STARS4Water

Water scenarios for river basin hubs

Deliverable D1.5

31 May 2024

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Work Package	1: Co-creation with stakeholders in river basin hubs
Due date	20
Submission date	Actual submission date
Lead beneficiary	SGGW
Lead author(s)	Tomasz Okruszko (SGGW), Marek Giełczewski (SGGW), Mikołaj Piniewski (SGGW), ...
Contributors	Helmut Habersack, Mario Kloesch, Martin Glas, Max Preiml (BOKU), Albert Scrieciu, Andrei Toma (GEOECOMAR), Trine Jahr Hegdahl, Shaochun Huang, Hege Hisdal (NVE), Pedro Martinez Santos (UCM), Africa de la Hera Portillo (CSIC-IGME), Virginie Keller, Nathan Rickards, Gwyn Rees (UKCEH), Maggie Kossida, Klio Monokrousou (SEVEN), Judith ter Maat, Tatjana Edler, Femke Schasfoort, Harm Duel, Esmee Mes (Deltares), Jan Kruishoop (RWS), Maria-Helena Ramos, Alban de Lavenne (INRAE), Marinos Kritsotakis, Fotis Pantazoglou (KRITI)

Dissemination Level		
PU	Public	x
SEN	Confidential, only for members of the consortium and the granting authority (including other EU institutions and bodies)	
CI	Classified, as referred to EU Decision 2015/444 and its implementing rules	

Version log			
Version	Date	Released by	Nature of Change
0.1	30.04.2024	SGGW	Outline
0.5	15.05.2024	SGGW	First draft version
0.6	20.05.2024	NVE, UCM, CSIC-IGME, UKCEH, SEVEN, Deltares, RWS, INRAE	Internal feedback
0.7	21.05.2024	SGGW	Final draft version
0.8	24.05.2024	BOKU	Review draft version
0.9	29.05.2024	SGGW	Final draft, incorporated comments of internal review
1.0	31.05.2024	SGGW	Approval final version
			(update)
			(review of updated version)
			(final updated version)
			(approval final version)

Citation
Okruszko, T., Giełczewski, M., Piniewski M., Habersack, H., Kloesch, M., Glas, M., Preiml, M., Scrieciu, A., Toma, A., Hegdahl, T.J., Huang, S., Hisdal, H., Martinez Santos, P., de la Hera Portillo, A., Keller, V., Rickards, N., Rees, G., Kossida, M., Monokrousou, K., Kritsotakis, M., Pantazoglou, F., ter Maat, J., Edler, T., Schasfoort, F., Duel, H., Mes, E., Kruishoop, J., Ramos, M.H., de Lavenne, A. (2024): Water scenarios for river basin hubs. Horizon Europe project STARS4Water. Deliverable D1.5.

The STARS4Water project has received funding from the European Union's Horizon Europe research and innovation program under the Grant Agreement No 101059372

Summary

The main objective of this report is to present scenario narrative storylines (in short: narratives) for business as usual (BAU) developments up to 2050 for seven river basin hubs of the STARS4Water project. The co-creation of the BAU scenario narrative focus on both socio-economic and biophysical variables and represent the first step in the development of water scenarios in the project. In addition, several what-if scenario questions have been formulated for each hub, as an alternative or alternating scenario to the BAU scenario narrative to assess additional possible future consequences or impacts of changes. Both BAU scenario narrative and what-if scenario questions were developed for Danube (transboundary), Drammen (Norway), Duero (Spain), East Anglia (UK), Messara (Greece), Rhine (transboundary) and Seine (France).

The report also outlines the methodology used to develop the narratives, the core aspect of which is co-creation with stakeholders to raise awareness about water resources challenges in the river basins and arrive at meaningful water scenarios at the river basin levels. The backbone of all the narratives is the global Shared Socioeconomic Pathway 2 (SSP2) narrative from the IPCC AR6. This SSP2, also called "The Middle of the Road", can be understood as a business-as-usual (BAU) scenario and was inspirational for the development of the narratives. The co-creation process included the development of a matrix of anticipated changes for a number of river basin-specific socio-economic and biophysical variables as an intermediate step towards the narrative. Expected changes in variables were assessed qualitatively (either "no change" or between one and three pluses - increase, or minuses - decrease).

The main part of the report presents the synthesis of the results for all river basin hubs, while full information on the different steps of the narrative development can be found in seven annexes, one for each river basin hub. In total, 62 and 43 variables appeared in the socio-economic and biophysical categories of the narratives, respectively. Twenty-four scenarios based on the "business as usual narrative" and "what-if" questions, ranging from two to eight per hub, were grouped by type of driver: climate (change), water allocation, water or environmental policy, land use change, and socioeconomic change. Climate (change) was the most popular driver, appearing in 12 scenarios and all seven river basin hubs.

The developed BAU scenario narratives and what-if scenario questions will be further processed within the STARS4Water project to quantify their impacts on water availability and demand in all river basin hubs using available models (like hydrological, integrated river basin, e-flow, groundwater models).

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1. Introduction

1.1. STARS4Water project

The STARS4Water project, operating within the framework of the Horizon Europe Program (No 101059372), commenced a four-year initiative started in October 2022. Its primary goal is to transform our understanding of the impact of climate change on freshwater resources within river basins, shedding light on vulnerabilities that affect ecosystems, society, and economic sectors. The project serves as a shining example for innovative solutions, nurturing the advancement and implementation of cutting-edge data services and data-driven models.

Its objectives are diverse and encompass various aspects:

1. Expanding the utilization of data sourced from community-driven global to local monitoring networks within broader river basin networks is a core objective. Additionally, the establishment of a robust meta-data platform aims to sustain the longevity of STARS4Water services well beyond the project's completion.

2. Empowering stakeholders with decision-making tools—co-created dashboards—specifically designed to facilitate informed choices, while facilitating the uptake and adaptability of these essential resources through comprehensive guidance materials and capacity-building initiatives.

3. Assessing the existing framework of data processing, computational tools, and modelling capabilities aims to streamline the integration of hydrological and water use datasets. This evaluation seeks to support precision in future regional scale projections both in water quantity and quality, while concurrently identifying key research and infrastructural gaps for targeted improvements.

4. Strengthening the knowledge base and scientific foundation concerning diverse climate risks and impacts across various scenarios and time spans.

5. Customizing advanced data services and models to precisely match stakeholders' unique information needs and specifications.

STARS4Water operates based on the premise that even though river basin authorities already make use of numerous datasets for the purpose of system management, there still remains untapped potential. Every year, a significant amount of data is generated, but not all sources are effectively monitored or utilized due to constraints in terms of time, accessibility, or scalability within the context of basin scales. The objective aims to unlock the potential that exists within the current datasets and services, which have previously been underutilized by both public and private stakeholders.

Leveraging the abundance of all these data sets presents an opportunity to enhance the precision and spatial resolution of existing models and tools used in the management of water resources and adaptation to climate change. By incorporating advanced techniques in data science, particularly in the field of machine learning, new approaches to modelling and the integration of data can be developed, resulting in unprecedented insights. STARS4Water aims to harness these technologies to create data services and models in collaboration with stakeholders from seven river basin hubs, ensuring that their needs are met and promoting the continued use of these tools beyond the project's timeframe.

1.2. Co-creation with stakeholders in river basin hubs

The focal aim of work package WP1 revolves around engaging stakeholders in a collaborative approach to enhance their water resources information systems. By introducing new data, tools, and indicators, the objective is to augment the efficacy and timeliness of their water management decisions, particularly in the context of climate-resilient water resources planning. Specific objectives include:

1. Establishing cohesive river basin communities in collaboration with respective river basin organizations.
2. Identifying and understanding stakeholders' specific data needs and requisites essential for evaluating water resources availability and usage.
3. Facilitating accessibility of local data pertinent to the river basin hubs through these established communities.
4. Co-creating and developing a dashboard designed to support informed decision-making processes.
5. Collaborating with stakeholders to craft scenario narratives that delve into potential future water scenarios within the river basin hubs.

1.3. This report

This report presents the first steps to achieve the development of water scenarios in the river basin hubs of the STARS4Water project. These scenarios go beyond the Shared Socioeconomic Pathways or existing EU scenarios, since they are created at the river basin level in co-creation with the stakeholder communities in these basins. It makes them meaningful in river basin planning and water resources assessments under climate change.

The report presents the necessary steps to achieve a description of plausible future scenarios at the river basin level, such as the elaboration of a matrix of anticipated changes, scenarios narratives (based on Shared Socioeconomic Pathway "middle of the road" (SSP2) developments) and what if questions) for each river basin hub. In this development stakeholders play an important role in mobilizing local knowledge about the developments in the river basin. Therefore, they were invited to participate in the co-creation of these scenarios.

Chapter 2 presents the methodological approach proposed in this activity to move towards the elaboration of the above-mentioned water scenario elements, with special attention paid to developing narratives based either on the Shared Socioeconomic Pathway "middle-of-the-road" (SSP2), also named the BAU scenario, and developing alternative scenarios based on what-if questions, alternating this BAU scenarios. Chapter 3 synthesizes the results of the water scenario elements developed in the process of co-creation with stakeholders in all the river basin hubs. The synthesis focusses on three main aspects (i) the anticipated changes in two broad categories: socio-economic and biophysical, and (ii) developed SSP2 BAU scenario narrative and (iii) developed what-if scenario narratives. All relevant for the river basin hubs. An integral part of the report are seven Annexes, one for each river basin hub, which present their fully developed narratives, based on their matrix of anticipated changes and supplemented by detailed what-if scenario narratives. There is also additional information for selected river basin hubs, including scenarios based on Shared Socioeconomic Pathways other than the SSP2

2. Methodology

When building the STARS4Water methodology to ultimately achieve plausible water scenarios for water availability assessment in European rivers basin management, we proposed an iterative approach based on co-creation with stakeholders and on progressing gradually from one stage to the next (Figure 2.1). This means moving from current situation and recent trends to narratives and scenarios, and preparing the information needed for the modelling of impacts. Below, we explain the definitions used in the project and our approach to achieve the results.

The methodological approach proposed below was inspired by the scenario development process described in a study on ecosystem services in Bangladesh by Barbour et al. (2018) and Allan et al. (2018).

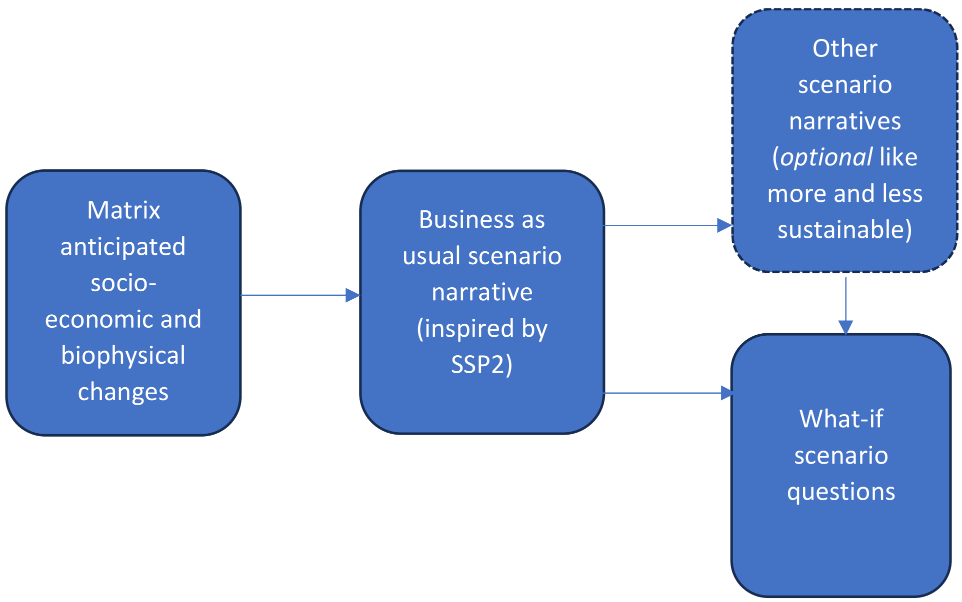

Figure 2.1 Methodology of scenario co-development in the 7 river basin hubs presented in this report.

2.1. Definitions

Scenario:

In general, a *scenario* is a plausible and often simplified description of how the future might develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections (e.g. climate or socio-economic projections), but are often based on additional information from other sources, sometimes combined with a "narrative storyline" (see below).

Scenarios cannot be considered as an end goal in themselves; they facilitate strategic discussions. Their goal is not to predict; they do not answer questions such as "how likely is this?", but rather they assist in thought provoking discussions in terms of "what will we do if this happens?".

In the project we distinguish three types of scenarios:

- Business as usual (BAU) or reference scenario
- (Future) climate scenarios
- What-if scenarios

Often these scenarios incorporate narrative storylines to facilitate the discussions on anticipated changes and future outlooks.

Narrative storyline:

Broadly speaking, a *narrative* is a description within a scenario and for a scenario. It may be complemented by or utilizes the numbers (or percentages) related to projected changes that will be later required for the modelling of impacts.

Scenario development typically starts with a narrative storyline, which describes both the changes that are likely to occur and the expected consequences of those changes. Since such a storyline does not typically include exact numbers, it can be called a qualitative scenario. A quantitative scenario can later be developed by assigning numbers to the qualitative statements of a narrative storyline/scenario, e.g. by using quantitative models. In this phase of the project all river basins have developed a narrative for the business as usual scenario.

Business as usual scenario:

Scenario comparisons often include a "Business-As-Usual" scenario (BAU) which assumes a future status without special changes or interventions from the current path of development. It is also about the situation if "no actions are taken", except actions that are formulated in policies and will be implemented in the coming years. Thus, a BAU scenario can be built by extrapolation of current trends. For this, a historic period has to be considered – it is usually referred to as the *baseline period*. The BAU scenario can thus serve as a reference scenario for comparison with other additional scenarios, which are typically developed as alternatives to the BAU scenario. These can be scenarios of alternative, but also plausible futures, which assume that there will be more significant changes in the future. In this project we used the Shared Socioeconomic Pathways SSP2 as an inspiration for formulating the narrative storyline for this scenario.

Alternative climate and socio-economic pathways scenarios:

In particular, *climate scenario* is a plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships, which have been constructed for an explicit use when investigating the potential consequences of anthropogenic climate change. Climate scenarios often serve as input to impact models. Climate projections are often used as the raw material for constructing climate scenarios. However, climate scenarios usually also require additional information, such as information about the observed current climate and past trends. In STARS4Water we will leverage existing climate scenarios that are already available.

Furthermore, 4 alternative Shared Socioeconomic Pathways exists. The SSPs provide scenario narratives describing alternative socio-economic developments, including more (SSP1) and less sustainable alternatives (SSP3, 4 and 5), that can be inspirational for more and less sustainable narratives about the future.

What-if scenarios:

What-if issues can be meaningful in our way of understanding possible future consequences or impacts of changes: climate changes, socio-economic changes (incl. land use, policies, etc.) or a combination of the two, both impacting water availability and water use.

The what-if scenario are based on simple what-if questions instead of a comprehensive narrative storyline (see previous paragraph) that have interest to specific actors in their need for information about a certain issue of development. It targets our knowledge for and understanding of particular developments or course of action in sectors that are expected to be most impacted (e.g. agriculture, land cover, demography). The what-if scenarios only describe the most important stressors to the functioning of the water management system.

2.2. Approach towards narratives for the BAU (SSP2) scenario

We proposed an iterative approach to identify key issues of concern for stakeholders. In the first step it includes a review of relevant literature (i.e. academic papers, policy documents, regional development plans and available grey literature) by the project's scenario group members, which include the focal points of the river basin hubs, in order to prepare bilateral interviews with the most important stakeholders and/or other key informants. As a result, issues that need to be addressed from at least two broad categories, socio-economics and biophysical, are documented. The results can be prepared in the form of table (see Table 2.1 as an example) or flow charts, as these issues often represent a range of interlinked challenges across the social, economic and environmental landscape of each river basin hub. In the example provided, a fictitious river basin in Europe is represented, and the template suggests 8 issues in the socio-economic category and 6 issues in the biophysical category. It was reminded that, according to the outcomes of the bilateral interviews, the number of categories as well as the number of issues in each category could (and even should) be modified to adapt to the specific situation of each hub.

Based on the table that identifies categories, issues and variables to be addressed, a matrix of anticipated changes can then be developed. It was recommended that this should be done during on-site workshop(s) and/or with stakeholders that represent a large number of water users in the river basin hub. It must be noted that, although each of the earlier prepared issues is a priori broken down by the project's scenario group into variables of interest, during the workshops, participants were, however, encouraged to verify the list of proposed issues/variables in order to discard non-relevant ones and/or bring others considered as important by the group. This allows each river basin hub to tailor the table to their hub's context first, before moving towards assessing the expected impacts.

Assuming there is an agreement on the breakdown of each category on issues and then on variables, the second part of the workshop starts. During this part, it is recommended that participants work in groups (minimum two), who will independently assess the extent of the expected increase (+) or decrease (-) over time, using a scale from '+' ('-') to '+++' ('---') to represent the magnitude of expected change, compared to 0 as 'no change'. The analysis is performed for one target time horizon (i.e. 2040). Each group should produce a matrix table (see illustrative example in Table 2.2), which is a modification of the Table 2.1, where the extent of the expected changes to all issues/variables considered relevant by the group is presented. As a final result of the workshop, one matrix of change should be agreed by all groups (see illustrative example in Table 2.3). This final matrix will be the basis for developing a narrative that will include all considered issues. The final matrix should be obtained in the third part of the workshop when the results of the work of each group are compared and discussed.

The three tables mentioned above (Table 2.1-2.3) illustrate the successive steps in the process of developing a final matrix of expected changes for the river basin hub based on business as usual trends. Due to the nature of the process itself, they are relatively similar to each other. Instead, they document the essential elements of the co-creation process with stakeholders. The process moves from the initial theoretical proposal of the matrix of expected changes to its final version developed through the discussions with the stakeholders representing the different groups that influence what happens in the river basin hubs.

Finally, the river basin hub focal points were able to develop their narratives, using the final matrix of anticipated changes (Table 2.2 and Table 2.3) and following the general assumptions of the SSP2 “middle-of-the-road” (O’Neill et al., 2017; Fricko et al., 2017). In our approach, we selected this SSP as in the methodology that inspired our approach, proposed by Barbour et al. (2018), they stressed that “A Business As Usual (BAU) scenario (...) is similar to the SSP2 Middle of the Road scenario”.

In summary, each narrative developed can be regarded as a building block for the BAU scenario in the respective river basin hub. As described above, the final matrix of anticipated changes is elaborated in a three-step process. In the provided illustrative example, we notice that the number of issues and variables considered for the narratives evolved: from 8 issues characterized by a total of 22 variables (Table 2.2) to 7 issues characterized by 17 variables (Table 2.3) in the case of the socio-economic category, and from 6 issues characterized by 16 variables (Table 2.2) to 5 issues and 12 variables (Table 2.3) in the case of the biophysical category. The narrative for this illustrative example (Table 2.4) is described per issues with two selected main categories.

The narratives obtained for each river basin hub using this systematic approach will serve as input for the next step in the scenario development: collecting accompanying datasets to describe the scenarios in a more quantitative way and generate model data input (Task T2.5). This way we will build up the water scenario for the BAU situation to be used to assess water availability under future conditions to come up with projections about future water resources availability and use in the basin (Task T4.2).

Table 2.1 Hierarchical approach to the development of a matrix of anticipated changes by identifying: categories (in bold), issues (underlined) and variables (in italic) (general template for an illustrative example)

Socio-economic	**Biophysical**
Agriculture: - *Main crop yields* - *Fertilizer use* - *Irrigation needs* - *Production intensification* - *Nutrient loss*	Eutrophication: - *Nutrient concentration and loads (different pathways: rivers, surface runoff, groundwater, drainage water)*
Nature protection: - *Biodiversity* - *Migration barriers*	Erosion and sedimentation: - *Suspended sediment concentration and loads* - *Soil erosion*
Infrastructure status: - *Number of hydraulic structures* - *River length impacted by hydraulic structures* - *Drainage system extent and efficiency*	Priority substances (pollution): - *Selected priority substances concentration and loads*
Well-being: - *Increased/decreased environmental or disaster risk* - *Increased/decreased vulnerability to climate change*	Water availability - *Water level in rivers* - *Discharge* - *Groundwater level* - *Water harvesting*
Demography/Migration: - *Population number (Net migration)*	Floods: - *Timing* - *Extent (Intensity)* - *Frequency* - *Duration*
Upstream/international issues: - *Water abstraction* - *Water storage (reservoirs)* - *International cooperation on water policy and river basin management*	Droughts: - *Timing* - *Frequency* - *Duration* - *Severity (Intensity)*
Energy: - *Hydropower demand* - *Hydropower installed capacity* - *Cooling water demand*	
Land Use: - *Arable land area* - *Forest area* - *Build-up area*	

Table 2.2 Matrix of anticipated changes identified by one group in a river basin hub stakeholder workshop (illustrative example)

Socio-economic	**Biophysical**
Agriculture: - *Main crop yields ++* - *Fertilizer use +* - *Irrigation needs +++* ~~- *Production intensification*~~ - *Nutrient loss ++*	Eutrophication: - *Nutrient concentration and loads (different pathways: rivers, surface runoff, groundwater, drainage water) +*
Nature protection: - *Biodiversity - -* - *Migration barriers +*	Erosion and sedimentation: - *Suspended sediment concentration and loads +* - *Soil erosion ++*
Infrastructure status: - *Number of hydraulic structures -* - *River length impacted by hydraulic structures -* - *Drainage system extent and efficiency ++*	~~Priority substances (pollution):~~ - ~~*Selected priority substances concentration and loads*~~
~~Well-being:~~ ~~- *Increased/decreased environmental or disaster risk*~~ ~~- *Increased/decreased vulnerability to climate change*~~	Water availability - *Water level in rivers -* - *Discharge 0* - *Groundwater level - -* ~~- *Water harvesting*~~
Demography/Migration: - *Population number (Net migration) 0*	Floods: ~~- *Timing*~~ - *Extent (Intensity) +* - *Frequency +* - *Duration 0*
Upstream/~~international~~ issues: - *Water abstraction ++* - *Water storage (reservoirs) 0* ~~- *International cooperation on water policy and river basin management*~~	Droughts: ~~- *Timing*~~ - *Frequency ++* - *Duration ++* - *Severity (Intensity) +*
Energy: - *Hydropower demand 0* ~~- *Hydropower installed capacity*~~ - ***Cooling water demand*** *+*	
Land Use: - *Arable land area -* - *Forest area 0* - *Build-up area +*	

Issues/Variables marked as ~~strikethrough~~ – not considered by the group as being important
Issues/Variables marked in ***bold*** – added by the group

Table 2.3 Final matrix of anticipated changes for a river basin hub: A) socio-economic category; B) biopsychical category (illustrative example).

A) Socio-economic							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Agriculture:							
Main crop yields		√					
Fertilizer use			√				
Irrigation needs	√						
Nutrient loss		√					
Nature protection:							
Biodiversity						√	
Migration barriers			√				
Infrastructure status:							
Number of hydraulic structures					√		
River length impacted by hydraulic structures					√		
Drainage system extent and efficiency		√					
Demography / Migration:							
Population number (Net migration)				√			
Upstream issues:							
Water abstraction		√					
Water storage (reservoirs)				√			
Energy:							
Hydropower demand				√			
Cooling water demand			√				

B) Biophysical							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Eutrophication:							
Nutrient concentration and loads			√				
Erosion and sedimentation:							
Suspended sediment concentration and loads			√				
Soil erosion		√					
Water availability:							
Water level in rivers					√		
Discharge				√			
Groundwater level						√	
Floods:							
Extent			√				
Frequency			√				
Duration				√			
Droughts:							
Frequency		√					
Duration		√					
Severity			√				

A) Socio-economic								B) Biophysical							
Issues / *Variables*	Increase			No change	Decrease			Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)		(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Land Use:															
Arable land area					√										
Forest area				√											
Built-up area			√												

Table 2.4 Narrative for an example (illustrative only) river basin hub, according to two categories: A) socio-economic category; B) biophysical category, and that describes the developments towards the future situation in 2050.

A. Socio-economic:

Due to a number of reasons, such as favourable climatic conditions (warm and more rainy), improvements in agriculture-related fields (e.g. cultivation techniques, seed quality), market demands (especially for fruit and vegetables), an intensification of **agriculture** will be observed. This will lead to a fairly significant increase in yields of major crops. It will be stimulated also by a slight increase in the use of fertilisers. At the same time, there will be a significant increase in the need to irrigate land, due to the need to irrigate crops during certain periods that do not always coincide with periods of increased rainfall. Such a situation, especially increased fertilisation and increased rainfall, can stimulate higher nutrient losses.

The changes in **land use** will not be significant. There will be a slight increase in built-up areas at the expense of arable land due to continued migration from rural areas. The area of forest will remain unchanged.

The total **population** will not change much. The population decline due to low birth rates will be compensated by migration from areas outside the hub-catchment area, including abroad. Migration from rural to urban areas will continue, but this will not affect the total population in the hub-catchment area.

The expected intensification of agricultural production, including an increase in the demand for irrigation water, will require an adequate drainage network, both in terms of coverage and efficiency. This will mean a fairly significant increase in the areas covered by this network and an increase in investment to ensure and maintain its high efficiency. In the case of the remaining **infrastructure elements**, including in particular hydraulic structures, their number will gradually decrease due to the progressive process of degradation and the consequent demolition of less important structures (e.g. weirs, barrages) that no longer fulfil their function. The removal of redundant structures will also lead to a reduction in the length of the sections of the river network affected by hydraulic structures. No new hydropower structures will be built, as the full potential for hydropower production in the hub-catchment area has been reached.

In the **energy** sector, the expected changes are related to a slight increase in the demand for cooling water due to the possible development of conventional and/or nuclear power. As the potential for hydropower generation in the catchment area is currently fully exploited, no change will be observed in this sector.

Economic development in the **upper part of the hub-catchment** will lead to increased water demand and therefore significant water abstractions in this part of the hub-catchment. This will result in reduced recharge to downstream areas. Lack of technical capacity and landscape conditions will not allow for increased reservoir storage in the upper part of the hub-catchment.

The intensification of agriculture and the growth of built-up areas will not be conducive to activities related to the growth or even conservation of biodiversity, which will decline significantly. **Nature protection** problems will be further exacerbated by the emergence of new migration barriers associated with the development of built-up areas or water works.

B. Biophysical:

The expected slight increase in fertiliser use combined with increased precipitation will contribute to higher nutrient losses from agricultural land. This in turn will lead to higher concentrations and loads of nutrients in watercourses, mainly due to their high concentrations in groundwater, drainage water and surface runoff, resulting in increased **eutrophication** of surface waters.

The expected higher precipitation, and in particular the increased frequency of heavy and torrential rainfall, will contribute to a significant increase in soil **erosion**. It will be reduced only to a small extent by nature based solutions such as the use of cover crops. The result of increased soil erosion will be higher concentrations and loads of suspended solids in rivers.

The pattern of rainfall will change. The increase in its volume will be accompanied by an increase in its irregularity over time, resulting in periods of intense rainfall and long periods without precipitation. This will affect the occurrence of **floods and droughts**. In the case of floods, this will lead to a slight increase in both their frequency and magnitude. Their duration will remain unchanged. Changes in precipitation will have a more significant impact on the occurrence of droughts. In this case, both the frequency and the duration of droughts are expected to increase significantly. In addition, more of these phenomena will be soil droughts.

Water availability will undergo some changes, mainly related to the use of water for irrigation and increased erosion. These will result in a slight decrease in river water levels and a fairly significant decrease in groundwater levels. Discharge will remain generally unchanged.

Scenario narratives for the Business as Usual scenario are developed in all river basins. Some basins also opt for developing narratives for other scenarios as well (inspired by SSP 1 and/or SSP3).

2.3. Approach towards scenarios

Moving from BAU narrative to a variety of scenarios (and then to impact modelling) requires a description of the present day situation (baseline reference), future situation according to business-as-usual trends and alternative climate, SSPs and/or what-if scenarios. The approach proposed to develop these elements is described below. It is an initial approach that will be further developed and detailed in the project, when BAU, climate, SSPs and/or what-if scenarios will be used to assess future water resources availability under climate change (Task T4.2).

Concerning climate scenarios, information collected from the focal points, during the second General Assembly of the project in Crete in October 2023, showed that all river basin hubs have some sort of national or regional climate scenarios available for impact assessment. Thus, from the practical point of view, it is expected that each river basin hub will use climate scenarios at hand in their modelling framework. These scenarios may be based on climate model projections with different characteristics (target RCP or SSP, time horizon, number of GCM/RCM used, downscaling or bias correction applied, etc.) and this should be also taken into account.

The scenario time horizon adopted in the approach towards the narratives presented in the previous section targets 2040 and SSP2, with the BAU scenario as reference in mind. Based on the fact that state-of-the-art climate models often project a small difference in most of climate variables between different RCPs (CMIP5) or even SSPs (CMIP6) by 2050 (Evin et al., 2021), we can assume that what has been adopted in the project will match well existing climate projections. Therefore, it should be safe to assume that the adoption of a single climate scenario in each river basin hub may be enough during the discussions with stakeholders and for the development of narratives at this stage of the project. This assumption may be reconsidered at a later stage, when it comes to modelling, for instance. We also suggest that, when several climate scenarios are available, the most extreme (e.g. RCP8.5) should be taken into consideration. It should also be noted that climate scenarios may have different baseline periods, which do not perfectly align with the baseline of 2000-2020 suggested for socio-economic scenarios in the scheme below. This should be also taken into consideration when communicating with stakeholders.

We propose to consider the period of approximately 2000-2020 as the baseline period for building scenarios in the STARS4Water project. The core future scenario, which would be developed as an extrapolation from this baseline, would be the so-called "Business-As-Usual" (BAU) scenario, and would refer to the period from today until 2050. Two additional future scenarios to be considered could span along the sustainability axis: Less Sustainable (LS) and More Sustainable (MS) based on Shared Socioeconomic Pathways and combined with one or more climate scenarios. For them, the BAU scenario should serve as the reference (Figure 2.2).

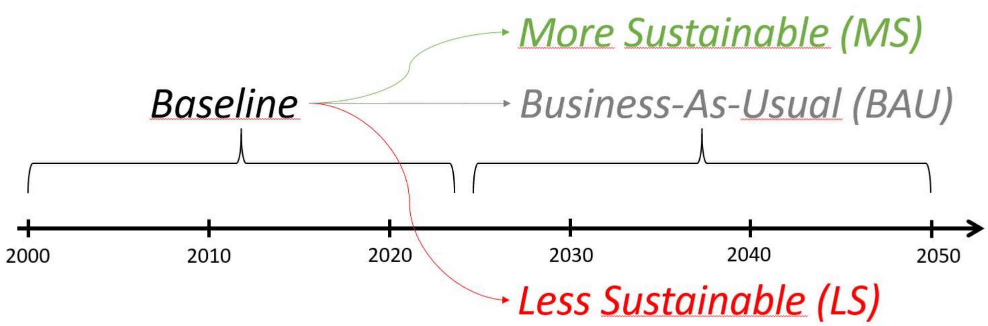

Figure 2.2 Schematic representation of scenarios on the timeline.

In summary:

- **the "core" scenario is based on the BAU approach**, and then alternative scenario(s) are built as deviations from that. The BAU scenario is stakeholder driven. It means we develop narratives for BAU scenario with time horizon 2040 and the available and agreed climate scenario;
- **the "more sustainable (MS)" and "less sustainable (LS)" scenarios** are alterations of the BAU scenario, including scenario narratives that describes plausible future developments (both climate and socio-economic) in a coherent matter;
- If the MS or LS scenarios are not interesting or realistic for a given river basin hub, we **can compare the BAU scenario with the "what-if" scenarios based on simple "what-if questions"** in order to evaluate the impacts. The what-if scenarios describe the most important stressors to the functioning of the water management system.

3. Results

Developing plausible water narratives and then scenarios for the river basins is a challenging process due to the complexity and interdependence of many natural and anthropogenic factors, and the large number and variety of water users and stakeholders involved. Therefore, to enhance plausibility, a common approach is to invite stakeholders to participate in the process and allow them to co-create the narrative. A methodological framework for effective implementation of such approach was presented in Section 2. Use of the proposed approach not only improves the quality of the narrative, but also secures ownership among stakeholders. In the STARS4Water project, the stakeholder co-creation process, including a development of the narratives, was planned and facilitated through a series of workshops and/or bilateral meetings organised in the river basin hubs by the responsible project partners (focal points; Table 3.1).

Table 3.1 Overview of the stakeholder narrative co-creation meetings undertaken in all river basin hub.

Event		River basin hub						
		Danube	Drammen	Duero	East Anglia	Messara	Rhine	Seine
Workshop 1	Date Location Participants	19/3/23 Vienna 9	30/3/24 Drammen 16	29/2/24 Arévalo	5/3/24 Grafham Water 10	10/4/24 Messara 18	23/03/24 Koblenz (D) 8	24/1/24 Paris 4
Workshop 2	Date Location Participants			12/3/24 Arévalo 23				2/05/24 Paris 2
Additional bilateral meetings (No. of)		2	4		1	1	10+	1
Other activities				√[1]				

[1] thematic questionnaire sent by mail to 800 stakeholders

Besides organising and facilitating workshops, which were key elements and resulted in the individual tables and the final matrix of changes developed in each river basin, the focal points undertook several pre- and post-processing activities to elaborate SSP2 narratives for their river basin hubs. The preparatory steps included (i) a review of the literature on scenario and socio-economic planning in their own countries, regions, hubs, as well as the literature on BAU and SSP scenarios, and (ii) defining the first table containing categories/issues/variables relevant for a given river basin hub. This table, revised during the workshops, was used to elaborate the narrative for each river basin, what was done by each respective focal point. Subsequently, the focal points validated the elaborated narrative with their stakeholders.

The methodological approach proposed in the project required each river basin hub to develop two elements concerning a targeted future that will allow to assess future water resource availability at a later stage of the project. These were scenario narratives for SSP2, seen as Business-as-Usual situation, and the identification of other alternatives to BAU through the development of what-if scenarios, as well as the possible development of scenario narratives for other SSPs. River basin hubs were able to choose their approach depending on available data and materials, as well as stakeholders attitude and expectations. What-if scenarios were developed in all river basin hubs, and they are summarized in Section 3.2. Scenario narratives for other SSPs were developed in the case of the Rhine and Drammen river basin hubs, and are presented in respective Annexes.

3.1. Changes anticipated in the river basin hubs – overview

The summary of anticipated changes in the field of socio-economics is shown in the Table 3.2. Direction and severity of changes, as seen by the stakeholders, have been presented using in total 62 variables. Some of them exclusively proposed and used for a particular river basin. The changes in agriculture, development of urban areas as well as demographical issues were reported in almost all the river basin hubs. It is also interesting to stress the important role of sectoral polices, seen as important factors shaping the river basins development in the coming 20 years. The issue of increasing numbers of hydraulic structures to respond to and fulfil the water management tasks was also raised in most of the river basin hubs.

Table 3.2 Summary of final matrixes of anticipated changes for all the river basin hubs for the category *socio-economic*. (Issues/Variables marked in **bold** – were added by the river basin hubs compared to the template provided).

Socio-economic	Danube	Drammen	Duero	East Anglia	Messara	Rhine	Seine
Agriculture:							
- *Main crop yields*	++	+		0	+	++	0
- *Fertilizer use*	+	+	--[1]	0	+	+	+
- *Irrigation needs*	+++	+		++	-	++	++
- ***Irrigation efficiency***				+			
- *Production intensification*	+			+	+		
- *Nutrient loss*	+++	+		0	-	++	
- **Crop types**				+			
Nature protection:							
- *Biodiversity* ***(protection[2])***	---	0		+++	+	--	+
- *Migration barriers*	+	0		-	-	+	
- ***E-flows***				++			
- ***Drought resilience***				+			
- ***Environmental designations***				+			
- ***Stewardship schemes***				++			
- ***Invasive non-native species (INNS)***				++			
- ***River restoration***				++			
Infrastructure status:							
- *Number of hydraulic structures*	+	0		0	+	++	+
- *River length impacted by hydraulic structures*	++	0		-	-	++	0
- *Drainage system extent and efficiency*	+	0		++	+	++	++
- ***Wastewater treatment***				++			
- ***Water leakage***				--			
- ***Water storage and transfer***				++			
- ***Desalinisation***				+			
- ***Non-potable water reuse***				++			
- ***Inter-basin transfers***				++			
Well-being:							
- *Increased / decreased environmental or disaster risk*	+++			+	-		
- *Increased / decreased vulnerability to climate change*	+++			++	-		

Socio-economic	Danube	Drammen	Duero	East Anglia	Messara	Rhine	Seine
- ***Recreational uses***				+			
- ***Landscape value***				+			
Demography / Migration:							
- *Population number (Net migration)*	-	+	--[3]	++	+	+	+
- ***Public awareness***				++			
- ***Agri-business presence***			0				
Upstream / international issues **(Policy[2])**:							
- *Water abstraction (**policy**[2])*	+	0		++	-	++	+
- *Water storage (reservoirs)*	+	0		++	+	++	0
- *International cooperation on water policy and river basin management*	+						
- ***Cross-departmental alignment of national policy***				0			
- ***Impact of Brexit***				0			
- ***Food security***				++			
Energy:							
- *Hydropower demand*	+++	0		0/+		0	+[4]
- *Hydropower installed capacity*	++			0/+		+	+
- *Cooling water demand (**decarb**[2])*	+++	0		++			++
- ***Energy demand***					+		
- ***Cooling water / process water***				++			
- ***Hydrogen-based generation***				++			
Land Use:							
- *Arable land area*	---	+		-	+	-	0
- *Forest (**Woodland**[2]) area*	+	0		0/+	0	0	
- *Build-up area*	+++	+		++	+	++	0
- ***Nature Based Solutions***				++			
- ***Peatland restoration***				+			
Environmental policy:							
- ***Conservation of aquatic ecosystems***			+				
Agricultural policy:							
- ***Water intensive crop surface***			0				
- ***Dryland crop surface***			-				
- ***Agricultural subsidies***			0				
- ***EU trade agreements with third countries***			++				

Socio-economic	Danube	Drammen	Duero	East Anglia	Messara	Rhine	Seine
<u>**Domestic:**</u>							
- ***Domestic water use***				+			
- ***Water metering + tariffs***				++			
- ***Water demand per capita***				--			
- ***Water efficiency***				+			
<u>**PWS – non-domestic:**</u>							
- ***Domestic water use***				++			
- ***Water metering + tariffs***				++			
- ***Water demand***				+			
- ***Water efficiency***				++			

[1] – placed under <u>Environmental policy</u> issues in the Duero river basin

[2] – described and considered as such in East Anglia

[3] – described as *Population growth* in the Duero river basin

[4] – described as *Power demand* in the Seine river basin

Concerning the biophysical category, there were 43 variables used for description of anticipated changes in the river basin hubs. They are summarised in Table. 3.3. Almost half of them was proposed by stakeholders for a particular river basin. There is a common belief that increased hydrological extremes will govern the situation of water management. This is followed by erosion and eutrophication.

In each river basin hub, the matrix of changes was used for the development of narratives for the BAU scenario (full versions of the matrixes and the narratives obtained for each river basin hub are presented in Annexes). Together, they form the basis for calculation of possible changes in the river basins using simulation models (socio-economic and hydrological ones, WP3 and WP4) that will be able to cope with the variables found as most important for the description of anticipated changes (modelling assessments will be carried out in Task T4.2).

In the next iteration, after another round of consultations with stakeholders, it will be decided if there is a need for a formal comparison of the BAU scenario with other coherent ones (described as more or less sustainable scenarios – see Figure 2.2), or there will rather a preference towards testing the water modelling system in a particular river basin hub with a number of what-if scenarios. The what-if scenarios describe the most important stressors to the functioning of the water management system. They were discussed in the meetings with stakeholders and are described in the Section 3.2.

Table 3.3 Summary of final matrixes of anticipated changes for all the river basin hubs for the category *biophysical*. (Issues/Variables marked in **bold** – were added by the river basin hubs compared to the template provided).

Biophysical	Danube	Drammen	Duero	East Anglia	Messara	Rhine	Seine
Eutrophication:							
- *Nutrient concentration and loads (different pathways: rivers, surface runoff, groundwater, drainage water)*	+	+		+	-	+	+
Erosion and sedimentation:							
- *Suspended sediment concentration and loads*	+++	0		+	--	+	
- *Soil erosion*	++	+		0	-	++	
- ***Soil management***				+			
Priority substances (pollution):							
- *Selected priority substances concentration and loads*	++			+	--		
- ***Algae***				+			
- ***Pathogens***				+			
Water availability							
- *Water level in rivers*	-	0		+	+	-	-
- *Discharge (**floods/low flow**[1])*	-	+		+	0	--	+/--
- *Groundwater level*	--	0		+	0	--	--
- *Water harvesting*	+			+	++		+
- ***Salt intrusion***				+			
Floods:							
- *Timing*	+			+			
- *Extent*	++	+		++	-	+	+
- *Frequency*	++	+		++	+	++	+
- *Duration*	+	0		++	-	0	0
- ***Severity***					+		
- ***Groundwater***				+			
- ***Fluvial***				+			
- ***Pluvial***				+			
- ***Coastal***				+			
Droughts:							
- *Timing*	++			+			
- *Frequency*	+++	+		+	+	++	++
- *Duration*	+++	+		+	+	++	++

Biophysical	Danube	Drammen	Duero	East Anglia	Messara	Rhine	Seine
- *Severity*	+++	+		+	+	++	++
- ***Severity of impacts***					-		
Climate change / climate related:							
- ***Rainfall***			-				
- ***Temperature***			+				
- ***Water availability***			-				
Water use:							
- ***Water demands***			+				
- ***Water reuse***			0				
- ***Balancing uses***			0				
Water quality:							
- ***Nitrate content in groundwater***			-				
- ***Arsenic content in groundwater***			-				
Peak rainfall:							
- ***Frequency***						++	
- ***Duration***						0	
- ***Severity (Intensity)***						++	

[1] – separated for *Discharge (floods)* and *Discharge (low flow)* in the Seine river basin

3.2. What-if scenario questions for the river basin hubs – overview

Table 3.4 shows the full list of what-if scenarios developed by the river basin hubs. The list contains 24 scenarios, ranging from two to eight scenarios per hub. The original versions formulated by the hub focal points can be found in the Annexes, while the wording of some scenarios has been shortened and/or rephrased here for the sake of conciseness and consistency. All scenarios were formulated in such a way that the "if" part included a hypothetical change in one of five possible drivers: climate (change); water allocation; water or environmental policy; land use change; and socio-economic change. Climate (change) was the most popular driver, appearing in 12 scenarios and all seven river basin hubs. Policy-related what-if scenarios were the second most common type, with eight occurrences in four river basin hubs. What-if scenarios related to socio-economic changes occurred seven times in five river basin hubs. What-if scenarios related to land use change occurred six times in five river basin hubs, and water allocation drivers were used in six scenarios and two river basin hubs. While the vast majority of scenarios included a single type of driver, eight included a combination of at least two types of drivers, and for the Rhine in particular, all five types of drivers were involved in both developed what-if scenarios. The outcome variables are typically related to water availability and/or water demand, and in a few cases to water security or water quality.

The what-if scenarios presented in Table 3.4 and their original versions in the Annexes are a first attempt, as formulated by the river basin hubs in co-creation with stakeholders. They will need to be refined in the later stages of the project in terms of their suitability for modelling. Changes in drivers will need to be quantified and outcome indicators clearly defined.

Table 3.4 The list of what-if scenarios developed by river basin hubs and their grouping by drivers.

Hub	What-if scenario	Drivers				
		Climate Change	Water Allocation	Water or Environmental Policy	Land Use change	Socio-economic change
Danube	DAN1: What would be the consequences of a 20% reduction of discharge caused by a disappearance of glaciers for various water users (e.g. navigation, hydropower, irrigation, habitats)?	+				
	DAN2: What would be the consequence of climate change induced increase in the design discharge for 100 years floods by 10 or 20% combined with a complete or partial losing floodplains for the flood risk?	+			+	
	DAN3: What if in dry periods the water availability does not allow to satisfy all water demands from industry to households to the environment?	+				
Drammen	DRA1: What would be the consequence of three consecutive drought years (two such years occurred in 2021-2022) for various water users and energy sector?	+				
	DRA2: What would be the consequence of the occurrence of unprecedented flood events (such as the one from August 2023, but with a one extra day of precipitation) for security and infrastructure?	+				
Duero	DUE1: What would be the consequence of climate change-triggered increase in ET and crop water consumption combined with more frequent extreme events for aquifer recharge?	+				
	DUE2: What would be the consequence of continued EU environmental policies advocating the reduction of fertilizer inputs for groundwater nitrate concentrations?			+		
	DUE3: What would be the consequence of gradual abandoning of the existing agricultural land combined with a massive implementation of new energy acquisition technologies (e.g. photovoltaic, solar thermal) for the use and availability of groundwater and its quality.				+	+

Hub	What-if scenario	Drivers				
		Climate Change	Water Allocation	Water or Environmental Policy	Land Use change	Socio-economic change
Duero	DUE4: What would be the consequence of the reduction (or elimination) of agricultural subsidies for crop patterns, and overall water use?			+		
East Anglia	EA1: What would be the consequence of more frequent droughts and/or drastic changes of seasons due to climate change for meeting the water demand (groundwater vs surface water availability, in particular)?	+				
	EA2: What if water demand is significantly higher than current predictions due to a) high per capita consumption b) high population growth c)high non-household water demand, d) more mainstream hydrogen production?				+	+
	EA3: What if there are significant changes in water policy licensing (e.g. reduced or more flexible licencing)			+		
Messara	MES1: How will climate change alter water resources availability (e.g. reduced precipitation patterns, increased T, ET) under different climate scenarios?	+				
	MES2: What would it mean for the water balance and water allocation if population growth and economic development patterns change, including land use and/or mix of agricultural crops changes (e.g. replacing olives trees with avocados)?		+		+	+
	MES3: What would it mean for meeting water demand and agricultural economic growth if the Faneromeni reservoir operating rules and related water allocation quotas are altered?		+			
	MES4: What would further exploitation of groundwater for irrigation mean for groundwater resources?		+			
	MES5: What if ecosystem/environmental requirements are tightened?			+		
	MES6: What if water conservation (e.g. deficit irrigation) and/or water reuse are introduced in some parts of the basin?			+		
	MES7: What if no further water abstraction licenses are granted and/or expanded, and stricter enforcement and control measures are imposed on the abstracted volumes and rates?			+		
	MES8: What if excess surface water (e.g. from the diversion of the nearby Platis River) is available for irrigation use (via the Faneromeni Dam) and/or is stored in groundwater aquifers (artificial groundwater recharge)?		+			
Rhine	RHI1: What if the Rhine countries in the Rhine river basin under climate change collaborate more closely, form a strong civil society, form circular and local economies, develop a high environmental awareness, shift to sustainable agricultural practices, shift to local crops and alternative farming techniques, and trade and transport grow between the Rhine countries?	+	+	+	+	+
	RHI2: What if the Rhine countries in the Rhine river basin under climate change distance from each other, form a nationally oriented society, form national economies, develop a high interest in security and stability, focus on self-sufficiency and independent food security, shift to more irrigation intense agriculture, reduce export and import on the Rhine?	+	+	+	+	+
Seine	SEI1: What if the upstream reservoirs cannot fulfil their management objectives in the future climate (more severe low flows) and socio-economic changes leading to a higher water demand downstream of reservoirs)?	+				+
	SEI2: What if climate change reduces groundwater recharge and therefore its natural capacity to support low flows, accentuating the future challenge of managing the upstream dams?	+				+
	Total	12	6	8	6	7

4. Next steps

The elements elaborated in the co-creation process, especially the narratives and what-if questions, will serve to build a set of water demand scenarios (Task T2.5), which also included identifying the necessary data sets for high-resolution water demand estimates. They will also contribute to assess water resources availability under risk by climate change (Task T4.2), which relies partly on the scenario for the "Business-as-Usual" (BAU) reference situation, but also on other scenarios (based on selected Shared Socioeconomic Pathways (SSPs) climate change scenarios of projected socioeconomic global changes, as defined in the IPCC Sixth Assessment Report) and/or what-if scenario questions that refer to most important stressors to the functioning of the water management system as defined by the stakeholder communities in the basin.

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ANNEX 1: Scenarios for the Danube river basin hub

A1.1 Introduction

The multi-national Danube River Basin is characterized by a strong diversity in economic conditions, principally showing a west-east decline in economic growth and prosperity. While agriculture covers about half of the basin area, industry accounts for a large share of the GDP. Shared waters fluxes across national borders act as the connecting lifeline for food, energy, and ecosystems, but also requires management strategies for saving and allocation freshwater resources under hydroclimatic changes.

Climate change is the main factor affecting water resources in the Danube River Basin. Future water demand is expected to increase due to GDP growth. Several water-dependent sectors are likely to experience extended periods of significant water shortages during summer months.

Given the different socioeconomic and geopolitical drivers, emerging challenges for the management of the freshwater resources were identified using the information provided by the stakeholders.

The develop STARS4Water narrative for the Danube River Basin primary builds on:

- Meeting with stakeholders in the Danube River Basin
- Expert meetings within the scientific community in the field of water management, ecosystem restoration, navigation and hydropower.
- Clime Projections such as bassline information such as Coordinated Downscaling Experiment over Europe (EURO-CORDEX)
- Reports and Strategies such as JRC reporting on Impact of a changing climate, land use, and water usage on water resources in the Danube river basin (Bisselink et al., 2018), Reporting on Water scenarios for the Danube River Basin: future challenges and preparedness (Pistocchi et al., 2020) or the ICPDR Strategy on Adaptation to Climate Change (ICPDR, 2018)

A1.2 Matrix of anticipated changes

Table A1.1 Final matrix of anticipated changes for the Danube river hub: A) socio-economic category; B) biopsychical category

A) Socio-economic

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Agriculture:							
Main crop yields		√					
Fertilizer use			√				
Irrigation needs	√						
Production intensification			√				
Nutrient loss	√						
Nature protection:							
Biodiversity							√
Migration barriers			√				
Infrastructure status:							
Number of hydraulic structures			√				
River length impacted by hydraulic structures		√					
Drainage system extent and efficiency			√				
Well-being:							
Increased/decreased environmental or disaster risk	√						
Increased/decreased vulnerability to climate change	√						

B) Biophysical

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Eutrophication:							
Nutrient concentration and loads			√				
Erosion and sedimentation:							
Suspended sediment concentration and loads	√						
Soil erosion		√					
Priority substances (pollution):							
Selected priority substances loads and concentrations		√				√	
Water availability:							
Water level in rivers					√		
Discharge					√		
Groundwater level						√	
Water harvesting			√				
Floods:							
Timing			√				
Extent		√					
Frequency		√					
Duration			√				

A) Socio-economic

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Demography / Migration:							
Population number (Net migration)					√		
Upstream issues:							
Water abstraction (policy)		√					
Water storage (reservoirs)		√					
International cooperation on water policy and river basin management			√				
Energy:							
Hydropower demand	√						
Hydropower installed capacity		√					
Cooling water demand		√					
Land Use:							
Arable land area							√
Forest area			√				
Built-up area			√				

B) Biophysical

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Droughts:							
Timing		√					
Frequency	√						
Duration	√						
Severity	√						

A1.3 Business as usual scenario narrative

Table A1.2 Narratives for the Danube river basin hub: A) socio-economic category; B) biophysical category

A. Socio-economic:

Around 80 million people currently live in the Danube region. Forecasts of **population development** based on historical changes show that the number of people in the Danube region is tending to decrease slightly (Habersack et al, 2022). It seems that there is a big difference compared to the urban areas (e.g., the city of Vienna is growing by 30,000 people every year). On the other hand, a decline in population can be observed in rural areas in many regions. In addition, an increase in population decline can be observed in the south-east European countries (due to migration to other countries). This means that the Danube region as a whole is experiencing a slight decline in population, while the individual cities are growing and rural areas are losing population, particularly in the south-east (Figure A1.1). Despite the population decline in the catchment area, there is an increasing demand for water in the Danube region, especially in the urbanised areas due to the individual increase in water consumption per person (bathing, etc.), but also for the growing industry.

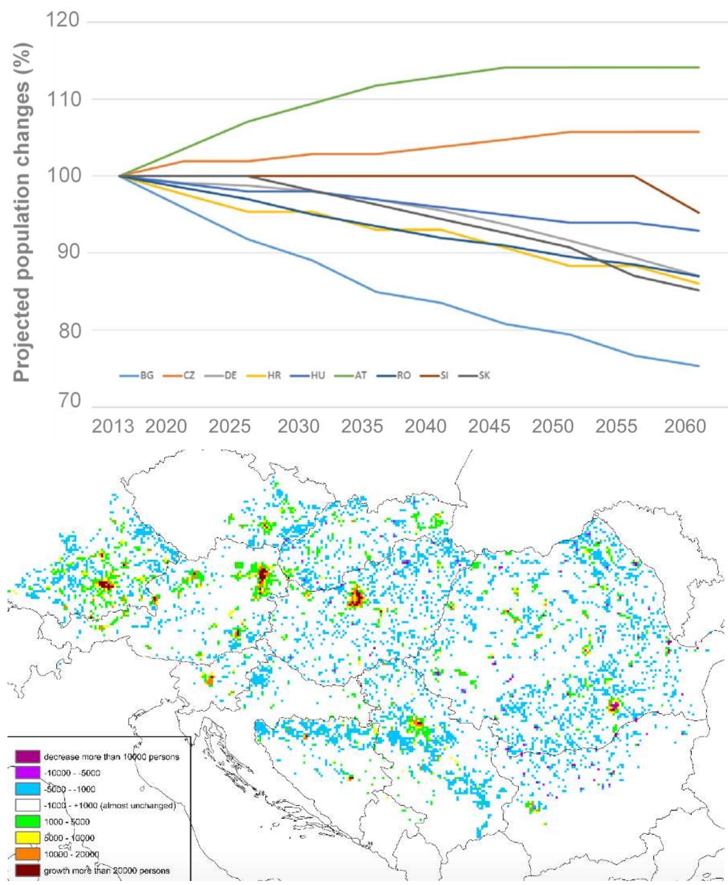


Figure A1.1: Top: Projected population developments for selected Danubian countries until 2060 after Habersack et al. (2022). Source: Bisselink et al. (2018), WHO (2015), modified. Bottom: Projected population developments in the Danube River Basin from 2010 until 2050 after Habersack et al. (2022). Source: Bisselink et al. (2018); WHO (2015); JRC LUISA (2016).

In the Danube catchment area, there has been a considerable loss of natural soils and wetlands in recent decades. In particular, increasing **sealing of the land surface**, despite a decline in population, together with the loss of floodplains, is leading to an increase in surface runoff and greater economic damage downstream (in Austria, for example, around 12.5 ha of land is sealed every day by houses, infrastructure, roads, shopping centres, etc.). This significantly changes land use in the Danube region, leading to an increase in surface runoff and also to soil losses for agriculture. This also hinders groundwater recharge and, in conjunction with the reduced retention capacity, leads to greater effects of droughts in the future. On the other hand, forest cover is increasing in the headwater catchments over time, e.g. due to a higher tree line due to warmer temperatures or the abandonment of mountain pastures previously used for cows, etc. The proportion of roads, shopping centres, etc. and living space per person increases over time, resulting in a continuous decrease in open soil areas.

As the climate warms, a significant **change in agriculture** is foreseeable in the Danube region. This will lead to different developments in the still water-rich mountain regions compared to the lowlands, especially along the middle and lower Danube. In the Alpine region, for example, maize or wine will grow at altitudes that could not previously be utilised. In the lowlands, there will be an intensification of the industrialisation of agriculture, where the need for irrigation will increase dramatically due to global warming. In addition to summer droughts, extreme precipitation events may also cause flooding and soil erosion, which are associated with the entry of nutrients and pesticides into the Danube river system.

In the Danube catchment, especially in the Alpine and mountainous regions, **hydropower** plays a significant role in electricity generation and supply. Even in the intensively utilised river systems in Germany and Austria (e.g., there are 5250 hydropower plants in Austria) further use of hydropower is planned (e.g., the current government in Austria intends to produce further 5TWh with new hydropower). At the same time, a new wave of hydropower development can be observed in the Balkan and Carpathian regions, where the focus on sustainability is of central importance (e.g., new hydropower types taking into account the continuity of biota and sediments).

With regard to energy supply from other sources than hydropower, the demand for **cooling water** is also important in the countries of the Danube region, where there are nuclear power plants, for example. As the water temperature has risen by more than 2 degrees in the last 30 years, there is a correlation between the demand for cooling water and climate change, which will most likely lead to an increase in demand.

Hydraulic engineering infrastructure such as weirs and barrages could be expanded in areas of the Danube basin where hydropower development is increasing (see above). On the other hand, obsolete hydraulic structures are being completely removed for ecological reasons or replaced by other structures such as ramps to improve river continuity.

B. Biophysical:

A mature issue due to climate change is the already existing and intensified melting of the **glaciers** in the Danube basin. It is to be expected that around 2050 over 90 % of the glaciers will not exist anymore. This will lead to significant reduction of discharges in the Danube River during drought conditions. According to the existing knowledge gained from comparable river basins like the Rhine, this reduction might be more than 10%. In the summer time this can lead in certain areas to a negative impact for navigation, but also a negative boundary condition for irrigation, cooling water demand, water supply for drinking water, hydropower and biodiversity. Beside the reduction of the discharge in dry periods the water temperature will further increase given the lack of the cooler melting water of the glacier.

Climate change together with land use change (see above) will lead to more stationary weather patterns which can cause long lasting **drought** periods especially in the summer time. So it can be assumed that water scarcity will increase over time, leading eventually to shortages of water for the different water uses and environment. This might cause a conflict between the different usages like irrigation, hydropower or navigation. At the same time, there is a negative impact on the biodiversity by less water and higher temperatures. This biophysical changes in conditions are thus linked back to the socioeconomics (chapter see above), leading to an urgent need to combine the biophysical changes with socioeconomic consequences. For this, water allocation modelling is urgently needed.

Climate change can be foreseen to intensify **flood risk**, which includes increasing fluvial and pluvial floods (Probst and Mauser, 2022). The fluvial floods are intensified by higher precipitation rates and rain instead of snow in the Alpine areas of the Danube basin, intensified in the consequences by a loss in retention capabilities due to land surface sealing and a disconnection of floodplains. Pluvial floods may increase due to local thunderstorms caused by an increasing water content in the atmosphere from global warming, and given higher temperatures of the oceans. Furthermore, people are exposing themselves more to extreme events by a wrong spatial planning and by not respecting dangerous areas.

These changes from glacier melting to extreme events combined with a land use change and river regulation lead in the Danube basin to an increase of soil erosion in agriculture, transferring sediments into the river systems together with the adsorbed pesticides or other hazardous substances. Industrialisation of agriculture might intensify these processes due to a lack of vegetation cover together with heavy rainfall events. In general, there will be the risk of having either too much water in certain periods of the year or too little water, which can lead to a discrepancy between water supply and water need. All this, the socioeconomic and biophysical changes may raise conflicts between economy and ecology of as well upstream and downstream countries or within different water usages.

A1.4 What-if scenario questions

What if scenarios:

- What if the glaciers are not existing anymore in 2050: the modelling could show that there is a minus of 20% of discharge (this could also be assumed as a scenario). What is then the consequence for navigation (fairway depth, hydropower, less electricity production, irrigation water availability) competing with the other usages (e.g., biodiversity, habitats vs. drying out of side channels, etc.). What if too little discharge is there for the question “Who gets the remaining water?” The intended water allocation model RIBASIM will allow to simulate such what-if scenarios based on hydrological water balance model at certain defined nodes.
- What if climate change increased the design discharge for 100 years floods by 10 or 20%, while the same time floodplains will be lost completely or partially and settlements will expose themselves to high risk zones. Reasonable assumptions of changes can be modelled for selected areas and the consequences can be estimated. Based on the stakeholder workshops

for STARS4Water, the focus will be lying on the water scarcity question, whereas this second what-if scenario will be handled more qualitatively.

- What if in dry periods the water availability does not allow to satisfy all water demands from industry to households to the environment? Here, the water allocation model would help to make these interactions and potential conflicts visible as a basis for modelling adaptations and solutions to improve the future critical situation.

ANNEX 2: Scenarios for the Drammen river basin hub

A2.1 Introduction

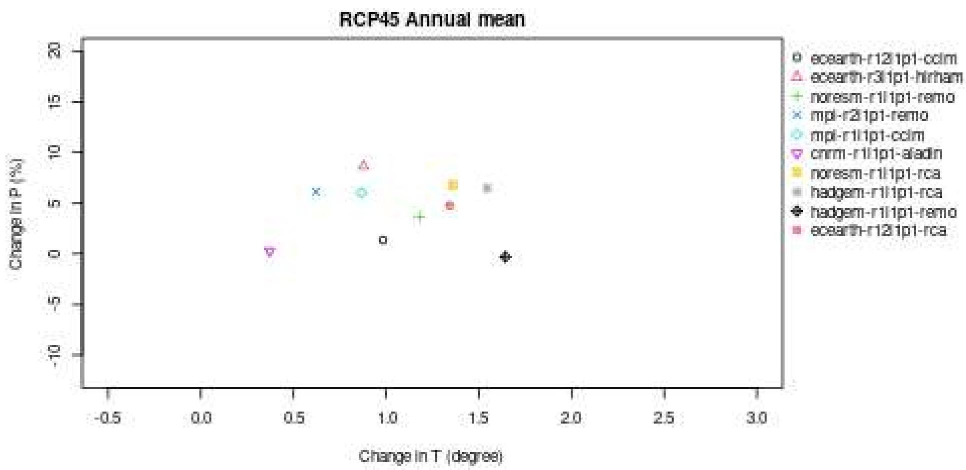
Future scenarios for the Drammen river basin hub are based on a combination of:

- climate projections provided by the Norwegian Centre for Climate Services where NVE is a partner,
- narratives for the Drammen river basin hub based on the Nordic bioeconomic pathways defined in Rakovic et al (2020), and anticipated socioeconomic and biophysical changes constructed in dialogue with the stakeholders,
- two what-if scenarios developed with the stakeholders.

Climate projections

We have selected 6 climate projections that we will run through the hydrological models. CMIP5-RCP4.5: Three combinations GCM – RCM and two downscaling methods (Figure A2.1, A) top panel). CMIP6-SSP370: Three combinations GCM – RCM and two downscaling methods (Figure A2.1, B) bottom panel).

A)



…………B)

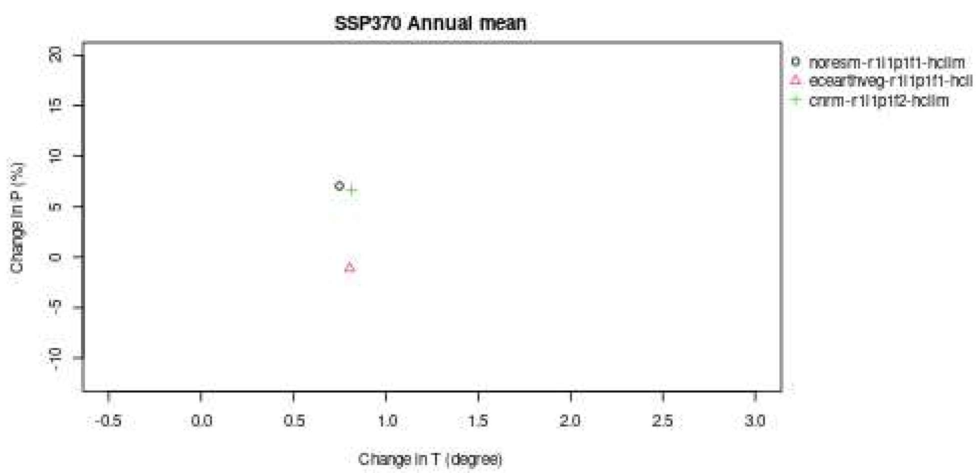


Figure A2.1 Climate projections selected for the Drammen river basin hub: A) CMIP5-RCP4.5; B) CMIP6-SSP370

A2.2 Matrix of anticipated changes

Table A2.1 Final matrix of anticipated changes for the Drammen river hub based on NBP2 - Business as usual towards 2050, and adjusted to represent the local scale: A) socio-economic category; B) biopsychical category

A) Socio-economic

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Agriculture:							
Main crop yields			√				
Fertilizer use			√				
Irrigation needs			√				
Nutrient loss			√				
Nature protection:							
Biodiversity				√			
Migration barriers				√			
Infrastructure status:							
Number of hydraulic structures				√			
River length impacted by hydraulic structures				√			
Drainage system extent and efficiency				√			
Demography / Migration:							
Population number (Net migration)			√				
Upstream issues:							
Water abstraction				√			
Water storage (reservoirs)				√			

B) Biophysical

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Eutrophication:							
Nutrient concentration and loads			√				
Erosion and sedimentation:							
Suspended sediment concentration and loads				√			
Soil erosion			√				
Water availability:							
Water level in rivers				√*			
Discharge			√				
Groundwater level				√			
Floods:							
Extent			√				
Frequency			√				
Duration				√			
Droughts:							
Frequency			√				
Duration			√				
Severity			√				

A) Socio-economic

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Energy:							
Hydropower demand				√			
Cooling water demand				√			
Land Use:							
Arable land area			√				
Forest area				√			
Built-up area			√				

B) Biophysical

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)

*- seasonality changes

A2.3 Business as usual scenario narrative

We have used the Nordic bioeconomic pathways (NBP) defined in Rakovic et al (2020) as basis for the narratives for Drammen river basin hub Figure A2.2 shows the approach going from global SSP to regional and thereafter local quantification to be implemented in modelling at the catchment scale.

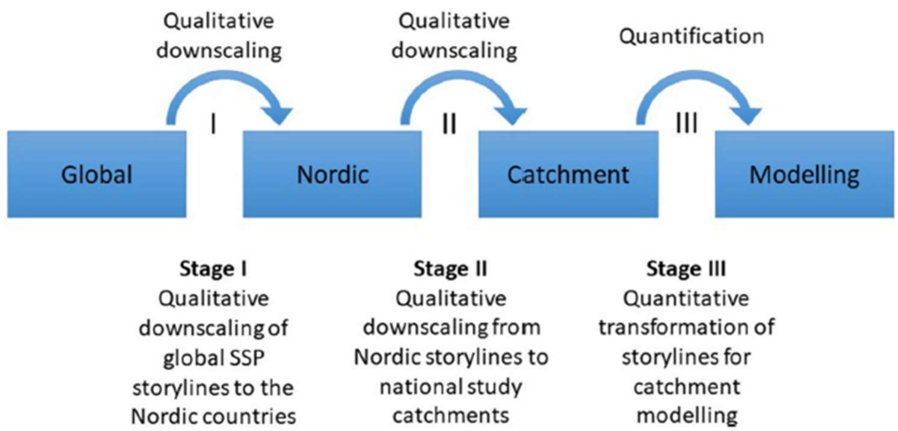


Figure A2.2 From global scenarios to catchment land use modelling (source: Rakovic et al., 2020)

Table A2.2 Narrative for the Drammen river basin hub - Narrative NBP2 – RCP4.5 -- middle of the road – based on the Nordic bioeconomic pathways, with local adjustments for the river basin scale: A) socio-economic category; B) biophysical category

A. Socio-economic: Higher temperature and more precipitation will increase the crop yield and enhance the agriculture-related fields. Intensification of **agriculture** with conventional approaches. There are moderate attempts to reduce the nutrient losses. Medium-scale animal husbandry farms, some are adjacent to arable land. Weak focus on sustainability. The changes in **land use** will be small. There will be a slight increase in built-up areas at the expense of arable land due to continued migration from rural areas. Regulations leads to slow decline in the ongoing deforestation. Forestry according to the current Nordic model, i.e. dominance of even aged stands of coniferous trees. The total **population** will have a medium growth. Migration from rural to urban areas within the basin hub will continue. It is not expected to be built new hydropower structures within the basin. Existing structures will be maintained and expanded. There are no anticipated changes to the **hydraulic infrastructure elements** within the basin. Longer periods without rainfall and changes in the water available from snowmelt will increase the need for irrigation. Water extraction for farming and agriculture will increase during dry periods. In the **energy** sector, the expected changes are related to variability in energy demand and hydropower production. As the potential for hydropower generation in the catchment area is

currently fully exploited, no change will be observed in this sector. There will be a relatively small interest in bioenergy. Still relying on HP and fossil fuels.

Nature protection concern for local pollutants, but limited success in implementations of environmental policies.

B. Biophysical:
The expected slight increase in fertiliser use combined with increased precipitation will contribute to higher nutrient losses from agricultural land. This in turn will lead to higher concentrations and loads of nutrients in watercourses, mainly due to their high concentrations in groundwater, drainage water and surface runoff, resulting in increased **eutrophication** of surface waters.

More intense precipitation will increase **soil erosion** and sediment transport.
Nature based solution to reduce soil erosion will be used only to a small extent. The result of increased soil erosion will be higher concentrations and loads of suspended solids in rivers.

Water availability will undergo some changes, mainly related to how increased temperature and precipitation will change the pattern of snow storage and snowmelt. Discharge is expected to increase during winter due to less snow storage and reduce during spring caused by earlier and less snowmelt.

Changes in rainfall patterns will further affect **floods and droughts**. More intense precipitation will lead to more floods in small and medium size rivers, whereas there will be less floods caused by snowmelt.
Longer periods without precipitation will increase the potential for droughts.

A2.4 Other scenario narratives

Drammen NBP3 -Self-sufficient – corresponding to SSP3

Table A2.3 Narrative for the Drammen river basin hub - Narrative NBP3 – RCP4.5 – self-sufficient – based on the Nordic bioeconomic pathways, with local adjustments for the river basin scale: A) socio-economic category; B) biophysical category

A. Socio-economic:
Higher temperature and more precipitation will increase the crop yield. Intensification of **agriculture** with conventional approaches. Expansion where possible. Whole removal of biomasses. There are moderate attempts to reduce the nutrient losses. Specialized, relatively largescale animal husbandry farms. Weak focus on sustainability. Policy orientation towards security. Oriented towards self-sufficient within the Nordic countries.

The changes in **land use** will be medium. There will be a slight increase in built-up areas at the expense of arable land due to continued migration from rural areas. **Forestry** will follow the current Nordic model, but intensified management, low priority for environmental concerns. Hardly any regulations. Continued deforestation due to competition over land and rapid expansion of agriculture.

Intensification of agricultural production will increase the need for irrigation water and will require an updated drainage network. In the case of other **infrastructure elements,** new hydropower structures will be built, due to the need for energy security and hydropower production in the catchment area.

There will be a low growth in total **population**. Migration from rural to urban areas within the basin hub will continue. Less migration from abroad.

It is not expected to be built new hydropower structures within the basin. Existing structures will be maintained and expanded. There are no anticipated changes to the **hydraulic infrastructure elements** within the basin. Longer periods without rainfall and changes in the water available from snowmelt will increase the need for irrigation. Water extraction for farming and agriculture will increase during dry periods.

The **energy** demand will be high. Expanding domestic energy systems and some reliance on Nordic fossil fuels. Allowing for more HP production in the catchment. There will be some investments in bioenergy, mainly waste and forestry residuals.

Nature protection low priority for local pollutants.

B. Biophysical:

The expected slight increase in fertiliser use combined with increased precipitation will contribute to higher nutrient losses from agricultural land. This in turn will lead to higher concentrations and loads of nutrients in watercourses, mainly due to their high concentrations in groundwater, drainage water and surface runoff, resulting in increased **eutrophication** of surface waters.

More intense precipitation will significantly increase soil erosion and sediment transport.
There is little focus on nature-based solution to reduce the **soil erosion**.

Water availability will undergo some changes, mainly related to how increased temperature and precipitation will change the pattern of snow storage and snowmelt. Discharge is expected to increase during winter due to less snow storage and reduce during spring caused by earlier and less snowmelt.

Changes in rainfall patterns will further affect **floods and droughts**. More intense precipitation will lead to more floods in small and medium size rivers, whereas there will be less floods caused by snowmelt.

Longer periods without precipitation will increase the potential for droughts.

Table A2.4 Final matrix of anticipated changes for the Drammen river hub for NBP3 – Self sufficient: A) socio-economic category; B) biopsychical category

A) Socio-economic

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Agriculture:							
Main crops yields			√				
Fertilizer use		√					
Irrigation needs			√				
Nutrient loss		√					
Nature protection:							
Biodiversity					√		
Migration barriers				√			
Infrastructure status:							
Number of hydraulic structures				√			
River length impacted by hydraulic structures				√			
Drainage system extent and efficiency			√				
Demography / Migration:							
Population number (Net migration)				√			
Upstream issues:							
Water abstraction			√				
Water storage (reservoirs)			√				
Energy:							
Hydropower demand			√				
Cooling water demand			√				

B) Biophysical

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Eutrophication:							
Nutrients concentration and loads		√					
Erosion and sedimentation:							
Suspended sediments concentration and loads			√				
Soil erosion		√					
Water availability:							
Water level in rivers				√*			
Discharge			√				
Groundwater level					√		
Floods:							
Extent			√				
Frequency			√				
Duration				√			
Droughts:							
Frequency			√				
Duration			√				
Severity			√				

A) Socio-economic								**B) Biophysical**							
Issues / *Variables*	Increase			No change	Decrease			Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)		(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Land Use:															
Arable land area			√												
Forest area						√									
Built-up area			√												

* - depending on season

A2.5 What-if scenario questions

We developed two what-if scenarios:

1. Droughts – energy crisis and dry years

Energy crisis and dry years. Using the situations from the years 2021-2022 and test the system including a third dry year. The situation in 2023 was that there was a large storage of snow during the winter season 2022/2023. Which was not the case of 2021/2022.

2. Floods – security and infrastructure

Using the case of august 2023, the largest flood in basin since 1867 (?). The extreme weather Hans was a two-day event. What would the event been if we add an additional day of precipitation. The additional day could be using the event of Lille Hans (Alternative if the precipitation was 20% higher, as indicated by the climate projections).

How often can we find that the two-day precipitation exceeds the values of Hans?

ANNEX 3: Scenarios for the Duero river basin hub

A3.1 Introduction

To identify the key issues of concern to the stakeholders, we sent a questionnaire to approximately 800 people, including public administrations, farmer associations, water supply companies, actors from the private sector, environmental conservation groups, and research institutes. This was done through the mailing list of the Duero Water Authority.

The questionnaire was made up of seventeen questions, three of which pertained directly to scenarios. We obtained just over 103 replies. Although this is a relatively small proportion of the emails we sent out, we believe the results are sufficiently representative for practical purposes.

Figure A3.1 presents the results of the survey. Each bar represents a specific issue, the size of the bar being the number of respondents that identified each issue as the single most important one for the future of the basin. As shown, climate change/climate-related variables appear to be the most pressing issue for most stakeholders in the basin, followed by water quality and agricultural policies.

Survey results were used subsequently to frame the debate during the second STARS4Water stakeholder workshop, held in the town of Arévalo, Duero basin, in March 12th, 2024. The purpose of this meeting was to clarify how stakeholders perceive that each of these issues could unfold in the future, in order to develop narratives. The meeting was attended by twenty-three stakeholders, eight of them in person and fifteen online. The online/in person strategy was adopted in view of the size of the basin, which results in long travel times for those living far away from the meeting venue. Participants included representatives from nearly all sectors outlined above.

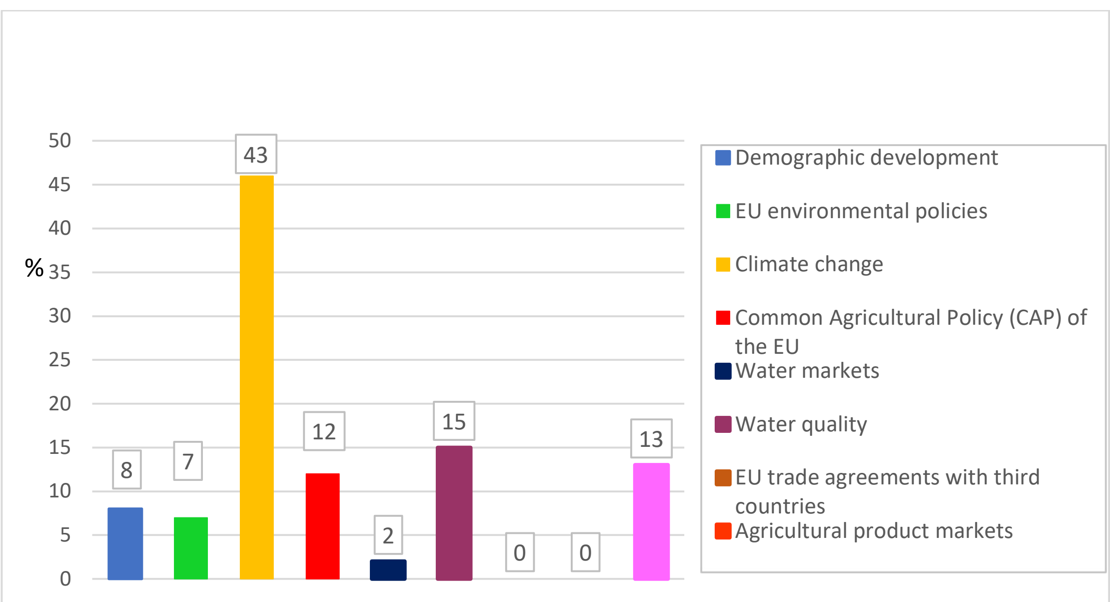


Figure A3.1. Identification of key issues of concern in the Duero basin as per the stakeholders' answers to the questionnaire.

The information below combines the research group's initial knowledge base with the results of stakeholder engagement in the Duero basin, described above.

The Duero basin is characterized by heavily imbalanced water demands (agriculture amounts to about 90% of total water use), an aging population, strong water use inertias and a general sense of reluctance to change. Hence, an important share of the issues identified below are external, and largely beyond the control of basin authorities. Furthermore, despite its semiarid nature, the basin is sparsely populated (25 inhabitants/km^2 vs 109 inhabitants/km^2 across the EU) and relatively well endowed with water resources, both in terms of surface water and groundwater. Therefore, there is little conflict among water uses, as well as between users and the authority.

A3.2 Matrix of anticipated changes

Table A3.1 Final matrix of anticipated changes for the Duero river hub - business as usual conditions: A) socio-economic category; B) biopsychical category

A) Socio-economic

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Demographics:							
Population growth						√	
Agri-business presences				√			
Environmental policy:							
Fertilizer use						√	
Conservation of aquatic ecosystems			√				
Agricultural policy:							
Water intensive crop surface				√			
Dryland crop surface					√		
Agricultural subsidies				√			
EU trade agreements with third countries		√					

B) Biophysical

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Climate change / climate related:							
Rainfall					√		
Temperature			√				
Water availability					√		
Water use:							
Water demands			√				
Water reuse				√			
Balancing use				√			
Water quality:					√		
Nitrate content in groundwater							
Arsenic content in groundwater					√		

A3.3 Business as usual Scenario narrative

Draft narrative – *business as usual* scenario

Variables leading to this narrative have been grouped in two categories, namely, socio economic and biophysical issues. Each category is further divided in several variables, whose potential evolution under a business as usual scenario is discussed below. This evolution is also summarized in the form of a matrix of anticipated changes (Table A3.1). Horizon is 2040 in all cases.

Table A3.2 Narrative for the Duero river basin hub: A) socio-economic category; B) biophysical category

A) Socio-economic issues

Demographics are an issue of concern in the Duero basin. Population in the region has declined steadily in recent decades, from 2.6 million inhabitants in the 1980s to 2.3 in 2023, a trend which is expected to continue into the future. The effects of demographics are particularly acute in the agricultural sector, as farming population is aging and the replacement rate appears insufficient to maintain the current workforce. Since agriculture is responsible for 90% of water uses in the basin, this could be expected to reduce water use overall. There is, however, an important “if”: as retired farmers sell their holdings, cheap land could favour the presence of large agri-businesses in the area, which in turn, could drive water demand in unexpected ways. Since domestic and industrial consumption amount to about 10% of the total water uses, urban water uses are not expected to change significantly despite population decrease.

Agricultural policy is another major issue, largely because agriculture is responsible for 90% of the basin’s water uses and because agriculture is policy-driven. Indeed, most of the basin’s agricultural production is subsidized. Subsidies explain, for instance, the presence of water-intensive crops such as sugar beet and corn, despite the semiarid nature of the region. The business as usual route seems likely to hold in the near future. While some stakeholders identify a slow shift from dryland crops to irrigated crops, crop patterns are unlikely to change in the coming years unless EU agricultural policy takes an unexpected turn. A potentially important driver for future change is the trade agreements that the EU continues to sign with third countries, which favour the import of certain crops. The concern is that producing these crops outside Europe is significantly cheaper due to less stringent environmental and health requirements, as well as to limitations in worker rights in many cases. As a result, cheap crop imports could eventually drive European farmers, including the Duero’s, out of business. This would favour the trends identified under the *demographics* issue. Water demands in the basin could decrease as a result.

Environmental policy is strongly intertwined with agricultural policy. The need to preserve environmental flows, coupled with limitations to fertilizers, places additional pressure on agricultural activities, and could also contribute to reduce water demand in the mid-term (see *agricultural policy* above). However, no matter how rigorously farmers follow environmental regulations, the issue of groundwater pollution is likely to stay for a long time. This is because the basin’s major regional aquifers are characterized by slow flow, which implies that a large share of the pollutants might still be a long way away from finding an outlet. Furthermore, there is an important nitrate load in the unsaturated zone that has not yet reached the water table.

B) Bio-physical issues

Climate change and climate-related variables are the single most important issue for the basin's future in the eyes of stakeholders (see annex). Forecasts for the Iberian Peninsula point at a slight increase in temperature, less rain overall, and an intensification of extreme events. It is currently unclear whether this will lead to less water availability. Given the semiarid nature of the climate, where recharge tends to take place preferentially during humid years and is relatively small in dry years, so aquifer recharge could decrease or increase depending on whether less rainfall prevails over a larger number of extreme precipitation events.

As explained above, **water use** is largely linked to agriculture. While population will continue to decline, a smaller domestic demand or water reuse for urban uses are not expected to trigger significant changes in relation to the basin's water demands. In this regard, the basin does not currently feature major conflicts among users. Furthermore, these seem unlikely to arise as a result of foreseeable changes within a business as usual narrative. In general terms, it could be argued that this is because it is a sparsely populated region relatively well endowed with water resources.

Finally, **water quality** is seen as a major issue of concern by a significant proportion of the stakeholders, although they do not always see this problem from the same perspective. Nitrate is widespread across the main aquifers in the central areas of the basin, systematically exceeding the 50 mg/l threshold in many monitoring wells. This is a problem from the point of view of water supply, particularly in the case of some small municipalities that cannot afford water treatment. Mitigation measures are also problematic for many farmers, who are subject to cuts on fertilizer use. The other issue pertaining to water quality is arsenic. Groundwater pumping in some areas, particularly towards the south east of the basin, has led to the mobilization of naturally-occurring arsenic, which currently threatens groundwater-based urban supply in the municipalities of this area. Mitigation measures have also been put into place in the case of arsenic. The potential evolution of pollution within the basin's aquifers has already been discussed under the *environmental policy* issue: due to the nature of the affected aquifers, characterized by long residence times and strong inertias, water quality issues are unlikely to experience significant changes in the coming years.

A3.4 What-if scenario questions

Potential what-if questions

What-if questions are based around some of the key issues identified above. In some cases, predicting the outcome of the business as usual trend is far from straightforward. This is seen as an argument in favour of adopting the what-if route in scenario simulation.

Climate-related variables and aquifer recharge

As explained above, average rainfall is expected to decrease and average temperature is expected to increase, which would in turn augment evapotranspiration and crop water consumption. These trends would likely be coupled with an increase in extreme events. Given the semiarid nature of the climate, where recharge tends to take place preferentially during humid years and is relatively small in dry years, this scenario could potentially lead to increased or decreased groundwater recharge (it depends on which of the two changes prevails over the other one: decreased average rainfall or the increase in extreme wet events).

Water quality

EU environmental policies currently advocate the reduction of fertilizer inputs. While farmers generally comply, nitrate content continues to increase in many monitoring points. This can be a result of long residence time in the aquifers, as groundwater movement is typically slow. Furthermore, the nitrate accumulated in the unsaturated zone might still take a long time to wash off, and an even longer time to traverse the aquifer until it finds an outlet.

Changes in land use patterns and demographics

As more and more farmers retire, agricultural surface could be replaced with other activities that require large expanses of land. Take for instance renewable energy sources such as solar energy. This could lead to important changes in water use and, potentially, in water quality.

Another what-if scenario arises from a joint analysis of land use and demographics. As explained above, a large share of the basin's farmers will reach retirement age in the coming decade. There is no guarantee that they will be replaced by younger farmers because most young people prefer other professional activities. This suggests that the gradual abandoning of the existing agricultural land could lead to two opposite outcomes from the point of view of water use. (1) As aging farmers retire, agricultural land is gradually left uncultivated, leading to a decrease in water use; and (2) as aging farmers retire, (a) land becomes cheap and ripe for large agribusinesses to establish themselves in the basin, which could eventually lead to an increase in water consumption; (b) the continuous growth of energy production through technologies that require large amounts of land (photovoltaic, solar thermal) can lead to a scenario of competition between the energy and agricultural industries. This fact does not necessarily have to be negative, at least from the perspective of water use. It is proposed to evaluate the impact that the massive implementation of these technologies in the Duero Basin may have in the future on the use and availability of groundwater and its quality.

Agricultural policy

As in many European regions, agriculture in the Duero basin depends heavily on subsidies. Thus, farmer decisions do not chiefly rely on considerations such as water savings, environmental concerns, or market fluctuations, but on which crops attract the most subsidies. A potential what-if scenario in this case would be how the reduction (or elimination) of agricultural subsidies could affect crop patterns, and, with these, overall water use.

ANNEX 4: Scenarios for the East Anglia river basin hub

A4.1 Introduction

Within the East Anglia river basin hub, a Business as Usual narrative was defined. The narrative combines information from the Shared Socioeconomic Pathways (SSP2) and expert opinion from a selection of key stakeholders in the basin hub. These key stakeholder worked collaboratively with the STARS4Water, via an in-person workshop to co-create a Business as Usual exploratory narrative based on a "most likely" anticipated outcome for the East Anglia river basin hub.

A4.2 Matrix of anticipated changes

Table A4.1 Final matrix of anticipated changes for the East Anglia river basin hub: A) socio-economic category; B) biopsychical category

A) Socio-economic							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Agriculture:							
Main crop yields				√			
Fertilizer use				√			
Irrigation needs		√					
Irrigation efficiency			√				
Production intensification			√				
Nutrient loss				√			
Crop types			√				
Nature protection:							
Biodiversity ***protection***	√						
Migration barriers					√		
E-flows		√					
Drought resilience			√				
Environmental designations			√				
Stewardship schemes		√		√			
Invasive non-native species (INNS)		√					
River restoration		√					
Infrastructure status:							
Number of hydraulic structures				√			

B) Biophysical							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Eutrophication:							
Nutrient concentration and loads			√				
Erosion and sedimentation:							
Suspended sediment concentration and loads			√				
Soil erosion				√			
Soil management			√				
Priority substances (pollution):							
Selected priority substances loads and concentrations			√				
Algae			√				
Pathogens			√				
Water availability:					√[1]		
Water level in rivers					√		
Discharge			√				
Groundwater level			√				
Water harvesting			√				
Salt intrusion			√				

A) Socio-economic							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
River length impacted by hydraulic structures					√		
Drainage system extent and efficiency		√					
Wastewater treatment		√					
Water leakage						√	
Water storage and transfer		√					
Desalinisation			√				
Non-potable water reuse		√					
Inter-basin transfer		√					
Well-being:							
Increased/decreased environmental or disaster risk			√				
Increased/decreased vulnerability to climate change		√					
Recreational uses			√				
Landscape value			√				
Demography / Migration:							
Population number (Net migration)		√					
Public awareness		√					
Policy:							
*Water abstraction **(policy)***		√					
Water storage (reservoirs)		√					
Cross-departmental alignment of national policy				√			
Impact of Brexit				√			

B) Biophysical							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Floods:							
Timing			√				
Extent		√					
Frequency		√					
Duration		√					
Groundwater			√				
Fluvial			√				
Pluvial			√				
Coastal			√				
Droughts:							
Timing			√				
Frequency			√				
Duration			√				
Severity			√				

A) Socio-economic								B) Biophysical							
Issues / *Variables*	Increase			No change	Decrease			Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)		(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Food security		√													
Energy:															
Hydropower demand			√												
Hydropower installed capacity			√												
Cooling water demand ***(decarb)***		√													
Cooling water / process water		√													
Hydrogen-based generation		√													
Land Use:															
Arable land area					√										
Woodland *area*			√												
Built-up area		√													
Nature Based Solutions		√													
Peatland restoration			√												
Land Use:															
Domestic water use			√												
Water metering + tariffs		√													
Water demand per capita						√									
Water efficiency			√												
PWS – non-domestic															
Domestic water use		√													
Water metering + tariffs		√													
Water demand			√												
Water efficiency		√													

Issues/Variables marked in ***bold*** – added for the East Anglia river basin hub

[1] - Regarding water availability for human use.

A4.3 Business as usual Scenario narrative

Table A4.2 Narrative for the East Anglia river basin hub: A) socio-economic category; B) biophysical category

A) Socio-Economic: An increasing population, and thus market demand, will see a slight intensification of agriculture in East Anglia, a key-crop growing region of England. Due to a warming climate and changing patterns in rainfall, irrigation needs will see a moderate increase, forcing irrigation efficiency to increase slightly, although actual crop production will remain relatively stable. There will be a drive towards a better use of fertilizers due to political pressure, which will also see a slight diversification away from the growth of traditional crop types. This, along with the continued use of import and export markets, will ultimately lead to a moderate increase in food security. The population will continue to increase at a modest rate, partly driven by continued migration into the region. However, due to more stringent water tariffs and moderate increases in the use of water meters, water demand per capita will see moderate decreases. This decrease will also be driven by slight improvements in both water efficiency measures and water reuse in the domestic sector. Due to modest increases in public awareness around climate change and water availability, the measures put in place will be relatively well received. As a result of the increasing population, the extent of built-up areas will see modest expansion. As such the importance of water in terms of its value to the regional landscape, along with its benefits towards wellbeing via recreational uses, will also increase slightly. However, climate change is likely to place the environment at a slightly higher level of risk to droughts, floods and the associated water shortages and surpluses – as such, the region's population are also likely to see moderate increases in their levels of vulnerability towards these impacts. The drive for a more efficient use of water will generate improvements in water infrastructure. Wetter winters will put increased pressure on the wastewater system, forcing modifications to increase system capacity. The extent and effectiveness of drainage systems will therefore moderately increase, in line with a similar magnitude of reduction in network leakage. As a result of these factors, the treatment of wastewater will also rise moderately. Water storage in reservoirs, and associated transfers both within and external to the river basin hub, will see moderate increases across the region to meet demand in the drier summer periods, although the actual river length impacted by hydraulic structures will decrease slightly. Infrastructure for the desalination of sea water will be employed to help meet rising sectoral demands and accommodate the change in temperature and rainfall, although the implementation of this technology will only be slight. The re-use of non-potable water will be utilised at moderate levels in line with the requirement for better efficiency around water and water recycling. This use of 'hard' infrastructure will also be complimented by approaches via nature-based solutions where appropriate, where land outside of urban areas will be used to help store and slow the movement of water. Moderate increases in this type of intervention will be seen across the region, along with slight increases in the restoration of peatland environments to help minimise carbon loss and maintain water table levels. Legislation around water abstraction will also heighten moderately, as increased demand from all sectors puts further stress on limited water resources in the region. In the energy sector, hydrogen-based energy generation will see moderate increases, alongside a slight increase in hydropower supply. As part of the national net-zero initiative, innovative technologies around water for cooling (e.g. hydropower, water data centres) and water heat extraction will also increase moderately, such as using heat from

sewage effluent to heat up fuel waste. Such technologies will be utilised as alternatives to more traditional approaches to reduce the region's carbon footprint.

Nature protection and the requirement to ensure environmental sustainability will become more prevalent in the region. The protection of biodiversity and ecosystems will increase considerably, resulting in significant reductions in permissible groundwater and surface water abstractions. River restoration and stewardship schemes will play an increasing role, both seeing moderate levels of increased deployment. As a result, the number of migration barriers in rivers are expected to decrease slightly. Invasive non-native species (INNS) are expected to increase moderately, and so measures around how best to manage any influx will be a key element of river restoration schemes. In line with these schemes, environmental flows will continue to be prioritised at modest levels.

B) Biophysical:

Changes in climate will induce a slight change in the occurrence of droughts. The pattern of rainfall will change and accentuate the extreme events. The yearly pattern of floods and droughts will slightly change with a shift of events across the seasons. In terms of droughts, a slight increase in their frequency, duration and severity (intensity) will be observed. There will be a slight augmentation across all types of floods, namely groundwater, fluvial, pluvial and coastal. A moderate change in the frequency, duration and extent (intensity) of floods will take place.

As a result of increased rainfall intensity, erosion and sedimentation will slightly increase. Higher rainfall intensity will induce small accretion in erosion, in particular from agricultural land, causing increased sediment loadings reaching water courses. Increased soil management practices, to drive production intensification, will also contribute to a slight rise in suspended solid concentrations in surface waters across the East Anglia region.

Despite no expected increase in fertiliser use, due to an incentive to better use fertilisers, slightly higher nutrient losses from agricultural land will occur. This rise is due to an increase in acute rainfall events driven by climate change. Thus, increased loadings from agricultural land will result in slightly greater nutrient concentration in groundwater and surface water, resulting in a small increase in eutrophication of surface waters. Consequently, a slight increase in pollution due to algae will also be observed in rivers, lakes and reservoirs. This increase will be further exacerbated with increased water temperature.

A slight increase in priority substances such as micro-plastics, pharmaceuticals, persistent organic chemicals (POPs), Per- and Polyfluorinated Substances (PFAS), and pathogens will occur, mostly driven by increased population and increased monitoring. More substances will be added to the priority substance list, thus increasing awareness to a wider range of chemicals and thus greater monitoring will take place. The changes regarding priority substances in East Anglia are likely to follow similar responses across Europe as all nations are gaining understanding and adapting legislation and regulation with regards to these substances. The rate of change will vary through time: soon, a higher increase will be observed but it will then improve in the longer term. It is worth noting that with regards to drinking water, there will be a drive to lower accepted concentrations for these various substances.

A slight increase in water availability will occur in the future, driven largely by climate change . Increased rainfall intensity will induce a slight augmentation in water levels in rivers and groundwater, whereas increased population will generate slightly higher discharges. More initiatives promoting water harvesting including grey water recycling and roof harvesting will take place, thus contributing to slightly higher water availability. The phenomenon of saltwater intrusion will slightly increase due to rising sea levels. It is important, however, to note that higher water availability will not necessarily translate into increased water availability for human consumption, largely offset by increased water demand, limited storage capacity, stricter freshwater quality standards and environmental sustainability requirements.

A4.4 What-if scenario questions

The participants were asked to think of relevant what if scenarios for their water planning activities. Participants were given 5-10 minute to reflect and capture thoughts on post-its. They were then asked to present their top 2 what if scenarios.

After the meeting, UKCEH combined the scenarios into themes where possible. The themes with the most input and interest from participants were then taken forward and organised into a set of primary scenarios, alongside related auxiliary scenarios. These auxiliary scenarios are not priorities but relate to the priority scenario. The 3 selected priority scenarios are presented in Table A4.2; the auxiliary scenarios related to these are also detailed.

Table A4.2 Priority and auxiliary what if scenarios for East Anglia river hub

Primary Scenario	**Auxiliary Scenarios**
What if droughts become more frequent?	○ What if groundwater was used more to meet demand (due to decreased river flows or floods)? ○ What if climate change predictions change dramatically? ○ What happens if seasons drastically change?
What if water demand is significantly higher than current predictions?	○ What if per capita consumption (PCC) remains stubbornly high? ○ What if population growth increases (higher than predicted)? ○ What if non-household water demand remains high? ○ What if hydrogen production becomes more mainstream?
What if there are significant changes in water policy licensing?	○ What if groundwater flooding occurs due to reduced licensing? ○ What if water licensing is more flexible (e.g. water needs will fluctuate...)?

ANNEX 5: Scenarios for the Messara river basin hub

A5.1 Introduction

The “business-as-usual” scenario for the Messara river basin hub draws on the Shared Socioeconomic Pathways (SSP2) and is based on a comprehensive review of various factors influencing the region's development by 2040. SSP2, often referred to as the "Middle of the Road" pathway, assumes a future where development trends follow historical patterns without significant shifts towards sustainability or degradation. This scenario anticipates moderate advancements in technology, economic growth, and environmental policy, with an emphasis on maintaining current trajectories in agricultural practices, water management, and economic and community development. The narrative was developed through a stakeholder consultation process, designed to gather diverse perspectives and ensure that the analysis is grounded in local realities and needs. The stakeholders involved represented governmental bodies (e.g. the Region of Crete, the Water Directorate of the Decentralized Administration of Crete), the local land reclamation organisations (responsible for agricultural water supply and irrigation), the municipalities, the local domestic water supply and sewerage corporations, and farmers. To be able to downscale the SSP2 in the Messara basin, a wider narrative of the SSP2 in Crete was first elaborated by the stakeholders. Then, the focus was drawn on the specificities of the Messara basin, which is the main agricultural area of the Crete island. Existing sources of information were also taken into account by the stakeholders, such as: the Regional Plan of Crete for Adaptation to Climate Change (PESPKA) (provide insights into adaptive measures that are already considered or need to be enhanced in the region, per sector), the Crete Agricultural Sector Reports (for understanding the baseline conditions and trends in the agricultural sector), the River Basin Management Plan of Crete, Reports on Renewable Energy Potential in Crete (fundamental in planning for energy strategies).

The following key elements were considered at the basis of the SSP2 analysis and dialogue among the stakeholders:

- Economic and Technological Development: the analysis considered moderate economic growth with steady advancements in technology that influence agricultural productivity and infrastructure development.
- Agricultural Focus and Dynamics: the analysis considered the impact of continued traditional farming alongside gradual integration of some innovative practices in crop management and production.
- Environmental Management: the analysis evaluated the implications of ongoing efforts in water conservation, soil health, and biodiversity, reflecting current policies and practices.
- Community and Social Dynamics: the analysis examined demographic trends, migration patterns, and community engagement in local governance and development initiatives.
- Climate Change Adaptation: the analysis also incorporated projected climate conditions and their likely impact on agriculture and water resources, considering current adaptation strategies.

The stakeholder consultation process not only fostered transparency and inclusiveness in developing the SSP2 scenario narrative but also ensured that the projections are well-grounded in local realities and have broad-based support as local knowledge and consensus were incorporated. The diverse input from various community members and experts led to a richer, more comprehensive understanding of potential future pathways and the challenges and opportunities these might present. Furthermore, this stakeholder-driven approach not only enriched the SSP2 analysis for Messara but also promoted a collaborative atmosphere among the participants, fostering a shared commitment to achieving sustainable development goals in the region.

A5.2 Matrix of anticipated changes

To project how specific indicators will change by 2040 in the Messara basin under the SSP2 scenario, we consider several key metrics that are crucial for assessing the development of agriculture in the region. These could include:

1. **Crop Yields**: This indicator reflects the productivity of agricultural practices. By 2040, with moderate technological adoption and improved practices like precision agriculture and efficient irrigation, crop yields in Messara are expected to increase by approximately 5-10%. This takes into account the effects of improved seed varieties and more efficient water and nutrient management, offset by the stress of changing climate conditions.
2. **Water Usage Efficiency**: With the gradual shift to more efficient irrigation systems, such as drip and sensor-based irrigation, water usage efficiency is projected to improve. We might expect a reduction in water use per unit of crop output by around 15%. This improvement is critical given the potential increase in drought conditions due to climate change.
3. **Economic Returns from Agriculture**: Economic returns are influenced by both yield improvements and market access. With better yields and improved market integration and/or accessing premium markets, as well as the diversification into high-value crops, the economic returns from agriculture in Messara could see a moderate increase of around 5-10%. This is bolstered by the growing agrotourism sector, which adds value to the agricultural products through direct sales and tourism-related activities.
4. **Soil Health Indicators**: Soil health will be maintained or slightly improved (by 15%) due to the adoption of sustainable practices such as crop rotation and organic farming. Indicators like organic matter content, soil pH, and nutrient levels are expected to stabilize or improve slightly, contributing to overall sustainability.
5. **Greenhouse Gas Emissions from Agriculture**: The shift towards more sustainable practices and the integration of crop varieties better suited to local conditions should lead to a stabilization or slight reduction in greenhouse gas emissions per unit of agricultural output. Emissions reduction of about 5-10% might be achieved through improved management practices and reduced reliance on synthetic fertilizers.
6. **Biodiversity in Agricultural Areas**: With the implementation of environmental policies that encourage the preservation of natural habitats around farming areas, biodiversity is expected to improve. The increase in buffer zones, use of cover crops, and reduced pesticide use contribute to a healthier ecosystem, which might show a modest improvement in species diversity indices.
7. **Adoption Rate of Technology in Agriculture**: Considering the moderate pace of technological acceptance in the SSP2 scenario, by 2040, approximately 40-60% of farms in Messara are expected to utilize some form of technology in their operations, particularly in areas like irrigation management and crop monitoring.

These projections for 2040 under the SSP2 scenario reflect a balanced path of development and depict a phase of transition where initiatives and improvements begin to take hold, setting the stage for more pronounced changes to follow. This pathway balances growth and sustainability, adapting gradually to changing environmental, social, and economic conditions. The gradual improvements in technology, policy, and practices help Messara navigate future socio-economic challenges and opportunities.

Table A5.1. Final matrix of anticipated changes for the Messara river basin hub: A) socio-economic category; B) biopsychical category

A) Socio-economic

Issues / *Variables*	Increase (+++)	Increase (++)	Increase (+)	No change (0)	Decrease (-)	Decrease (--)	Decrease (---)
Agriculture:							
Main crop yields			√				
Fertilizer use			√				
Irrigation needs					√		
Production intensification			√				
Nutrient loss					√		
Nature protection:							
Biodiversity			√				
Migration barriers					√		
Infrastructure status:							
Number of hydraulic structures			√				
River length impacted by hydraulic structures					√		
Drainage system extent and efficiency			√				
Well-being:							
Increased/decreased environmental or disaster risk					√		
Increased/decreased vulnerability to climate change					√		
Demography / Migration:							
Population number (Net migration)			√				
Upstream issues:							
Water abstraction (policy)					√		

B) Biophysical

Issues / *Variables*	Increase (+++)	Increase (++)	Increase (+)	No change (0)	Decrease (-)	Decrease (--)	Decrease (---)
Eutrophication:							
Nutrient concentration and loads					√		
Erosion and sedimentation:							
Suspended sediment concentration and loads						√	
Soil erosion					√		
Priority substances (pollution):							
Selected priority substances loads and concentrations						√	
Water availability:							
Water level in rivers			√				
Discharge				√			
Groundwater level				√			
Water harvesting		√					
Floods:							
Severity			√				
Frequency			√				
Duration					√		
Extent					√		
Droughts:							
Frequency			√				
Duration			√				
Severity			√				
Severity of impacts					√		

A) Socio-economic							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Water storage (reservoirs)			√				
Energy:							
***Energy** demand*			√				
Land Use:							
Arable land area			√				
Forest area				√			
Built-up area			√				

B) Biophysical							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)

Issues/Variables marked in ***bold*** – added for the Messara river basin hub

A5.3 Business as usual scenario narrative

Specific Narrative for the Messara river basin hub (under SSP2)

Under the SSP2 scenario for 2040, the Messara Valley in Crete would continue to be a vital agricultural hub, balancing traditional farming practices with modern adaptations to address changing environmental and economic conditions.

Table A4.2 Narrative for the Messara river basin hub

Economic and Technological Development: By 2040, the Messara plain, being one of the largest and most fertile agricultural areas in Crete, continues to be a crucial hub for agriculture in the region. Economic development here is characterized by gradual advancements in agricultural technologies. The agricultural sector would increasingly adopt sustainable farming techniques to improve soil health, conserve water, and increase crop yields. Practices such as crop rotation, organic farming, and the use of natural pest control methods would become more prevalent. The adoption of precision agriculture becomes more widespread, with moderate investments in technology like drones for monitoring crop health and automated irrigation systems that adjust water use based on real-time soil moisture levels. These technologies help farmers increase yields and manage resources more effectively, but the transformation is gradual and does not disrupt traditional farming methods significantly.

Crop Diversification and Production: Farmers in Messara adapt to changing market demands and climate conditions by diversifying their crops. Traditional staples like olives and grapes continue to dominate, but there is an increased production of high-value crops such as avocados and goji berries, which are suited to the climate and soil of Messara. Crop rotation practices become more common, enhancing soil health and reducing the reliance on chemical fertilizers and pesticides, aligning with a slow but steady shift towards more sustainable farming practices. The cultivation of drought-resistant crop varieties would also be emphasized. Research and development efforts would focus on enhancing the resilience of traditional crops like olives and grapes as well as introducing new varieties suited to drier conditions.

Water Management and Environmental Policies: Water management becomes a critical focus area due to the irregular rainfall patterns and occasional droughts exacerbated by climate change. The implementation of advanced irrigation techniques, such as drip irrigation, is further promoted and partially subsidized by local government initiatives. These efforts are aimed at conserving water while maintaining crop yields. Policies would promote the recycling and reuse of agricultural and municipal water, with facilities set up to treat water for irrigation purposes, ensuring that water resources are used judiciously. Increased use of rainwater harvesting systems would help supplement water supplies for agriculture and reduce dependence on groundwater. Environmental policies at the local level also encourage the preservation of natural habitats around the agricultural lands to maintain biodiversity, which in turn supports agricultural resilience.

Market Integration and Economic Policies: The agricultural market in Messara becomes better integrated with both national and European markets. Moderate government policies help streamline distribution channels, reducing barriers for local farmers to sell their products across Europe. There would be a push towards producing higher value-added products, such as organic and PDO (Protected Designation of Origin) certified foods, which command higher prices on national and international markets. Farmers in the Messara valley might band together to form cooperatives for better marketing and bargaining power (cooperative marketing), leveraging collective resources to access wider markets and secure better prices for their products. There is also an increase in agrotourism, which becomes an integral part of the local economy, providing an additional income stream for farmers and promoting Messara's agricultural heritage, with farms offering tours, stays, and local product tastings, creating an additional revenue stream that complements traditional agriculture.

Governance and Community Aspects: Local government would actively support the agricultural sector by facilitating access to funding, providing training in new agricultural techniques, and supporting infrastructure development. The community in Messara remains closely knit, with strong ties to the land and traditional farming practices. However, there's a growing acceptance of new agricultural techniques among the younger generations, who are more open to integrating technology with traditional methods. Educational programs focusing on sustainable agriculture are introduced in local schools and community centres, increasing awareness and skill development in modern agricultural practices. There would be a strong emphasis on community engagement and decision-making, ensuring that the policies and projects implemented reflect the needs and insights of local farmers and stakeholders.

Adaptation to Climate Change: Specific climate adaptation strategies would be developed for agriculture, focusing on managing the impacts of higher temperatures, less predictable rainfall, and potential pest invasions. Farmers in Messara proactively adopt measures to adapt to climate change, such as selecting crop varieties that are more resistant to heat and drought. Efforts are made to improve soil carbon storage through organic farming practices, which also helps mitigate the impact of farming on climate change. Efforts would also be made to conserve natural landscapes and biodiversity, integrating environmental stewardship into agricultural practices. This might include maintaining buffer zones around natural habitats and using biological methods for pest and weed control.

Concluding, in this SSP2 scenario for 2040, the agricultural sector in Messara evolves in a balanced manner, maintaining its cultural roots while embracing moderate technological and economic changes to ensure sustainability and productivity in the face of evolving environmental and market conditions.

A5.4 What-if scenario questions

The relevant what-if policy questions to be addressed are listed below:

- How will climate change alter water resources availability (e.g. reduced precipitation patterns, increased T, ET) under different climate scenarios?
- What if population growth and economic development patterns change, including land use and/or mix of agricultural crops changes? For example replacing olives trees with avocados and/or other high-value crops according to the global markets demand
- What if the Faneromeni reservoir operating rules and related water allocation quotas are altered?
- What if groundwater is further exploited?
- What if ecosystem/environmental requirements are tightened?

- What if water conservation (e.g. deficit irrigation) and/or water reuse are introduced in some parts of the basin?
- What if no further water abstraction licenses are granted and/or expanded, and stricter enforcement and control measures are imposed on the abstracted volumes and rates?
- What if excess surface water (e.g. from the diversion of the nearby Platis River) is available for irrigation use (via the Faneromeni Dam) and/or is stored in groundwater aquifers (artificial groundwater recharge)?

ANNEX 6: Scenarios for the Rhine river basin hub

The annex presents the memo that was prepared for the Rhine river basin commissions for the dialogue and workshops on scenario development. These draft narratives are currently under review by the stakeholder community in the Rhine river basin hub.

A6.1 Introduction

Introduction

Together with the EU STARS4Water project the CHR develops **socio-economic scenarios (SES)** (Figure A6.1) in order to create knowledge on water availability and water use in the Rhine river basin to support informed decision making on taking joint actions in the basin. The scenarios help to identify the implications for the flow of the River Rhine (Water quantity) due to current and future water use under climate change The ambition of this SES research theme is:

- Provide scientific-based information on water availability, water use and consumption, and water allocation for the Rhine river basin in the transboundary context
- Improve system understanding, identify issues and support planning and decision making on water security and climate actions to address those issues
- Create public awareness on future water shortages under plausible future scenarios

A **scenario** (as we describe it in this project) is a plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections but are often based on additional information from other sources, sometimes combined with a "narrative storyline."

Scenarios cannot be considered as an end goal in themselves; they facilitate strategic discussions. Their goal is not to predict; they do not answer questions such as 'How likely is this?', but rather assist in thought provoking discussions in terms of 'What will we do if this happens?'.

These scenarios could be meaningful in our way of understanding of the water system and in devising water management strategies plans. They are based on a narrative storyline that have the interest of specific actors (i.e. the Rhine commissions) in their need for information about a certain anticipated change, or issue of development. It is targeted of our knowledge for particular developments / course of action (e.g. agriculture, land cover, demography) and might begin with: "what if…?" to explore.

Often, for the scenario development two major developments or categories are distinguished: climate change and socio-economic change. The first is a plausible and often simplified representation of the future climate, while the other is based on simplified representation of the future socio-economic situation. The last scenarios have been constructed for explicit use in investigating the potential consequences of socio-economic pressures, often serving as input to for example water demand, water infrastructure and impact models. National trend and exploratory analysis (both in- and outside the water domain) often serve as the raw material for constructing these scenarios.

Often the climate change scenario and socio-economic scenario are combined to one scenario, considering interferences and feedback loops. E.g. extreme climate change is combined with high end economic growth in one scenario.

Scenario development typically starts with a **narrative storyline**, which describes both the changes that are likely to occur and the consequences of those changes. Since such a narrative storyline does not include exact numbers, it can be called a qualitative scenario. A quantitative scenario can later be developed by **assigning numbers to the narrative storyline of a scenario**, e.g. by using models and/or data analysis.

The CHR and STARS4Water conduct this work in strong cooperation with the ICPR and CCNR.

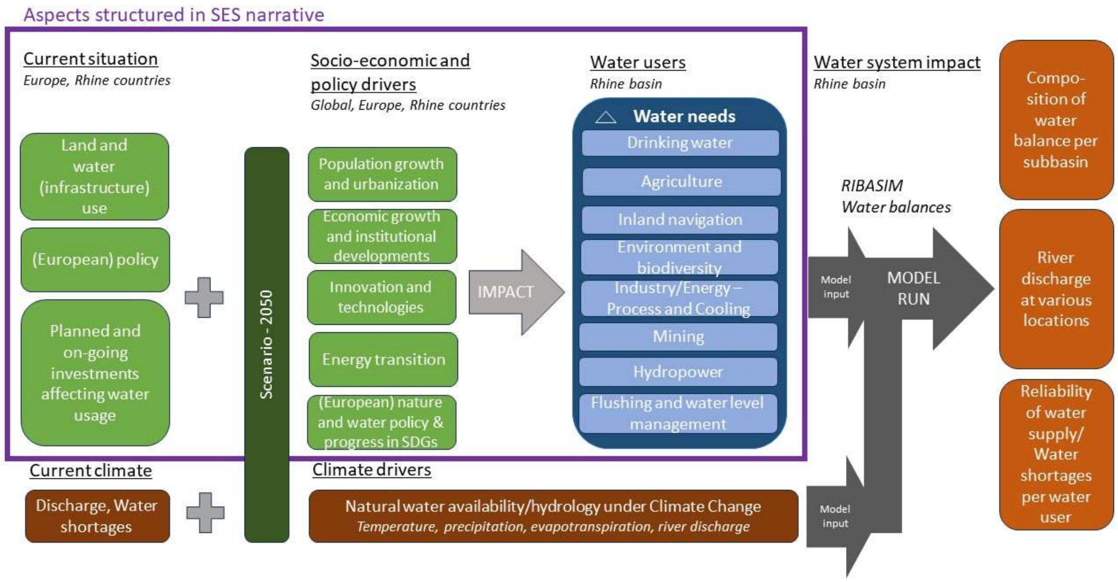


Figure A6.1 Developing a socio-economic scenario for the Rhine river basin

It is the ambition of the CHR and STARS4Water to make first scenario narratives and after that perform a quantitative analysis of the scenarios using the RIBASIM water balances scenario modelling tool.

The current memo describes the narratives that under development: one middle of the road scenario and two alternative scenarios.

The RIBASIM tool is currently under development and meant to support risk assessments and provide information of the impact of various scenarios in terms of water availability, demand and supply and consequences for the Rhine river discharge. After the scenario narratives have been formulated, we will discuss how to quantifying the narratives and/or brainstorming on how and where collect relevant data (on European, river basin, national or regional level) for modelling purposes.

The Rhine Basin

Within the river basin, regional strategies aim to strike a balance between economic prosperity, social well-being, and environmental sustainability, while addressing issues like social inequality and environmental degradation. Nine states and regions in the Rhine watershed (Figure A6.2) co-operate in order to harmonize the interests of use and protection in the Rhine area. For the benefit of the Rhine and of all waters running into the Rhine the core countries Switzerland, France, Germany, Luxemburg, the Netherlands successfully cooperate with the bordering countries Austria, Liechtenstein and the Belgian region of Wallonia as well as Italy. Challenges such as climate change impacts and sustainable water management persist, necessitating collaborative actions. Effective strategies across sub-catchments, regions, and transboundary between riparian states will safeguard ecosystems and ensure water resource sustainability at regional waters for future generations. Intensified cooperation between the Rhine riparian countries is jointly supported by three Rhine commissions: ICPR, CCNR and CHR.

Figure A6.2 Rhine riparian states (Schulte-Wülwer-Leidig et al, 2018)

The future is uncertain. Climate and socio-economic scenarios describe various plausible futures and are helpful instruments for developing adaptation strategies for better water resilience under climate change. Both climate and socio-economic scenarios work in tandem, setting pathways for greenhouse gas concentrations and future emissions reductions . All climate change scenarios presented by IPCC in their latest report (AR6 climate change scenarios) indicate that most regions in the world will face more frequent extreme weather events, changes in precipitation and evaporation patterns, and higher temperatures. These alterations impact hydrology, ecology, (natural) water availability, with implications for river flow regimes, water quality, and infrastructure resilience. These general trends also reflected in the latest report of the ICPR's Expert Group on Climate Change based on the previous IPCC AR5 and most extreme climate change scenario (EG HCLIM) (ICPR, 2024). In addition, regional projections for the Rhine river discharge (KNMI’23 scenarios) based on the latest IPCC AR6 scenarios (re-)confirmed that temperature in the basin will rise in all climate change scenarios. The changes in precipitation are more uncertain and differ per season and per sub-basin. The precipitation changes have a non-linear effect on the Rhine discharge. The average discharges in winter and spring season will increase and average discharges in (late) summer will decrease. The 7-day minimum discharge at Lobith is consistently projected to decrease in *all* climate change scenarios, i.e. in both wet and dry climate change scenarios. The decrease varies between 5 to 15% for 2050 (Sperna Weiland et al, 2023). Low flows require better balancing water availability and demand, to satisfy water needs for humans, nature and economic activities.

A6.2 Matrix of anticipated changes

Table A6.1 Final matrix of anticipated changes for the Rhine river basin hub: A) socio-economic category; B) biopsychical category

A) Socio-economic

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Agriculture:							
Main crop yields		√					
Fertilizer use			√				
Irrigation needs		√					
Nutrient loss		√					
Nature protection:							
Biodiversity						√	
Migration barriers			√				
Infrastructure status:							
Number of hydraulic structures		√					
River length impacted by hydraulic structures		√					
Drainage system extent and efficiency		√					
Demography / Migration:							
Population number (Net migration)			√				
Upstream issues:							
Water abstraction		√					
Water storage (reservoirs)		√					
Energy:							
Hydropower demand				√			
Cooling water demand			√				

B) Biophysical

Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Eutrophication:							
Nutrient concentration and loads			√				
Erosion and sedimentation:							
Suspended sediment concentration and loads			√				
Soil erosion		√					
Water availability:							
Water level in rivers					√		
Discharge						√	
Groundwater level						√	
Floods:							
Extent			√				
Frequency		√					
Duration				√			
Droughts:							
Frequency		√					
Duration		√					
Severity		√					
Peak rainfall:							
Frequency		√					
Duration				√			
Severity		√					

A) Socio-economic							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Land Use:							
Arable land area					√		
Forest area				√			
Built-up area		√					

B) Biophysical							
Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)

Issues/Variables marked in ***bold*** – added for the Rhine river basin hub

A6.3 Business as usual scenario narrative

The Middle of the Road scenario is inspired by "current-trends-continue" (SSP2 like) reasoning. It portrays a moderate development path from the present until 2050 characterized by steady economic growth, medium population expansion, and intermediate technological advancements.

Table A6.2 Middle of the Road narrative for the Rhine river basin hub: A) socio-economic and policy drivers; B) biophysical category

A) Socio economic and policy drivers
Population growth: Major socio-economic drivers are population growth and urbanization. Both continue to grow, with varying trends across Rhine countries. The human population of the Rhine basin equals 58 million now, many of them crowded in large urban areas extending along the river. The population in the Rhine catchment is expected to slightly increase in most countries: moderate population growth for Austria (+4%), Belgium (+6%), France (+5%), Luxembourg (+x%), Netherlands (+3%) and Switzerland (+12%). Germany is expected to experience an overall decline (-3%), whilst having the largest share in the Rhine catchment. Even if the population grows only slightly, this growth is expected to be concentrated in towns and cities, leading to further urbanization.
Urbanization: The largest cities in the Rhine catchment area are Cologne (1 084 831), Frankfurt (773 068)*, Rotterdam (671 125) (CBS, 2024), Stuttgart (632 865)*, Dusseldorf (629 047), Dortmund (593 317)*, Essen (584 580)*, Nurnberg (523 026)*, Duisburg (502 211)*, Strasbourg (484,217) (Wikipedia 2024), Zurich (421 878) (Source Joerg, 2020), Utrecht (374 000) (CBS, 2024), Bochum (365 742)*, Wuppertal (358 876)*, Bonn (336 465)*, Basel (177,595) (Wikipedia 2024), Arnhem (152,850) (Wikipedia 2024) (*Source Joerg, 2022). In this scenario, urbanization continues and current major metropolitan areas continue to grow.
Economic growth: Most economies in the Rhine states are politically stable with functioning and globally connected markets. In 2050, the Rhine basin remains a vital economic hub and GDP in the countries are expected to grow in Austria (+55%), Belgium (+55%), France (+55%), Germany (+40%), Italy (+x%), Liechtenstein (+x%), Luxembourg (+x%), Netherlands (+55%) and Switzerland (+42%).
Economic sectors: Free trade within and between Rhine countries flourishes. The EU trade relationships with Switzerland are stable and collaborative. The private sector will grow. Major economic sectors in the Rhine catchment such as manufacturing, agriculture (0.5%-3.5% now), trade and logistics, tourism, energy, and services (65%-80% now) will continue to drive economic expansion, supported by stable markets and globalization. Cities become hubs of technological development and there is a high attention for digital transformation in economic sectors. . The Rhine River continues to play an important role in transport to accommodate economic growth and trade between the Rhine countries, although it has to deal with more low flow situations.
Technologies and innovation: Technologies and innovation further increase water efficiency of companies and households. There is no major breakthrough in innovation.
Resource and energy: Efforts are underway with reductions in resource and energy consumption. The reduction follows the trends that we see in the past decades. The overall share of energy from renewable sources is currently between 13 and 21% in the Rhine states. Netherlands 15%, Germany 21%, Austria 34%, Belgium 14% and Luxembourg 13% (Eurostat, 2022). The overall share of renewable energy will increase slowly.

Sustainable Development Goals and EU Green Deal: Policies, goals and legislation like the Sustainable Development Goals (SDGs), EU Green Deal and Water Framework Directive promote ecological restoration, renewable energy adoption, and sustainable water management. These directives are integrated into Rhine catchment policies, albeit at varying paces. There is a delay in full implementation of these directives by several decades. A gradual shift towards renewable energy sources is reducing fossil fuel dependency and enhancing energy security.

Cooperation: Joint cooperation by the Rhine commissions has evolved significantly, focusing on harmonizing interests and addressing challenges. Flood risk management and water quality management will remain a priority, with ongoing efforts to reduce risks and strengthen awareness. Finding solutions in water allocation and prioritization, among different water users and between countries has gained priority.

B) Water user needs

Natural environment: The Rhine catchment will experience various impacts from both climate change and socio-economic drivers. Biodiversity and forests are under high pressure. Changes in hydrological patterns will threaten water quality during low-flow events, necessitating adaptation strategies and minimum flow requirements. The Rhine is located in a drought risk transition area, in which the south of the region is affected first, which will shift to the north in higher climate change scenarios (EEA, 2021). It seems that wetlands in the northern part of central Europe will be less affected by increased variability while the forest ecosystems there will suffer to a greater extent (EEA, 2021).

Water supply – agriculture: All countries are in search for additional sources for water supply, including non-conventional water sources and raise of water efficiency and water treatment, and require sustainable management practices to ensure responsible water use.
The largest water user in the Rhine basin is the agricultural sector, of which the water needs in the Rhine catchment are growing. Crop cultivation will become more intensive and sophisticated, driven by technological advancements like precision farming. The size of irrigated area will grow especially in Switzerland and Germany. If the demand for biomass from energy crops is met using standard arable crops, perhaps necessitating greater use of irrigation, then agricultural water demand is likely to increase even more. In addition to higher abstractions from the Rhine River, groundwater reliance for irrigation will increase during droughts.

Drinking water: In the future, groundwater and surface water from the Rhine catchment will remain essential for drinking water. Groundwater extraction will predominate for geographical, technical and more complex surface water treatment reasons (surface water pollution). Currently most of the drinking water in Germany (66%), Switzerland (80%), Netherlands (60%), France (65%) and Luxembourg (57%) is sourced from groundwater. A high percentage of the return flow of the water supplied (95%) is collected in sewerage system after use.

Industrial water: In the upcoming decades industrial water needs in the Rhine catchment will be shaped by economic and technological factors. While some regions will decrease water consumption through modernization and efficiency, others will experience increases due to a growing economy. Sustainable practices will be increasingly used in managing industrial water demand and ensuring responsible usage.

Cooling water: Power plants in the Rhine Basin will optimize cooling water usage through efficiency measures and technical advancements. Electrification and alternative cooling sources will gradually replace freshwater cooling, driven by climate and socio-economic factors. In total, growing water demand necessitates additional water resources and water efficiency measures, requiring careful water distribution and prioritization.

Inland water transport In the future, inland waterway transport (IWT) in the Rhine catchment, as a non-consumptive user, will adapt to climate change impacts, with fluctuations in water levels requiring also adjustments to infrastructure such as adjustments to shipping infrastructure and technical adaptation of the fleet. IWT on the Rhine will also continue to mitigate climate change by implementing the CCNR roadmap on emission reduction. Sustainable IWT will continue to support economic growth and innovation in the region.

Recreation: These alterations in hydrological patterns are projected to adversely affect water quality, particularly during low-flow events under high temperatures, further threatening ecosystem integrity. The impacts of these changes are multifaceted and contingent upon local conditions, often necessitating minimum flow requirements and adaptation strategies. Forestry practices, including changes in forest cover, can further influence basin hydrology, altering rainfall distribution, runoff mechanisms, and groundwater-surface water interactions. Understanding the importance of recreational activities and ecosystem services, such as biodiversity conservation, is crucial for prioritizing policy measures and assessing their potential impacts on minimum river flows and water quality standards in the future.

Hydropower generation: Hydropower generation in the Rhine catchment will face challenges during low-flow periods. Minimum storage and flow requirements will sustain operations, but environmental considerations incl. biodiversity connectivity and minimum environmental flows, will increasingly influence hydropower practices, in addition to managing floods and droughts.

Lignite mines: Towards 2050 the demand for natural resources will slightly decline, however due to technological development the demand for rare earth materials increases. These materials could be found in the Rhine basin. The lignite mines in Germany will close in the upcoming decades, which will lead to a temporary (several decades) water demand to fill the pits. For filling the Garzweiler and Hambach lignite mines with water diverted from the Rhine River a schedule has been drawn up for the planned extraction to minimize the effect on the water level (shipping): at low discharges (up to 1000 m^3/s) 1.8 m^3/s is extracted, increasing to 18 m^3/s at Rhine discharges of approximately 2200 m^3/s and more. The minimum of 1.8 m^3/s is mainly intended for keeping wetlands in the vicinity of the mines wet during dry periods. The excess is for filling the mines. It is estimated that over 25 billion cubic metres of water will be required for the entire project, which will begin in 2030 and extend over several decades. (The pit of Tagebau Inden will be filled with water diverted from the Meuse river basin.)

Flushing and water level management: To address land subsidence, peat oxidation and salinization (increased by sea level rise), enhanced flushing and water level management practices will be implemented in the Rhine catchment to mitigate impacts of climate change. In particular, Netherlands' efforts to reduce land-based emissions form the meadow areas (greenhouse gases) by rewetting peat meadow areas to prevent from peat oxidation affects the water demand. The expected reduction in CO_2 emissions from peat meadow areas is approx. between 1.0 and 1.6 Mton CO_2/year when the surface water level is raised towards approx. 20-40 cm below ground level. In the current situation the total water demand for flushing all polders is 20 m^3/s. In 2050 it will be approx. 38 m^3/s based on sea level rise of approx. 25 cm. (Van der Brugge, R., R.C. de Winter (2024)).

A6.4 Other scenario narratives

Development of additional scenarios

The previously described “middle-of-the-road” scenario (Section A6.3) served as a basis for the development of two additional scenarios. The Scenario 2: Rhine of Regions leans towards regional development, environmental protection and a strong civil society and the Scenario 3: Rhine of Nations shows a low economic development, with a strong focus on national development. National security is prioritized and the Rhine countries collaborate less in the catchment. This is affecting inland water transport and trade, as well as agricultural production and export/import. Table A6.3 shows the accompanying climate change scenarios from the global RCP’s and the underlying qualitative socio-economic assumptions underlying the narratives. These qualitative assumptions were then quantified where possible by both using global and local data. The global data was derived from the global SSP’s per Rhine country and local datasets from various sources.

Table A6.3: Qualitative Assumptions Scenario 2 and Scenario 3

No	Aspects	Scenario 2 Rhine of Regions – Strong Civil Society and Environmental Protection Collaboration	Scenario 3 Rhine of Nations – Strong Private Sectors and Economic Growth Fragmentation
Biophysical environment			
	Accompanying climate change	Low Climate Change impact	High climate change impact
	Global Climate scenario	RCP 1/2.6	RCP 7/8.5
	Rhine discharges	KNMI’23 L Scenario	KNMI’23 H Scenario
Socio-economic developments			
1	Population growth	Low population growth	Lower population growth and urbanization
2	Urbanization	Slight increase in population in cities like Cologne, Frankfurt, Rotterdam, Stuttgart, Dusseldorf	Slight increase in population in cities like Cologne, Frankfurt, Rotterdam, Stuttgart, Dusseldorf
3	Economic growth	Lower growth GDP	Lower growth GDP
4	Economic sectors	Small growth in industrial sectors Growth in Recreation and Tourism	Limited industrial sectors
5	Technology and innovation	Strong investment in education and technologies, especially efficiency technology	Some Investment in technologies
6	Resource and Energy	Fast transition to more renewable energy and less mining	Slow transition to more renewable energy and less mining
7	SDG’s and EU Green Deal	Increasing commitment to achieving development goals. Green Deal aspects are integrated, at accelerated pace: Investment in Clean Technologies, Carbon Pricing Mechanisms etc.	Slow commitment to achieving development goals and significant environmental degradation Lack of environmental concern. Delayed integration of Green Deal aspects. Climate neutrality is achieved by 2100.
8	Cooperation	Strong national and regional cooperation	Strong competition between Rhine countries and focus on national interests
Impacted water related sectors			
1	Natural Environment	Declining Influx of micropollutants Reduction of fish migration obstacles:	Increased Influx micropollutants Reduced habitat connection

No	Aspects	Scenario 2 Rhine of Regions – Strong Civil Society and Environmental Protection Collaboration	Scenario 3 Rhine of Nations – Strong Private Sectors and Economic Growth Fragmentation
		habitat connection Minimum flow requirement	No minimum flow requirement for the natural environment
2	Water supply - Agriculture	Extensive agriculture	Intensive agriculture
3	Drinking water	Water source more from groundwater	Much more water source more from groundwater, less surface water
4	Industrial water	Unchanged Cooling efficiency Changes in efficiency	Increased cooling efficiency
5	Cooling water	Unchanged Water use efficiency	Increased Water use efficiency
6	Inland water transport	More containers and emission free transport. Minimum flow requirement	More bulk transport Minimum flow requirement
7	Recreation		
8	Hydropower	No new Hydropower stations	Opening of new hydropower stations
9	Mining	Closure lignite mines in 2035 requires filling. Exploration mines rare earth.	Re-opening of mines and new mining sites
10	Water level management and flushing	Flushing required	Increased flushing required

Narrative 2: Rhine of Regions

The Rhine of Regions Scenario portrays a development in favour of regional growth, environmental protection and a strong civil society. Central aspects of this narrative are human well-being and the and the acceptance of environmental boundaries. There is enhanced cooperation and trade between countries, which supports global economic growth.

Table A6.4 Rhine of Regions narrative for the Rhine river basin hub: A) socio-economic and policy drivers; B) biophysical category

A) Socio economic and policy drivers

Population growth: The population is stabilizing between 2020 and 2050 in the Rhine countries, 65 million now, many of them crowded in large urban areas extending along the river. The population in the Rhine catchment is expected to slightly increase in most countries with small variation between the core Rhine countries France (+18%), Germany (0%), Luxembourg (+42%), the Netherlands (+11%) and Switzerland (+16%).

Urbanization: Urbanization rates stay moderate in the Rhine countries France (+5%), Germany (11%), Luxembourg (+7%), the Netherlands (+7%) and Switzerland (+11%). The largest cities in the Rhine catchment such as Cologne Frankfurt, Rotterdam, Stuttgart, Dusseldorf, Dortmund, Essen, Nurnberg, Duisburg, Strasbourg, Zurich, Utrecht, Bochum, Wuppertal, Bonn, Basel, Arnhem are growing. At the same time, the population's footprint is decreasing, resulting in lower energy and water use. This is mainly due to technological improvements and growing environmental awareness. The dietary pattern shifts towards a planetary health diet (EAT Lancet commission), which includes less intake of dairy foods and meat. The agricultural sector adapts to the change in demand and develops towards a less intensive system that includes more arable and less livestock farming. This is also dictated by stricter (European) environmental regulations, and rapid improvement of technologies to maintain production efficiency with less input of resources.

Economic growth: The GDP of countries in the Rhine basin is growing until 2050 with an average of 1.5% per year (SSP1). The economic growth per country between 2020 and 2050 varies France (+88-138%), Germany (+35-49%), Luxembourg (+69-146%), the Netherlands (+65-82%) and Switzerland (+61-77%) (Source: IIASA and OECD, SSP1). There is sufficient money available to adapt to climate change, and to invest in more sustainable technologies.

Economic sectors: Free trade within and between Rhine countries flourishes. The EU trade relationships with Switzerland are stable and collaborative. Major economic sectors in the Rhine catchment such as manufacturing, agriculture, trade and logistics, tourism, energy, and services were adjusted to the new green policies. The sectors of agriculture and tourism are shifting towards more sustainable practices and enhance recreation. The industrial sectors are not significantly growing anymore, with improved technology to save and protect the water resources of the Rhine catchment. Industry is subject to stricter environmental regulations, which steers green innovation, leading to more efficient water and energy use.

Technologies and innovation: The Rhine River continues to play an important role in transport to accommodate economic growth and trade between the Rhine countries, although it has to deal with more low flow situations. Technological advancements are only realized with a strong environmental agenda such as the reduction of pollution.

Resource and energy: The Rhine countries increased their renewable energy share over the 30-year period reaching the following shares for each Rhine country France (+63%), Germany (+74%), Luxembourg (+46%), the Netherlands (+53%) and Switzerland (+100%). Targets will be set to phase nuclear power and hydropower out after 2050.

Sustainable Development Goals and EU Green Deal: Initiatives like the Sustainable Development Goals (SDGs), EU Green Deal and Water Framework Directive promote ecological restoration, renewable energy adoption, and sustainable water management. Major efforts will integrate green aspects into Rhine catchment policies. A shift towards renewable energy sources occurs in the Rhine catchment reducing fossil fuel dependency and enhancing energy security. The target to increase to at least 40% renewable energy sources in the EU's overall energy mix in 2030 is reached and these trends continue up to 2050. This is due to a significant increase in renewable energy, and an equal share of nuclear power and hydropower in the energy mix. All these initiatives are addressing environmental degradation and societal challenges, implementation is according to plan and major milestones are reached in the decades up to 2050.

Cooperation: Joint cooperation by the Rhine commissions will evolve significantly, focusing on harmonizing interests and addressing challenges. Flood risk management and water quality management will remain a priority, with ongoing efforts to reduce risks and strengthen awareness. Finding solutions in water allocation and prioritization, among different water users and between countries has gained priority. Nature and biodiversity are protected and valued by the population for multiple ecosystem services and for support to reach climate mitigation and adaptation goals. There is an active afforestation plan, which led to an increase in forest areas. Peat and wetlands are well-maintained to limit emissions and increase carbon sequestration. As such, data is shared openly, and the system is managed and operated together with the countries of the Rhine basin. This means that major Rhine treaties is maintained.

B) Water user needs

Natural environment: The natural environment will experience less severe impacts from both climate change and socio-economic drivers. Biodiversity and forests will face challenges and major mitigation strategies are implemented. The goals part of EU birds and habitats directives, and Water Framework Directives have been met, which means that the quality of nature increases. Aside from the quality, the quantity also grows, as there is more demand for nature and the ecosystem services that nature delivers. This means that the forest area in the Rhine basin increases with +X%. Changes in hydrological patterns will threaten water quality during low-flow events, necessity implementation of adaptation strategies and minimum flow requirements. The importance of the conservation of rivers, peat and wetland areas increases, due to their importance for biodiversity conservation, but also for climate mitigation. This leads to an approximate increase in water demand for nature of ………. This scenario also includes the installation of fish traps at all sluices and locks in the river.

Water supply – agriculture: As the largest water user agriculture's water needs in the Rhine catchment will adapt to changing conditions. The agricultural sector becomes less intensive, which also means reduced use of fertilizers. The size of irrigated area will decline in the Rhine countries. Still due to longer dry periods in summer higher abstractions from the Rhine River, groundwater reliance for irrigation will increase during droughts. There are more frequent combinations made between agriculture and nature conservation, and agricultural and other functions, such as tourism. Due to changes in dietary patterns the livestock sector decreases by 15%, whereas arable agriculture only slightly decreases 2%. However, the area that could be irrigated increases with approximately 30%. These are more efficient types of irrigation, such as drip irrigation.

Drinking water: All the countries within the Rhine basin strive for a more efficient use of drinking water. In the future, groundwater and surface water from the Rhine catchment will remain essential for drinking water. Groundwater will predominate due to pollution concerns. A high percentage of the return flow of the water supplied (95%) is collected in sewerage system after use. The European average of water use of 144l/day per person will be reduced to 90l/day per person. Rainwater is infiltrated in these wells and used to flush the toilet, to clean and wash laundry.

Industrial water: The industry in the Rhine basin stabilizes in the Ruhr area and slightly reduces in the other parts of the basin. The type of industry changes to industry related to the circular economy and data centres. Heavy industry becomes cleaner or is phased out. Water use of the industry is slowly reducing, with a total reduction of approximately 19% (Delta scenarios).

Cooling water: Fossil fuelled power plants are not part of the energy generation anymore, which means that the cooling water demand decreased significantly. Only nuclear power plants and hydrogen production plants make use of cooling water to make energy carriers. The fraction of nuclear power in the energy mix stays the same in the Rhine basin countries. However, along the Rhine most nuclear power plants will be closed in 2035, and there is no replacement foreseen.

Inland water transport: There is a strong cooperation between countries in the Rhine basin. In the future, inland waterway transport (IWT) in the Rhine catchment, will adapt to climate change impacts, with fluctuations in water levels requiring adjustments to infrastructure. The economy is globalized, and there is more focus on sustainable local production. This means that the demand for transportation is stabilizing or for some transportation classes slightly increasing (e.g. containers). All the transport modalities transition towards emission free transport, through electrification or hydrogen. IWT on the Rhine will hold a strong position to mitigate climate change by implementing the CCNR roadmap on emission reduction. Sustainable IWT will continue to support economic growth and innovation in the region.

Recreation: Environmental recreation and green tourism will become an important economic sector in Rhine catchment.

Hydropower generation: Hydropower generation in the Rhine catchment will face challenges during low-flow periods. Minimum storage and flow requirements will sustain operations, but environmental considerations incl. biodiversity connectivity and minimum environmental flows, will increasingly influence hydropower practices, in addition to managing floods and droughts. The hydropower capacity does not change in 2050.

Lignite mines: The lignite mines in Germany closed in 2035, which led to a temporary water demand to fill the pits. After the pits are filled there is a permanent demand of 0.5-1 m^3/s to restore the groundwater levels until 2200. The demand for natural resources slightly declines, however due to technological development the demand for rare earth materials increases. The lignite mines in Germany will close in the upcoming decades, which will lead to a temporary water demand to fill the pits. For filling the Garzweiler and Hambach lignite mines with water diverted from the Rhine River a schedule has been drawn up for the planned extraction to minimize the effect on the water level (shipping): at low discharges (up to 1000 m^3/s) 1.8 m^3/s is extracted, increasing to 18 m^3/s at Rhine discharges of approximately 2200 m^3/s and more. The minimum of 1.8 m^3/s is mainly intended for keeping wetlands in the vicinity of the mines wet during dry periods. The excess is for filling the mines. It is estimated that over 25 billion cubic metres of water will be required for the entire project, which will begin in 2030 and extend over several decades. (The pit of Tagebau Inden will be filled with water diverted from the Meuse river basin.)

Flushing and water level management: To tackle the challenges of land subsidence, peat oxidation, and salinization exacerbated by rising sea levels, the Rhine catchment will implement advanced flushing and water level management strategies. These measures aim to mitigate the adverse effects of climate change. Specifically, the Netherlands will focus on curbing land-based emissions, particularly from greenhouse gases emitted by meadow areas. This will involve the rewetting of peat meadows to prevent peat oxidation, thereby reducing water demand and fostering environmental sustainability.

Narrative 3: Rhine of Nations

The Rhine of Nations Scenario portrays a development in favour of economic growth, a strong private sector and focus on security. A revival of nationalism due to concerns about security and competitiveness pushed countries to focus on domestic issues. Policies are oriented toward national and regional security issues. This comes at the cost of broader-based developments, such as investments in innovation and technology. Economic development is steady. Furthermore, there is little priority to address environmental concerns and to enforce environmental and biodiversity policies.

Table A6.5 Rhine of Regions narrative for the Rhine river basin hub: A) socio-economic and policy drivers; B) biophysical category

A) Socio economic and policy drivers

Population growth: Population growth in the countries of the Rhine basin shows contrasting patterns with approximately core Rhine countries France (+0%), Germany (-17%), Luxembourg

(+11%), the Netherlands (+7%) and Switzerland (-4%). The economic footprint of the population increases, with more use of resources per capita. Countries want to reach food security within their country, which leads to the stimulation of high intensity agriculture. The interests of the agricultural sector take precedence over the interests of nature. This leads to a small decline of natural areas, such as forests and wetlands.

Urbanization: Urbanization rates stay moderate in the Rhine countries France (+5%), Germany (+4%), Luxembourg (+7%), the Netherlands (+7%) and Switzerland (+4%). The largest cities in the Rhine catchment such as Cologne Frankfurt, Rotterdam, Stuttgart are growing. At the same time, the population's footprint is decreasing, resulting in lower energy and water use. The agricultural sector adapts to the political changes in demand and intensifies production on arable and livestock farming.

Economic growth: Most economies in the Rhine states are politically stable with functioning and growing national markets. The economy in the Rhine basin countries grows in all countries in varying ranges: France (+31-36%), Germany (2-9%), Luxembourg (+28-60%), the Netherlands (+23-33%) and Switzerland (+27-31%). Technological development is slow, the increase in technological efficiency of natural resources is overshadowed by the larger demand due to population growth and a higher (and faster) consumption demand. The European energy goal of 2030 (>40% renewable energy sources) has not been made, due to lower investments in technology for renewable energy and less ambitious renewable energy strategy. The striving to become energy self-sufficient led to a growing number of hydropower and nuclear power plants, and a slow reduction of fossil-fuelled energy (especially coal). In 2050, 50% of the energy in Europe's energy mix comes from renewable energy sources.

Economic sectors: Trade between Rhine countries is slightly reducing, as the countries are driven by the goal to become as self-sufficient as possible. The private sector will slightly grow. Major economic sectors in the Rhine catchment such as manufacturing, agriculture, trade and logistics, tourism, energy, and services will only moderately continue to drive economic expansion.

Technologies and innovation: The Rhine River continues to play an important role in transport to accommodate economic growth, but trade between the Rhine countries is less prioritized. Generally, the industrial sector has to deal with more low flow situations.

Resource and energy: The overall share of energy from renewable sources will slowly grow between X and X% in the Rhine states. The Rhine countries increased their renewable energy share, reaching at the following shares for each Rhine country France (+36%), Germany (42%), Luxembourg (+26%), the Netherlands (+30%) and Switzerland (+100%). No targets will be set to phase nuclear power and hydropower out after 2050. Industry does not prioritize environmental regulations and focuses on local resources and self-sufficiency.

Sustainable Development Goals and EU Green Deal: Nature and biodiversity have low priority in comparison with other functions. This results in great pressure on natural areas that are not part of the Natura2000 network. The growing population and housing demand results in more houses built in natural areas. Furthermore, industry and agriculture further expand in these areas. This results in a smaller natural area in the Rhine basin, which is under higher pressure from pollution and water extraction.

Cooperation: There is competition between the Rhine basin countries. Every country strives for its own interests. This becomes particularly evident during dry periods, in which especially Switzerland, France and Germany use reservoirs for water retention, filling lignite mines and fulfilling industrial and drinking water needs.

B) Water user needs

Natural environment: The public gives less importance to nature and biodiversity conservation. This is reflected in the failure to meet the goals of the EU birds and habitats directives and Water Framework Directives. No new European regulations have been introduced since then. The quality and quantity of natural areas (especially non-Natura2000) is declining (-2% surface area). This is due to the growing pressure in these areas for housing, industry and agriculture. This results in a decline in water demand for nature in the Rhine basin of X %. This will pose major challenges to the natural environment biodiversity and forests.

Water supply – agriculture: The agricultural sector becomes more intensive, which implies larger farms, and no change in the use of fertilizers and pesticides. Irrigated area increases with 95% (delta scenarios), in which the mix of irrigation methods stays the same (e.g. drip irrigation, sprinkler etc.). There is no change in diet in Western Europe, resulting in a similar food demand. The reduction in international food export is compensated for by fewer food import, the growing (food) consumption per capita and population growth. The favourable conditions for agricultural production along the Rhine basin in comparison with other regions, results in an increase of agricultural land of 5%.

Drinking water: The drinking water use per person in the Rhine countries stays the same. The slight increase in efficiency of the drinking water system is offset by the higher use of drinking water in summer. Furthermore, the growing population increases the total drinking water demand. In the future, groundwater and surface water from the Rhine catchment will remain essential for drinking water. Groundwater will predominate due to pollution concerns. A high percentage of the return flow of the water supplied (95%) is collected in sewerage system after use.

Industrial water: In the upcoming decades industrial water needs in the Rhine catchment will be shaped by economic and technological factors. The industry in the Rhine basin is slightly growing. Especially along the border between France and Germany. The economic activity is growing, due to large investments in the sub-basin as compensation for the closure of the lignite mines.

Cooling water: Power plants in the Rhine Basin will optimize cooling water usage through efficiency measures and technical advancements. Still, fossil fuelled power plants remain part of the energy mix, although the number of fossil-fuelled power plants have been reduced by approximately 50%. To become energy self-sufficient countries currently running nuclear power plants along the Rhine will be maintained.

Inland water transport: The competition between countries leads to stabilization of trade. At the same time, total consumption increases, which requires (natural) resources. The transport of bulk goods grows, whereas container transport reduces. The demand for inland water transport grows (especially within countries) more rapidly than other modalities, this results in an increase in inland water transport of approximately X%.

Recreation: Recreational areas in the Rhine catchment are declining due to housing shortages and prioritization of national economic interests. Still, the tourist industry in the Rhine remains an important part of the economy and many inhabitants use areas along to river for recreational activities.

Hydropower generation: Most of the hydropower reservoirs have combined functions, such as for drinking water use, industrial water uses and flood safety. Due to less investments in operation and maintenance of the power plants, the hydropower capacity is reduced. No new hydropower plants are foreseen to be built in this scenario.

Lignite mines: The closure of the lignite mines in Germany has been delayed, due to national discussions about the importance of energy self-sufficiency and access to natural resources. In 2050 the mines are still open. Countries are searching for new potential of natural resources, as the demand for natural resources increases. This leads to re-opening of former mines, and exploration of new sites for rare earth materials (Europe's rare earth element resource potential: An overview of REE metallogenetic provinces and their geodynamic setting - ScienceDirect)

Flushing and water level management: To address land subsidence, peat oxidation and salinization (increased by sea level rise), enhanced flushing and water level management practices will be implemented in the Rhine catchment to mitigate impacts of climate change. More flushing will be necessary in this scenario due to a more severe SLR scenario.

A6.5 What-if scenario questions

For the Rhine river basin hub we have developed two scenarios (inspired by SSP1 and SSP3, see Section A6.4) that are alternative for the scenario that was presented under Section A6.3 (inspired by SSP2). The "what-if" questions for the Rhine are clustered and arranged according to these two scenarios and presented in the Table A6.6.

Table A6.6 What-if questions for two alternative scenarios for the Rhine river basin hub.

	Scenario 2 *Rhine of Regions*	*Scenario 3* *Rhine of Nations*
What-if…	… countries in the Rhine catchment	
	• Collaborate more closely	• Distance from each other
	• Form a strong civil society	• Form a nationally oriented society
	• Form circular and local economies	• Form national economies
	• Develop a high environmental awareness	• Develop a high interest in security and stability
	• Shift to sustainable agricultural practices	• Focus on self-sufficiency and independent food security
	• Shift to local crops and alternative farming techniques	• Shift to more irrigation intense agriculture
	• Trade and transport grows between the Rhine countries	• Reduce export and import on the Rhine

ANNEX 7: Scenarios for the Seine river basin hub

A7.1 Introduction

The "business-as-usual" BAU narrative for the Seine river basin is based on trends, i.e. observations of the present, and reflections on how these observations are projected into the future. It focuses on expected impacts on the management of the reservoirs upstream the river basin and on water availability through the river network downstream. It is based on published reports, personal communications and bilateral meetings with stakeholders held on January and May 2024. It is supported by other narratives (under development or recently proposed) in the river basin for specific purposes. The main sources of information used to write the STARS4Water narrative for the Seine River basin are listed in the section References to Annexes at the end of the document.

A7.2 Matrix of anticipated changes

Table A7.1 Final matrix of anticipated changes for the Seine river basin hub: A) socio-economic category; B) biopsychical category

A) Socio-economic

<u>Issues</u> / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
<u>Agriculture:</u>							
Main crop yields				√			
Fertilizer use			√				
Irrigation needs		√					
<u>Nature protection:</u>							
Biodiversity			√				
<u>Infrastructure status:</u>							
Number of hydraulic structures			√				
River length impacted by hydraulic structures				√			
Drainage system extent and efficiency		√					
<u>Demography / Migration:</u>							
Population number (Net migration)			√				
<u>Upstream issues:</u>							
Water abstraction			√				
Water storage (reservoirs)				√			
<u>Energy:</u>							
Power demand			√				
Hydropower installed capacity			√				
Cooling water demand		√					

B) Biophysical

<u>Issues</u> / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)
<u>Eutrophication:</u>							
Nutrient concentration and loads			√				
<u>Water availability:</u>							
Water level in rivers					√		
Discharge (floods)			√				
Discharge (low flow)						√	
Groundwater level						√	
Water harvesting			√				
<u>Floods:</u>							
Extent			√				
Frequency			√				
Duration				√			
<u>Droughts:</u>							
Frequency		√					
Duration		√					
Severity		√					

A) Socio-economic								**B) Biophysical**							
Issues / *Variables*	Increase			No change	Decrease			Issues / *Variables*	Increase			No change	Decrease		
	(+++)	(++)	(+)	(0)	(-)	(--)	(---)		(+++)	(++)	(+)	(0)	(-)	(--)	(---)
Land Use:															
Arable land area				√											
Built-up area				√											

A7.3 Business as usual scenario narrative

The main regional impacts of climate change on the Seine-Normandy basin are a reduction in precipitation during summer, an increase of evapotranspiration, and an increase in the intensity and frequency of strong rainfalls. The impacts on water are a reduction in water resources and lower water levels on the watercourses. A reduction in low flow rates is projected, with a more marked impact on the sub-catchments located in the heads of river basin. Projections also indicate a reduction in aquifer recharge and in the height of the water table, as well as an increase in the average water temperature and a rise in sea level.

Downscaled climate projections (30 simulations from EURO-CORDEX) made available through the French Explore2 project were used in the semi-distributed GR6J hydrological model for the Seine River basin and indicators of annual resources, high and low flows were obtained (Figure A7.1).

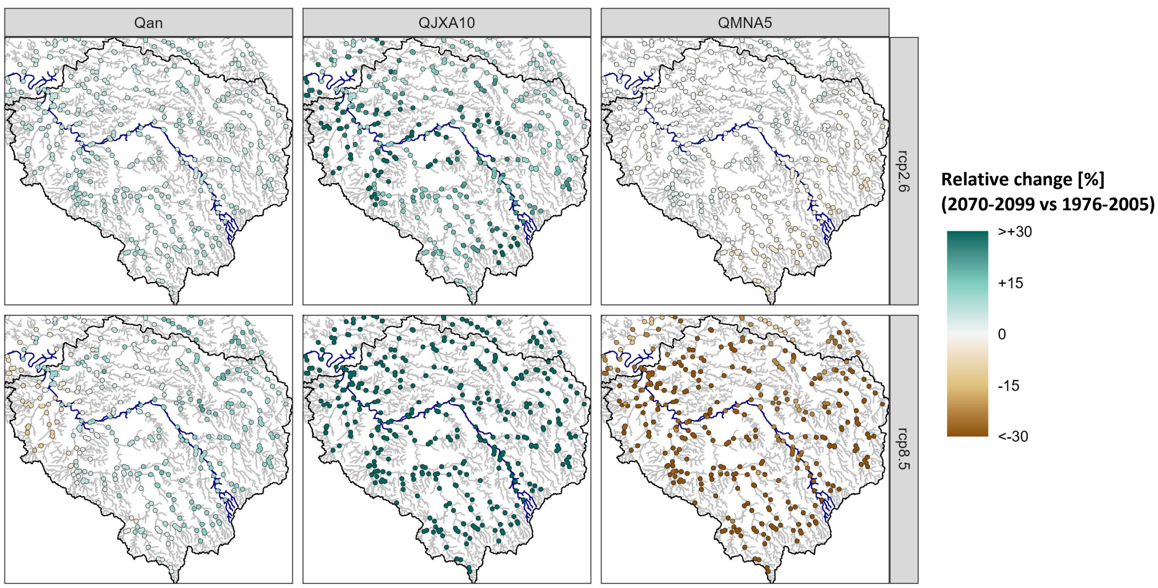


Figure A7.1 – Indicators of relative changes (%) in annual resources (Qan), high flows (QJXA10) and low flows (QMNA5) for the Seine River basin at Paris and the end of the century, following RCP2.6 (top) and RCP8.5 (bottom) scenarios (source: INRAE Antony)

Table A7.2 Narrative for the Seine river basin hub: A) socio-economic category; B) biophysical category

A. Socio-economic: It is expected that the region will continue to be economically attractive, with overall **<u>population growth</u>**. Demographic projections for Paris (major metropole in the Seine River basin) indicate a declining and older population by 2040. However, the population of Île-de-France (main economic region within the Seine River basin) is projected to increase and peak during the decade 2040-2049. The region would remain "young territories", compared to the rest of mainland France (INSEE). In terms of **<u>urban growth and spatial planning</u>**, after a gradual peri-urbanization of fringe areas, a movement of "paraurbanization" has succeeded, i.e. a deconcentration of the population away from urban centres, with workers living in the countryside while working in the city. The urban plan in Île-de-France (SDRIF) promotes a ZAN (zero net artificialization) and ZEN (zero net emissions)

territory, by placing **circularity** (less losses, more circularity) at the heart of the Ile-de-France economic model. Overall, construction of homes will be stimulated, as well as reduced consumption and increased transportation options (incl. public transportation). The tendency is for the **reindustrialization** of the Île-de-France region to create jobs and improve the resilience of the region's supply of industrial goods, while promoting the decarbonisation of the **industry** as well as the **freight transport**. Overall, the general tendency is to preserve the **agricultural sector** and to place emphasis on the development of green **energy** production, with the aim of achieving 100% carbon-free energy by 2050. ADEME scenarios for 2050 range from "behaviour-change" scenarios, which are marked by a decrease in energy consumption, a more plant-based diet and contained irrigation, to "technology-developments" scenarios, which are marked by innovation of decarbonized energy services, a reduction of energy demand by the industry sector, and an increased irrigation demand with an intensification of agriculture and the use of synthetic agricultural inputs to improve crop yield. RTE/ADEME scenarios include a reduction of CO_2 emissions in the building sector, as well as the development of electrical solutions, with a production parc adapted via modulations of nuclear energy production or installed wind capacity.

B. Biophysical:

In terms of **nature and biodiversity**, the National Biodiversity Strategy 2030 (SNB) includes objectives of reducing pressures on biodiversity, restoring degraded biodiversity wherever possible, and mobilizing stakeholders, in compliance with the EU's biodiversity strategy for 2030. In a "business-as-usual" scenario, the works of the water agency in the Seine River basin (AESN) and its governance mechanisms are expected to continue. The agency supports targeted projects on water and aquatic environments necessary to achieve the environmental objectives set in the Water Development and Management Master Plan (SDAGE). These are projects linked to the **restoration** of aquatic and coastal environments as well as wetlands, and the prevention of diffuse pollution, in particular by micropollutants including phytosanitary products, and of erosion. Trends towards "reclaiming nature" are expected to continue, with **green spaces** created or expanded.

The projected increases of the severity of rainfall events and of the severity of low flows put emphasis on two systems managed by the Seine hub stakeholder (EPTB SGL). First, the Bassée alluvial plain for **flood control and ecological conservation** will require a strengthened coordination with the water freight transport (diversion channel), which tend to increase in the future "business-as-usual" scenario. The management of flood expansion zones (ZEC, for "Zones d'Expansion des Crues"), carried by EPTB SGL and shaped by connections between surface and groundwater, will be affected by the impacts of climate change on surface river flows as well as on groundwater levels and recharge. Second, and interlinked, impacts are expected on water resources availability downstream of the four upstream lake-reservoirs, managed for flood mitigation and to support **low flows** downstream and up to Paris during dry summer periods and **droughts**. Changes in reservoir inflows from upstream catchments (reduced inflows) and increased water demand downstream are expected to put the current year-round management rules of the reservoirs under pressure. In the Seine River basin, approximately 60% of **water withdrawals** are taken from watercourses and 40% from groundwater. Drinking water supply is the water use sector that represents the largest share of the volumes withdrawn from groundwater annually, followed by agriculture (mainly during the summer period) and industry. More than 60% of agricultural withdrawals are located on two groundwater bodies in the river basin. However, projected changes in groundwater recharge with climate change might lead the agriculture sector to claim water withdrawals from (sub-)surface areas (connected to the surface waters) or directly from the storage in the upstream reservoirs, which is reserved to be used to support low flows downstream the river basin during dry periods.

The main use of surface (watercourses) water today is for freshwater supply, industry supply and cooling of nuclear power plant. With the projected increase in population and industrial activities, changes are expected on water demand and, consequently, on the way managers can maintain low flows through the water releases of the upstream reservoirs, in particular during the dry summer periods. The expected higher temperatures in summer are also expected to contribute to an increase in water withdrawals for cooling needs in buildings with air conditioning.

A7.4 What-if scenario questions

The main what-if questions discussed are:

- What if the upstream reservoirs cannot fulfil their management objectives in the future climate (more severe low flows) and socio-economic changes leading to a higher water demand downstream of reservoirs)?
- What if climate change reduces groundwater recharge and therefore its natural capacity to support low flows, accentuating the future challenge of managing the upstream dams?

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All used for the Rhine river basin hub literature and quantified data is referenced in the text. Non-scientific sources were used as an orientation and background information for the development of this narrative and is listed below.

Seine

The main sources of information used to write the STARS4Water narrative for the Seine River basin are listed below:

- The climate projections and reports on climate change impacts from the national Explore2 project (https://professionnels.ofb.fr/fr/node/1244 (2022-2023);

- The updated Seine Normandy basin adaptation strategy to climate change (https://www.eau-seine-normandie.fr/domaines-d-action/strategie_adaptation_climatique), adopted by the Water agency (AESN) in October 2023;
- The reference document for strategic planning on urban growth and spatial planning in the Ile de France region (SDRIF), which determines land use planning between now and 2040; https://www.iledefrance.fr/participer-la-vie-citoyenne/je-participe-la-vie-de-la-region/le-sdrif-e-ile-de-france-objectif-2040;
- The National Biodiversity Strategy 2030, https://www.ecologie.gouv.fr/strategie-nationale-biodiversite, 2023;
- The National Prospective energy-climate-air scenarios (AME), https://www.ecologie.gouv.fr/scenarios-prospectifs-energie-climat-air, 2023;
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- The national low-carbon strategy (SNBC), which is France's roadmap for driving the climate change mitigation policy. It defines a trajectory for reducing greenhouse gas emissions until 2050 and sets short- to medium-term objectives: carbon budgets. It has two ambitions: to achieve carbon neutrality by 2050 and to reduce the carbon footprint of French consumption, https://www.ecologie.gouv.fr/strategie-nationale-bas-carbone-snbc (last report from March 2020);
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