->natural vegetation
- potentially forested secondary land->natural vegetation
- potentially non-forested secondary land->natural vegetation
- C3 perennial crops->crop
- C4 perennial crops->crop
- C3 nitrogen-fixing crops->crop
- managed pasture->pasture
- rangeland->pasture

Annex I Table 5 Global gridded total, urban and rural population.

Variable:	Population		
Dataset download link:	https://sedac.ciesin.columbia.edu/data/set/popdynamics-1-km-downscaled-pop-base-year-projection-ssp-2000-2100-rev01/data-download		
Dataset			
Time range	Time step	Format	Unit of measure
2010-2100	10 years	NetCDF4, 1x1 km	Number of persons
Reference:	Data Set: Gao, J. 2020. Global 1-km Downscaled Population Base Year and Projection Grids Based on the Shared Socio-economic Pathways, Revision 01. Palisades, NY: NASA Socio-economic Data and Applications Center (SEDAC). https://doi.org/10.7927/q7z9-9r69. Accessed DAY MONTH YEAR. Scientific Publication: Gao, J. (2017). Downscaling Global Spatial Population Projections from 1/8-degree to 1-km Grid Cells. NCAR Technical Note NCAR/TN-537+STR, https://doi.org/10.5065/D60Z721H. Jones, B., & Oneill, B. C. (2016). Spatially Explicit Global Population Scenarios Consistent with the Shared Socio-economic Pathways. Environmental Research Letters, 11 (2016): 084003. https://doi.org/10.1088/1748-9326/11/8/084003.		
Short description:			
The Global 1-km Population Base Year and Projection Grids Based on the Shared Socio-economic Pathways, Revision 01, data set consists of global urban, rural, and total population data for the base year 2000, and population projections at ten-year intervals for 2010-2100 at a resolution of 1-km (about 30 arc-seconds), consistent both quantitatively and qualitatively with the SSPs. This 1-km data set is a downscaled version of the one-eighth degree (7.5 arc-minutes) data published in Jones and O'Neill (2016). The downscaling methods were published in Gao (2017).			
Model (if relevant)			
SSP1	SSP3	SSP5	
Processing			
The data have been converted from netCDF4 to Geo tiff rasters, clipped by each basin and for each year, the number of people within the basin was summed up and recorded into a table.			

Annex I Table 6 Historical and RCPs temperature mean monthly projections for 5 GCMs

Variable:	Historical and SSP-RCPs scenarios temperatures		
Dataset download link:	https://cds.climate.copernicus.eu/api/v2		
Dataset			
Time range	Time step	Format	Unit of measure
1850-2100	Monthly mean	NetCDF4, 1x1 deg	°C
Reference:	Copernicus Climate Change Service, Climate Data Store. (2021). CMIP6 climate projections. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.c866074c (Accessed on 20-February-2023)		
Short description			
CMIP6 - Mean monthly temperature (T) in °C from the following global circulation models: MRI-ESM2-0, GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-LR, IPSL-CM6A-LR on the global scale.			
Model (if relevant)			
SSP1	SSP3	SSP5	
MRI-ESM2-0, GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-LR, IPSL-CM6A-LR	MRI-ESM2-0, GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-LR, IPSL-CM6A-LR	MRI-ESM2-0, GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-LR, IPSL-CM6A-LR	
Processing			
Downloaded data have been clipped for each basin. For each time step, i.e., month, the average over the basin was computed and used to plot a monthly mean and a future projection chart.			

Annex I Table 7 Historical and RCPs precipitation mean monthly projections for 5 GCMs

Variable:	Historical and scenarios SSP-RCPs precipitations		
Dataset download link:	https://cds.climate.copernicus.eu/api/v2		
Dataset			
Time range	Time step	Format	Unit of measure
1850-2100	Monthly mean	NetCDF4, 1x1 deg	kg m-2 s-1
Reference:	Copernicus Climate Change Service, Climate Data Store. (2021). CMIP6 climate projections. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.c866074c (Accessed on 20-February-2023)		
Short description			
CMIP6 - Mean monthly precipitation flux in kg m-2 s-1 from the following global circulation models: MRI-ESM2-0, GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-LR, IPSL-CM6A-LR on the global scale.			
Model (if relevant)			
SSP1	SSP3	SSP5	
MRI-ESM2-0, GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-LR, IPSL-CM6A-LR	MRI-ESM2-0, GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-LR, IPSL-CM6A-LR	MRI-ESM2-0, GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-LR, IPSL-CM6A-LR	
Processing			
Downloaded data have been clipped for each basin. For each time step, i.e., month, the average over the basin was computed and converted to mm. The converted values have been used to plot monthly mean and future projection charts.			

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