Ref. Ares(2024)1575377 - 29/02/2024

GoNEXUS

Tools and solutions for governing the nexus

Deliverable 2.2: River basin and local climate, socioeconomic, and land use scenarios

February 2024, WP 2

GoNEXUS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 101003722.

www.gonexus.eu

Version 2

February 2024

2.2: Report on River basin and local climate, socioeconomic and land use scenarios

Lead by Brgm

J-D Rinaudo, L. Seguin (Brgm); A. Tilmant &L. Bruckman (University Laval); E Gómez Martin, D. Martínez Domingo, V Mónico González, A Rubio Martin, M Pulido Velázquez (Univerity Polytechnica Valencia); S. Sinclair & P. Burlando (ETHZ); André Müller (Adelphi); S. Ricart-Casadevall, M. Guiliani, A. Casteletti (POLIMI) Rens van Beek (UU), János Fehér & Beáta Pataki (FAMIFE) Guido Schmidt (FT) Awa NIANG FALL, Khady Yama SARR and Mbayang THIAM (UCAD)

Dissemination level of document

Public

Abstract

This document describes the methodological approach used in the six case studies to develop scenarios depicting possible future evolution of the WEFE complex systems under various long term change assumptions. Changes taken into account are driven by global factors such as climate change, global economic change, demographic growth as well as local factors which can be influenced by water managers and policy makers at river basin level (water infrastructure management rules, water allocation rules). The scenarios are intended to support dialogue 2 organized in WP6 as well as to serve an input for river basin model simulation. Different scenario building approaches have been deployed in each case study, taking into account scenarios already used to develop existing the management plans, as well as the characteristics of models. Also, uncertainty is dealt with in different ways by the different teams. Overall, while several case study teams adopted a bottom-up approaches, relying a lot on stakeholders to define scenarios before simulating their impacts, other teams used a more top-down approach where models are first used to simulate the impact of global changes before involving users in a discussion of adaptation scenarios.

GoNEXUS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 101003722.

Version History

Version	Date	Authors	Description
V1	Nov 2023	JD Rinaudo	Outlines for D2.2 with proposed structure and graphical representation of links between qualitative scenarios and models +first draft Senegal section
V2	Nov 2023	JD Rinaudo, Amaury Tilmant, Laurent Bruckman, Laura Seguin: Senegal case study	Complete Senegal section (except local scenarios)
V3	Dec 2023	E Gómez Martin, D. Martínez Domingo, V Mónico González, A Rubio Martin, M Pulido Velázquez	Complete section on Tajo-Segura and Jucar case studies
V4	Jan 2024	S. Sinclair, P. Burlando, André Müller	Complete section Zambezi case study
V5	Jan 2024	S. Ricart-Casadevall, M. Guiliani, A. Casteletti	Complete section Como lake case study
V6	Jan 204	Rens van Beek (UU) János Fehér, Beáta Pataki (FAMIFE) and Guido Schmidt (FT)	Complete section Danube case study
V7	January 2024	Awa NIANG FALL, Khady Yama SARR and Mbayang THIAM	Local scenarios in Senegal case studies
V8	February	JD Rinaudo	Final complete version
V9	February	Review by Maria Blanco (UPM)	Complete reviewed version
V10	February	Final revision by Hector Macian-Sorribes (UPV)	Complete final version

Table of contents

List of Tables

List of Figures

Executive summary

This document describes the methodological approach used in the six case studies to develop scenarios depicting possible future evolution of the WEFE complex systems under various long term change assumptions. Changes taken into account are driven by global factors such as climate change, global economic change, demographic growth as well as local factors which can be influenced by water managers and policy makers at river basin level (water infrastructure management rules, water allocation rules). The scenarios are intended to support dialogue 2 organized in WP6 as well as to serve as an input for river basin model simulation. Different scenario building approaches have been deployed in each case study, taking into account scenarios already used to develop existing management plans, as well as the characteristics of models. Also, uncertainty is dealt with in different ways by the different teams. Overall, while several case study teams adopted a bottom-up approaches, relying a lot on stakeholders to define scenarios before simulating their impacts, other teams used a more top-down approach where models are first used to simulate the impact of global changes before involving users in a discussion of adaptation scenarios.

Zambezi watercourse

In the Zambezi Watercourse, river basin and local development scenarios will be derived and assessed using an interdisciplinary approach that mobilizes (i) stakeholders' knowledge and expertise (through the Dialogues), (ii) scientific data sets derived from external studies and global models and (iii) the use of a two stage model simulation strategy, coupling a strategic system optimization model (MORDM) with a high resolution hydrological model (TOPKAPI-ETH) through a common set of optimal system operation policies (reservoirs, and irrigation allocations).

The approach for this case study focuses on refining and later simulating an existing set of high-level basin development scenarios developed by ZAMCOM as part of the Strategic Plan (ZSP) for the Zambezi Watercourse 2018-2040 (ZAMCOM, 2019). This ZSP aims to maximize value for the riparian countries, aligning with their interest in optimizing and building upon scenarios previously developed through a broad stakeholder engagement process.

The overall approach is graphically depicted in Figure 37 and the main components of stakeholder interaction, and scenario simulation described in Section 6

Spanish river basins

For the construction, evaluation, and validation of the local scenarios considered in the Spanish case studies, a participatory and multisectorial approach was adopted involving representatives from all components of the WEFE nexus. After reviewing the baseline information on the current state of the basins and future projections, a first participatory stage (1st Dialogue) was conducted to establish a shared vision of each system and the identification of current and future challenges. This stage also included stakeholder interviews. Based on this information, two local scenarios for 2050 were developed for each case study, projecting the future system behaviour in relation to the four elements of the WEFE nexus. Each initial scenario presented to stakeholders in 2nd dialogue is summarised below:

Jucar river basin:

Scenario 1: Increase in agricultural exploitations and free market. This scenario aims to explore the possibilities of expanding agricultural activities and the use of renewable energies, assessing their impact on the environment.

Scenario 2: Environmental protectionism. This scenario seeks to establish possible synergies between agricultural and energy sectors with a sustainable focus and a reduction of current environmental impacts, considering future reductions in contributions due to climate change.

Tagus river basin:

Scenario 1: Over the past two decades, the prioritization of the Tagus River has brought about significant changes. The transfer of water to the Segura Basin, despite protests, allowed the Tagus to address its own needs, fostering territorial development and mitigating some effects of climate change. The upper stretch witnessed growth in tourism, recreational activities, and rural revival. Regional development extended to new agricultural industries, though concerns about future aquifer overexploitation emerged. The central Tagus, up to Talavera, resisted climate change effects, restoring ecosystems. The middle and lower basin, prioritized since 2030, pleased Portugal but led to decreased hydroelectric production. By 2050, reduced water contributions raised questions about the Albufeira Treaty, causing tensions between Spain and Portugal over potential revisions.

Scenario 2: In the current scenario, the relationship between Spain and Portugal is strained due to escalating tensions over water resources, particularly in the shared river basins. The primary source of conflict is Spain's alleged violation of the Albufeira Treaty, specifically regarding water flow to Portugal. The Tagus River, impacted by transfers to the Segura basin, faces unacceptable pressure despite reduced water transfers. Overexploitation concerns in the Tagus River Basin Authority's latest Hydrological Plan intensify the issue, with increased pumping to compensate for lower precipitation and expanded irrigated areas. Madrid's efforts to enhance water efficiency and public awareness fall short for the Tagus basin. The middle and lower basin experience additional challenges, including the negative impact of hydroelectric production on ecosystems. Portugal demands continuous flows, while Spain calls for a treaty review with climate-adapted limits.

Segura river basin:

Scenario 1: Sustainable energy transformation. This scenario envisions a highly instrumentalized basin where renewable energies take precedence, and agricultural irrigation is maximally digitized and modernized. The use of alternative water sources for agricultural sustainability is also evaluated.

Scenario 2: Ecological transformation. Considering climate change predictions, this scenario evaluates a situation where current agricultural activities disappear, and sustainable economic alternatives are sought for the basin.

Once the local scenarios were established, a second participatory stage was conducted to discuss the coherence, feasibility, and viability of these scenarios with stakeholders by validating approximately ten assumptions for each case study. This exercise allowed for prioritizing these assumptions and co-creating new scenarios (new narratives) based on the initial ones. In this second stage, various solutions were also proposed for each basin's challenges through the interaction of nexus components. Finally, the information gathered in this second stage also facilitated the identification of preliminary indicators, which would later serve as inputs for different modeling efforts.

Lake Como

In the Lake Como case study, a multifaceted and participatory approach was adopted to create and assess climate and policy scenarios. The participatory process in Dialogue 1 was based on a series of semi-structured interviews and questionnaires with key stakeholders (20, e.g. regional authority, lake operator, irrigation districts, hydropower companies, environmental associations, tourism associations, mountain communities) representing the four dimensions of the WEFE nexus to identify a shared vision of the Lake Como system. Insights were used to develop contrasting local policy scenarios to integrate the possible long-term evolution of the WEFE nexus in the system. The two policy scenarios were defined as 1) Hydropower maximization and 2) Risk management; while the Business as Usual (BAU) scenario was considered as the reference scenario. The purpose of the 'Hydropower maximization' scenario is to increase hydropower production, flexibility, and storage to maximize green energy transition and reinforce renewable energy self-sufficiency at the regional and national scale, while the target of the 'Risk management' scenario is to strengthening water management to better respond to extreme weather events emphasized by climate change (which are projected to be more frequent and intense, particularly regarding flood events and drought periods). In Dialogue 2 (Feb. 13-14th, 2024), a list of 10 assumptions defining each scenario will be discussed with stakeholders to check its relevance and priority, and internal coherence and feasibility. Additionally, Dialogue 2 will also allow participants to prioritize among different possible solutions to increase the adaptive capacity of the WEFE nexus and identify preliminary indicators to be then transferred as input for the modelling approach. An integrated model (combining a hydrological model, different operational models for the alpine area and the Lake Como system, irrigation diversion models for the Adda river, and irrigated districts model) will evaluate both scenarios. Three WEFE indicators have been considered for the Lake Como Basin experiments (see D4.1 for details): a) the water deficit of the downstream users, b) the frequency of flooding events in Como, and c) the lake low levels. The relevance and accuracy of these indicators and different operating space limits will be discussed in Dialogue 2 considering the alignment with assumptions, indicators, and solutions. Likewise, Dialogue 2 will be useful to discuss with stakeholders which scenario or time horizon they prefer to go further considering the expected outputs of the compromised operating policies.

Danube

In the Danube River Basin Case Study, we used a top-down approach to develop scenarios. In the first step, we performed a preliminary assessment of the challenges and gaps that are relevant for the WEFE nexus in the Danube Basin, using many documents available for the watershed (e.g. scientific articles, case study documents, documents related to the implementation of EU regulations and directives, etc.). As a result of the preliminary assessment, we have identified 3 main challenges out of the many challenges that can be discussed with the stakeholders and the scenarios supported by them can be examined in more detail by modeling, taking into account (i) the available scientific data, (ii) the global and regional climate models provided data and applied climate scenarios, (iii) the characteristics of the water resource models available in the project. The 3 challenges in relation with climate change are: water scarcity and increased flood risk; water scarcity due to growing irrigation demand; and vulnerability of riverine and terrestrial ecosystems (biodiversity). In the first round of dialogues at basin level, sub-basin level and local level the discussions with the stakeholders confirmed that the 3 preliminary identified challenges were also rated as the highest priority by the stakeholders.

As part of the modelling of the 3 challenges, the hydrological trade-offs within the WEFE nexus is simulated with a large-scale hydrological model, the PCR-GLOBWB, which included land use changes and water demand in the simulations. Prior to Dialogue 2 in total 21 simulations have been performed including simulation of the reconstructed historical climate; simulations using the five GCM members of the ISIMIP3b experiment and simulations comprising simulations for the three Shared Socioeconomic Pathway (SSP) and Representative Concentration Pathways (RSP) combinations. Model results from PCR-GLOBWB comprise a large number of hydrological variables and these model results can be subdivided into three broad categories in addition to the input data from the scenarios, such as (a) soil hydrology, including groundwater, at cell level; (b) water demand and withdrawal data per sector (domestic, industrial, livestock, irrigation) and per source (surface water, renewable groundwater, non-renewable groundwater and desalination); and (c) surface water hydrology including discharge, water levels and water body storages (lakes, reservoirs).

In addition to the hydrological information, information is available from the agricultural model CAPRI of UPM, PROMETHEUS – PRIMES (E3-modeling) and GLOBIO (PBL) pertaining to the food, energy and ecosystem components of the WEFE nexus.

As part of the second dialogue, local scenarios will be presented and adapted to meet the concerns of the stakeholders in relation to the challenges and reflecting on the questions that were raised by the stakeholders during the first round of dialogues.

It is intended to develop three narratives along axes that represent different needs of the challenges and span the actual scenarios within this. These axes are:

- Emphasis on agriculture; in this case a large but realistic area will be taken up by intensive agriculture, including irrigation;
- Emphasis on hydropower, in this case precedence is given to hydropower generation;
- Emphasis on ecology, in which case the priority is to protect vulnerable areas of biodiversity.

Stakeholders will also be consulted in the 2nd Dialogues on the nature of the scenarios and the information that is used to create the scenarios eventually. The outcomes of this round of dialogues would be an agreed set of manageable narratives and relevant and vetted information that can be used to define the scenarios.

During the second dialogues, the nature of these solutions will be discussed and linked to the narratives. On the basis of the model evaluation on robustness and the optimal solutions (Steps 8 and 9 of Figure 1), the third and final dialogue will be organized.

Among others, the following solutions are considered and will be discussed: (i) Implementation of protected areas in which certain human activities (irrigation, groundwater pumping etc.) are prohibited; (ii) Improved irrigation efficiency by considering more drought tolerable crops, increased irrigation water efficiency etc.; (iii) Environmental flow requirements to ensure river system health; (iv) Improved reservoir operations to mitigate the downstream impact of dams or restricted dam allocation; (v) Prioritization of water withdrawals on the basis of sectoral demand; (vi) Improved water use efficiencies (other sectors than irrigation).

The above summarized approach is visualized in a flow chart (Figure 40) which shows the different steps from Step 1 (Review of research projects/publication) block till Step 9 (Dialogue 3) that is planned to produce recommendations on the preferable solutions (sustainability / desirability).

Senegal

In the Senegal river basin, scenarios were developed and assessed using an interdisciplinary and bottom-up approach that mobilized (i) stakeholders' knowledge and expertise (through interviews and workshops), (ii) scientific data sets derived from external studies and global models and (iii) the use of a river basin optimization and simulation hydroeconomic model. The first step was an understanding of the river basin context and the different dimensions of the nexus, by reviewing existing policy documents such as the River basin Master plan developed by the River Basin Agency OMVS (*Organisation pour la Mise en Valeur du fleuve Sénégal*,Organization for the development and management of the Senegal river valley). Then, we collected stakeholders knowledge and viewpoints by conducting 40 interviews with stakeholders to identify actual WEFE trades-off and tensions. We conducted a first Dialogue to allow stakeholders to build a common understanding of WEFE issues, and to identify the main driving forces that are likely or unlikely to modify the context in the next decades. After dialogue 1, with the results of the first steps, the research team developed 3 narrative scenarios, which are contrasted action scenarios or policy scenarios, depicting three possible long-term evolutions of the nexus in the Senegal river basin, including also external changes like climate change or global economic changes. These scenarios were presented and discussed with stakeholders during Dialogue 2 using fictional press releases. The team uses these narrative scenarios as a basis for running river basin model simulation with the hydroeconomic model developed by University Laval. We translate qualitative scenarios into quantitative ones, to quantify the main scenario assumptions, for example the number and capacity of reservoirs constructed, the operation rules for those reservoirs, the new irrigated areas, the change in climatic conditions… Overall, 5 scenarios are specified: a baseline; a business as usual; and the three strategic vision scenarios discussed in Dialogue 2. Once quantitative hypotheses are defined, the river-basin model is employed to evaluate scenarios. Two distinct evaluation methods are employed, utilizing the optimization and simulation functionalities of the model. To finish, a third dialogue is dedicated to present and discuss with stakeholders the modeling results.

1 Introduction

Author: JD Rinaudo, Brgm.

1.1 Objective

This deliverable presents the result of task 2.2. which aims to develop socioeconomic and land use scenarios for the river-basin case studies, in coordination with the river basin and local Nexus Dialogues developed in WP6.

River basin and local scenarios take into account the global trends and climate projections eluded from tasks 2.1 and 2.2. Combining use of qualitative storylines and quantitative modelling tools, they contribute to provide evidence of global change impacts and to obtain insight on future water, food and energy management strategies.

The outcomes of this task will provide the river basin models (WP4) with a range of future socioeconomic and land use scenarios, whose impacts will be compiled (WP5) and analysed through the Nexus Dialogues (WP6) in search of local solutions (WP7).

Coordinated by BRGM, this task was implemented by partners in charge of case studies: POLIMI for the Lake Como; UPV for the two Spanish case studies; UU, FAMIFE and Fresh thoughts for the Danube basin; ETHZ, Adelphi and ZAMCOM for the Zambezi basin; and BRGM, ULAVAL and UCAD for the Senegal case study. Results are reported in a specific section for each case study.

1.2 The purpose of scenarios

1.2.1 Purpose of scenario development

The work undertaken at the river basin scale by the GoNEXUS teams aims to assist stakeholders in projecting into the future to (1) assess the impacts that global changes (climatic, economic, demographic) are likely to generate in these basins and (2) contemplate the solutions they could implement to mitigate negative impacts.

However, not all stakeholders with whom the project will work are familiar with this type of forward-looking thinking. Some may have a rather partial and static vision of the complex system to which they belong. To support their reflection, it is first necessary to make them aware of all the factors influencing the evolution of the system as a whole and the part of the system that concerns them. Once this systemic understanding is acquired, their reflection can be informed by more quantitative information based on model simulations, allowing for the qualification of the relative intensity of phenomena and the comparison of the effectiveness of various solutions they will consider.

Depending on the basins, stakeholders have a fairly variable culture of foresight. For example, riparian countries of the Zambezi have already conducted a foresight exercise in 2018-19, while those in the Senegal basin have very little experience in this matter. Different approaches must be established to engage these stakeholders in such diverse contexts. This partly explains the diversity of approaches presented in the rest of this report.

The diversity of methods deployed to design scenarios also reflects that of the models developed by teams to simulate their effect on the WEFE (Water, Energy, Food, Environment) system. Some teams have simulation tools that essentially represent hydrological phenomena and simulate the impact of exogenous changes (e.g., climate, water withdrawals for irrigation, land use) on the system's state. This is notably the case in the Danube basin. Other teams have optimization tools that not only simulate the consequences of assumptions regarding exogenous changes but also design action programs that optimize objectives defined by stakeholders for different exogenous conditions. Such hydroeconomic models are mobilized in Lake Como, the Senegal basin, the Zambezi basin, and the Jucar basin. Finally, a third type of model is used in the Tagus and Segura basins. It is a System Dynamics Model that allows exploring the overall dynamics of the WEFE system through semi-quantitative simulations for different assumptions of exogenous or endogenous evolution.

1.2.2 Definition and typology of scenarios

A scenario is defined as a plausible description of how the future may develop based on a set of coherent and consistent assumptions about key driving forces (e.g. rate of technological change, population growth) and relationships. Scenarios are not predictions or forecasts but represent possible future state of the world. They are useful to provide insight into the implications of possible future developments and planned policy interventions.

Different types of scenarios will be considered in the following pages:

- **A reference scenario** depicts the evolution of the WEFE system assuming the hypothetical continuation of current climatic and economic conditions. It serves as a reference to compare future evolution with today's conditions.
- **Baseline scenarios** represent future trends of the WEFE system assuming no additional policies beyond those already in place. A baseline scenario serves as a comparison or counterfactual scenario to assess impacts of alternative scenarios (e.g. policy changes).
- **Policy scenarios** describe the evolution of the WEFE system assuming specific actions have been implemented, modifying some of the factors that drive the dynamics of the system. These actions may alter hydrological processes (e.g. construction of reservoirs, new water uses, change in management rules of hydropower dams) as they can affect economic variables (food or energy price or supply).

1.2.3 Addressing uncertainty in scenario development

Uncertainty is a key issue to be dealt with when developing scenarios. Future evolution of the key drivers that determine the evolution of the WEFE systems is unpredictable. This applies to climate change, which depends on human decisions (reflected in SSP scenarios) but also to the economic context (world market prices, political instability risks, etc.). It is therefore impossible to explore the future using a deterministic approach which would only consider one baseline scenario that can serve as a reference for assessing the impact (or effectiveness of policy scenarios).

The project teams address this issue of uncertainty in two different ways, that we will call top-down and bottom-up approaches:

- **The top-down approach** starts from the SSP scenarios defined by the GIEC, which describe several possible global evolutions of economic and political systems, and their climate change implications. These global change scenarios are downscaled at river basin level and models used to describe how the WEFE system would evolve at basin level, under those conditions. This approach implies that stakeholders are clearly presented, from the beginning of the dialogue process, the uncertainty that exists about the baseline scenario. With that approach, models are used before the dialogue with stakeholders starts, their results serve as a basis for debating what to do.
- **The bottom-up approach** starts from a discussion on the levers for action that can reasonably been activated to adapt to the unpredictable changes that will affect the WEFE system in the future. So instead of addressing the question "what will happen to us", this approach focusses on "what can we do to adapt". Once action strategies have been identified, models can be used to assess to what extent they can solve the problem, under different possible future evolution of the world (climate, economics). Models are hence used to assess the robustness of the solutions defined by stakeholders. This approach gives a greater role to stakeholders than the top-down.

1.2.4 Narrative storylines

Narrative scenario (or Storyline) are qualitative description of the relationships and dynamics of a scenario, focusing on the characteristics, general logic and developments underlying a particular quantitative scenario. A narrative highlights key scenario features and causal connections between driving forces, helping to interpret potential trajectories. Narratives can be used to describe plural and conditional possible futures of a system, in contrast to unique and definitive futures.

Following the example of the Senegal team, led by BRGM, several teams have used narrative scenarios to engage stakeholders in future-thinking (Lake Como, Spanish basins and possibly Danube in the near future). Storylines are written as **fictional press releases** which involve fictitious characters and relate facts supposedly taking place in the late 2030's and 2040's. This approach is thought to be effective for engaging stakeholders in future thinking for several reasons:

- Stories have the ability to evoke emotions and create a connection with the audience **(emotional connection)**. By embedding scenarios in a narrative format, stakeholders are more likely to emotionally engage with the content. This emotional connection can enhance the impact and resonance of the scenarios.
- People tend to remember stories better than abstract information **(improved retention**). By presenting scenarios as stories, we increase the likelihood that stakeholders will retain key insights, making the information more memorable and actionable.
- Storylines provide context and a holistic view of the scenarios **(contextual understanding)**. Stakeholders can better grasp the interconnectedness of various factors, potential impacts, and adaptation strategies when presented in a narrative format.
- Storylines make WEFE complex scenarios more accessible to a wider audience than if presented using scientific data and graphs, increasing the likelihood to engage stakeholders with limited technical background **(enhanced accessibility**). They can help stakeholders envision change as a dynamic and evolving process, fostering a mindset that is more adaptable to uncertainties and future challenges.
- Stories create a shared experience (linked to the emotional connection) and can serve as a focal point for discussions **(fostering dialogue**). Stakeholders are more likely to engage in meaningful dialogue when scenarios are presented in a compelling and relatable manner. Moreover, in a workshop setting, where active participation is crucial, storylines provide a structured framework for discussions.

Narrative scenarios used to support discussion during the dialogue are expected to evolve after collecting stakeholders' opinions. New narratives can then be created, combining assumptions taken from several of the initial scenarios. The research team then has to quantify the assumptions so that they can be used as numerical input values for model simulation. The results of the simulation can then serve as a basis for further debate with stakeholders in dialogue 3.

2 River Basin and local climate scenarios

A global overview of the scenarios analysed by GoNEXUS is shown in Figure 1. The scenarios addressed in this deliverable are within the red squares. Section 2 describes the selected climate scenarios and the projected climate variability during the 21st century. Section 3 onward presents land-use and socio-economic pathways for the 21st century per case study.

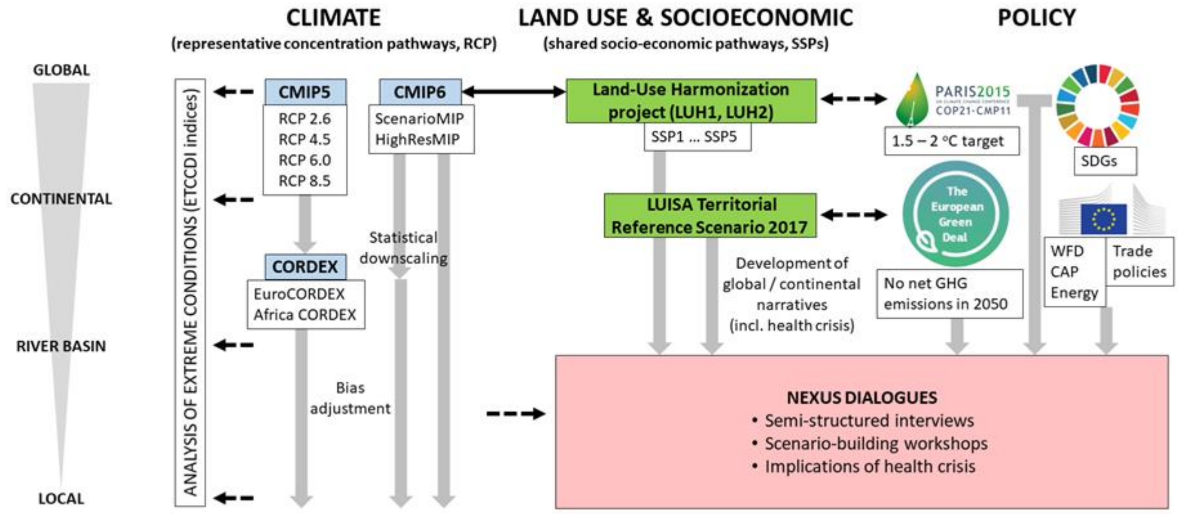


Figure 1: Overview of GoNEXUS scenarios

2.1 Summary of scenarios

The climate change scenarios analysed by GoNEXUS will be obtained from the Coupled Model Intercomparison Project (CMIP). In particular, two phases of the CMIP will be used: the established family of scenarios from CMIP5 and the novel CMIP6 family of scenarios. Both phases are not mutually exclusive. Consequently, it is possible to take advantage of their complementary features: the existence of dynamically downscaled experiments and the experience in the use of CMIP5, and the explicit link with Shared Socioeconomic Pathways -SSPs- and the scientific advance posed by CMIP6.

CMIP5 scenarios will refer to the Representative Concentration Pathways (RCPs) 2.6, 4.5 and 8.5. Since high-resolution variables are required in investigating the river basin and local scales, the Coordinated Regional Climate Downscaling Experiment (CORDEX) data will be exploited. In particular, the European and African CORDEX (EuroCORDEX and AfricaCORDEX) are evaluated in GoNEXUS. The EuroCORDEX data are available at a nominal resolution of about 11km, while the data over Africa have a nominal resolution of about 22km. These climate scenarios will be downloaded through the Earth System Grid Federation (ESGF) nodes (https://cordex.org/data-access/esgf/). No further bias adjustment would be required for these scenarios.

CMIP6 scenarios will include three climate scenarios: SSP1-RCP2.6 (related to achieving the goal of not surpassing 2 degrees of global warming as indicated in the Paris Agreement), SSP3-RCP 7.0 (business as usual scenario considering the ongoing energy transition) and SSP5-RCP 8.5 (worst case scenario). The high-resolution climate data are computed from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) data by applying statistical downscaling techniques. In particular, two statistical downscaling techniques will be used: the ISIMIP3BASD method (Lange 2019) and the analogs method (Yiou et al., 2013). The ERA5-land reanalysis data with a nominal resolution of about 10km are used as a reference in the downscaling methods. The ISIMIP variables will be downloaded from the ISIMIP repository (https://data.isimip.org/). The ERA5-land data will be retrieved from the Copernicus Climate Change Service (C3S, https://cds.climate.copernicus.eu/cdsapp#!/home). No further bias adjustment would be required for these scenarios.

Variable long name	CMOR name
Total precipitation	pr
Surface air pressure	ps
Near-surface relative humidity	hurs
Near-surface wind speed	sfcWind
Near-surface air temperature	tas
Minimum near-surface air temperature	tasmin
Maximum near-surface air temperature	tasmax
Surface downwelling shortwave radiation	rsds
Surface downwelling longwave radiation	rlds

Table 1 : climate variables requested to force the WEFE nexus

The requested variables (Table 1) have been retrieved from five CMIP6 models, namely GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, and UKESM1-0-LL, for historical and future scenarios in the ISIMIP framework. The selected variables will be downscaled on four local domains: Senegal and Zambezi basin rivers in Africa and Iberian peninsula and Lake Como basin in Europe. The ISIMIP3BASD technique will be applied to the entire set of regions, while the analogs method will be only used in the Iberian peninsula domain.

2.2. Climate scenarios variability (example of the Iberian Peninsula)

The selected climate scenarios identify various possible future pathways from Paris agreement compliant (RCP2.6) to business-as-usual (RCP8.5 and RCP7.0). Besides, the different statistical downscaling techniques can provide further variability to the climate trajectories (Figure 2).

Over the Iberian peninsula, the two downscaling techniques simulate similar trends in near-surface temperature and precipitation during the 21st century (Figure 2). The two downscaling techniques differ in the reproduced near-surface temperature interannual variability (Figure 2). The analog method maintains the original model-interannual variability, while the ISMIP method gives a variability closer to the ERA5-land one. On the contrary, the interannual precipitation variability is similar between downscaling techniques and original ISIMIP data. However, the two downscaled values change in magnitude (Figure 2). In particular, the ISIMIP technique tends to increase the native amount of precipitation, while the analog method reduces the total amount of precipitation over the Iberian peninsula.

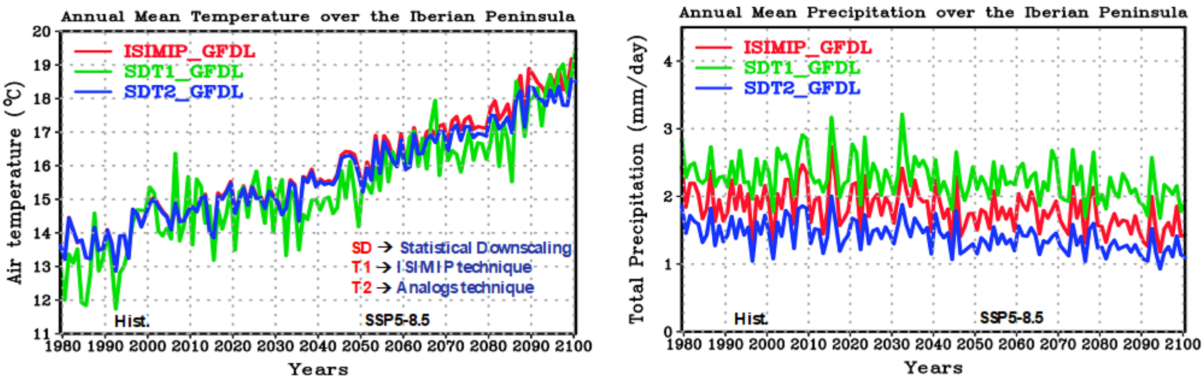


Figure 2: time evolution of global near-surface air temperature and precipitation for the GFDL-ESM4 model under the worst climate scenario (SSP5-RCP8.5) over Spain downscaled using ISIMIP3BASD (ISIMIP technique) and analogs method.

The differences between original ISIMIP data and downscaled variables are more evident in the spatial distribution. The downscaled near-surface air temperature, independently from the applied technique, presents more details over the Iberian peninsula, especially in areas characterized by orographic slopes, such as the Pyrenees, Cantabrian Range, and Sistema Central (Figure 3). The pattern of absolute change in near-surface air temperature during the 21st century is similar in the three cases (i.e. original ISIMIP, downscaled with ISIMIP3BADS, and downscaled with analogs) with slight discrepancies between them (Figure 3).

On the contrary, the two downscaling techniques produce two distinct precipitation distributions (Figure 4), as expected from the annual mean time series (Figure 2). In particular, the southwestern part of Spain displays the principal differences. The ISIMIP3BADS method delivers higher values of precipitation over the southwest of Spain both in the present-day (Figure 4d) and future (Figure 4e), leading to minor precipitation reduction during the 21st century (Figure 4f) compared to the original ISIMIP data (Figures 4a-c). The analog method exhibits lower values of precipitation in the southwest of Spain in both the 1995-2014 and 2081-2100 periods (Figures 4g,h) compared to the original ISIMIP data (Figures 4a,b). Despite this difference, the pattern of relative changes in precipitation during the 21st century obtained with analogs is similar to the ISIMIP one (Figures 4c, i).

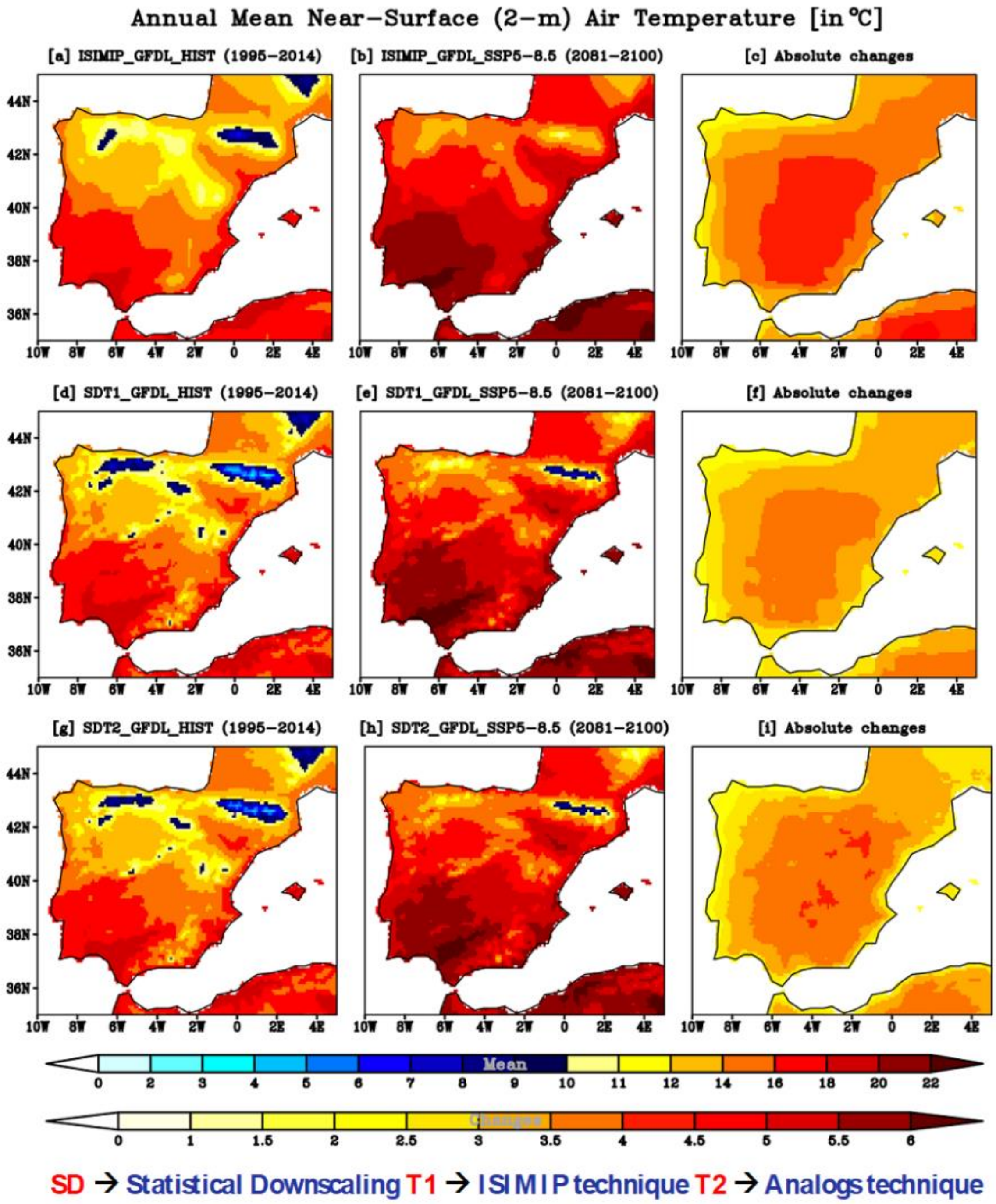


Figure 3: time evolution of global near-surface air temperature and precipitation for the GFDL-ESM4 model under the worst climate scenario (SSP5-RCP8.5) over Spain downscaled using ISIMIP3BASD (ISIMIP technique) and analogs method.

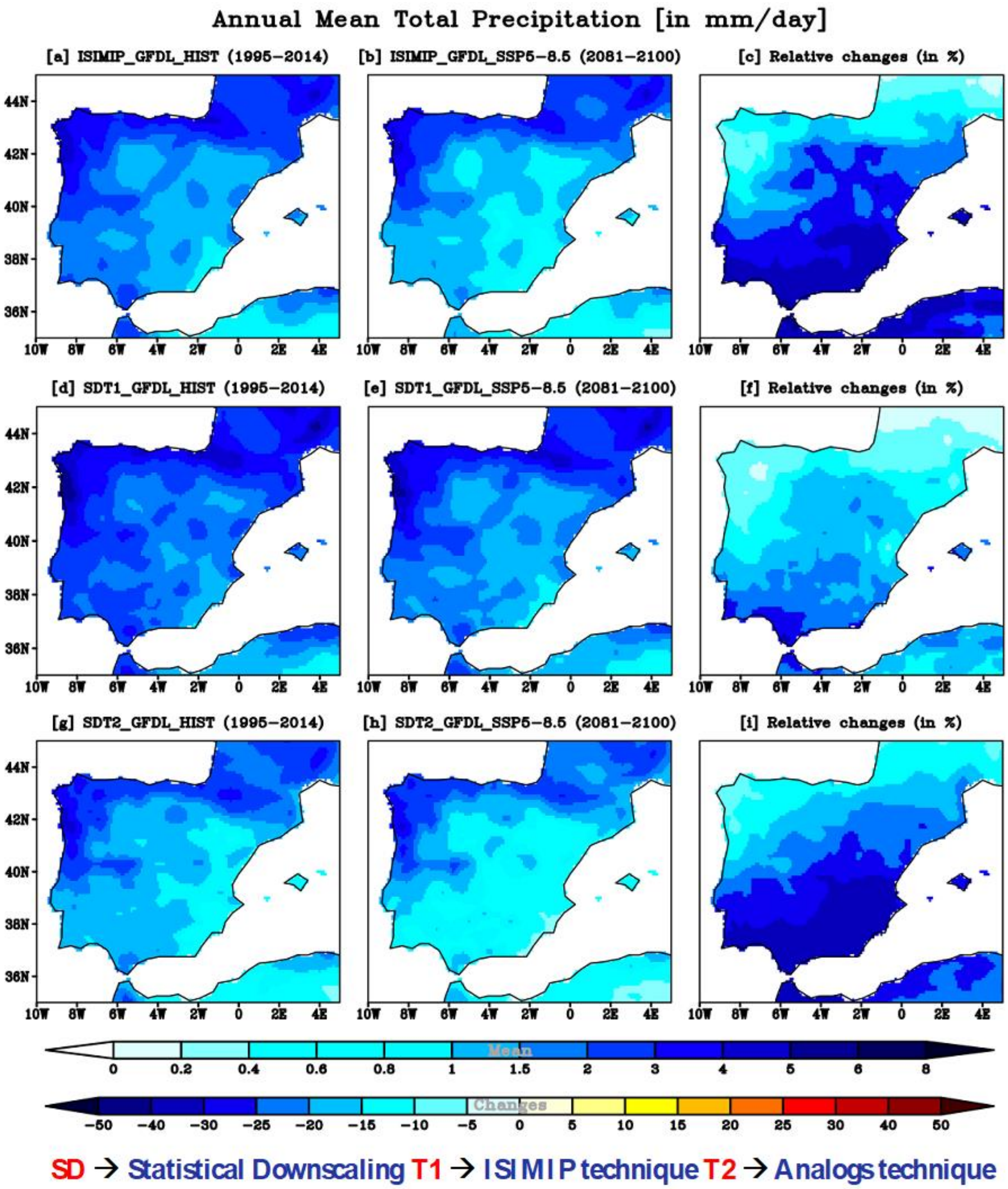


Figure 4: 21st century changes in precipitation under the worst climate scenario (SSP5-RCP8.5) for ISIMIP (first row, 50-km nominal resolution), statistical downscaling of ISIMIP based on ERA5-land using ISIMIP3BASD (second row, 10-km nominal resolution) and analogs (third row, 10-km nominal resolution)..

3 Local socioeconomic and land use scenarios: Senegal case study

Authors : JD RINAUDO & L. SEGUIN (Brgm), A. TILMANT & L. BRUCKMANN (Uni Laval), Awa NIANG FALL, Khady Yama SARR and Mbayang THIAM (UCAD)

3.1 Overview of the methodology

In the Senegal river basin, scenarios were developed and assessed using an interdisciplinary and bottom-up approach that mobilized (i) stakeholders' knowledge and expertise (through interviews and workshops), (ii) scientific data sets derived from external studies and global models and (iii) the use of a river basin optimization and simulation hydroeconomic model. The overall approach is graphically depicted in Figure 5 and briefly described in the following paragraphs. Following this overview, further details are provided in the next sub-sections (2.2, 2.3 and 2.4).

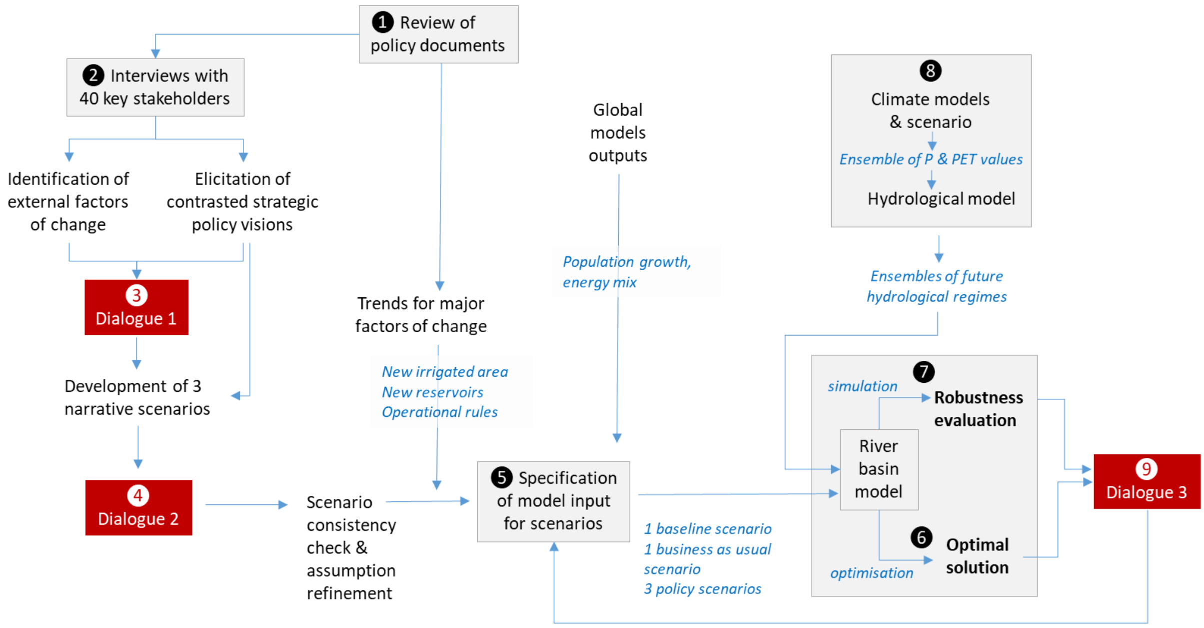


Figure 5 : overview of the inter-disciplinary approach used to develop and assess scenarios in the Senegal river basin case study.

The first step consists in a review of existing policy documents related to the different dimensions of the WEFE Nexus as well as the River Basin Master plan (SDAGE) recently developed by OMVS, the international organization in charge of managing the basin (❶). Documents help identifying some of the main changes likely to impact water management in the basin such as the construction of new reservoirs and agricultural policy support given to large private projects. However, unlike in other case studies (e.g. Zambezi), none of the documents we reviewed included a genuine forward-looking vision or presented diverse scenarios depicting possible shifts in terms of trade-offs among the competing objectives of food security, energy production, water supply, and ecosystem protection.

For more information, we conducted a series of interviews with more than 40 stakeholders representing the different sectors and institutions involved in the four dimensions of the nexus (❷). This consultation allowed better identifying tensions that currently exist between actors of the WEFE nexus, how they might develop in the future and what trade-offs are at stake. It also allowed eliciting contrasted strategic policy visions for the future of the Senegal river basin. The output of this consultation has been documented in a Brgm report (Ouedraogo et al, 2022).

Stakeholders were then brought together in a two-day workshop organized in Dakar (❸). The aim was to foster the exchange of perspectives, enabling participants to glean insights from one another and transcend the confines of their respective sectors (social learning). This dialogue also enabled participants to build a common understanding of issues and options, which we see as a prerequisite for the development of long-term evolution scenarios. An on-line video presents some of the visions expressed by stakeholders during the workshop [1].

The results of the three previous steps allowed the research team developing contrasted scenario depicting three possible long-term evolution of the WEFE nexus in the Senegal river basin (❹). The purpose of these scenarios was to raise stakeholders' awareness of the variety of global and regional changes that could affect their future. The intent was to encourage them to contemplate potential adaptation strategies across the four dimensions of the nexus that they can deploy to craft desirable futures. Scenarios therefore encompass hypotheses related to: (i) external changes to the basin (e.g., climate change, geopolitical risks, technological innovation); (ii) internal changes beyond their control (e.g., demographic growth); and (iii) actions within their purview (referred to as "solutions" in the terminology of the GoNEXUS project). Scenarios are described through a narrative presentation to facilitate their understanding by stakeholders. They are then discussed with stakeholders at a workshop (dialogue 2) for checking their internal consistency and refining the hypotheses comprising each scenario.

But scenarios aren't just developed to engage players in a future-thinking exercise. They should also serve as a basis for running river basin model simulations. This transition from qualitative forecasting to quantitative simulation involves quantifying scenario hypotheses (❺). This quantification of scenarios is informed by (i) existing global change studies, (ii) outputs of global model simulations carried-out in GoNEXUS and (iii) by existing policy documents. Quantitative assumptions are spatially distributed. They relate, for instance, to new irrigated areas; number and capacity of reservoirs constructed; operation rules for those reservoirs; minimum in-stream flows; change in climatic conditions; etc. Overall, five scenarios are specified: a baseline; a business as usual; and the three strategic vision scenarios discussed in dialogue 2. More details are provided in the modeling section below.

Once quantitative hypotheses are defined, the river-basin model is employed to evaluate scenarios. Two distinct evaluation methods are employed, utilizing the optimization (❻) and simulation (❼) functionalities of the model, respectively. Optimization is applied to identify management strategies (such as reservoir operation rules and allocation decisions) that enable the achievement of scenario-defined objectives (e.g., maximizing food production, maintaining minimum in-stream flow for navigation, ensuring minimum energy production) at the lowest possible cost. This also considers assumptions about the overall socio-economic context. Optimization is performed for five scenarios, including a baseline, a business-as-usual scenario, and three policy scenarios discussed with stakeholders (refer to section 2.2 for scenario details). Subsequently, simulations (❼) are conducted to evaluate the performance of each optimal strategy under various hydro-climatic conditions, serving as a robustness test. Details about the approach used to define the range of possible hydro-climatic conditions (❽) are presented in section 2.3 below.

A third dialogue is then organized to present and discuss with stakeholders the modeling results ❾.

[1] https://www.youtube.com/watch?v=MAcAH6zwrSw&t=3s

3.2 Developing scenarios

3.2.1 Types of scenarios

Different types of scenarios are developed, with two distinct objectives (Table 2):

- We first consider a **baseline scenario** (BS), which consists in a projection that assumes a continuation of current conditions (climate and socio-economic) and without any significant policy / management changes or interventions. This baseline scenario serves as a reference point for comparison with alternative scenarios that explore different future conditions or potential interventions. It will provide a benchmark against which we will assess the impact of the other scenarios, using the river basin model.
- We then consider a **business-as-usual scenario** (BAU), which assumes a continuation of current practices, policies, and socio-economic trends without significant changes. This BAU also assumes some change in the external context, considering the most likely evolution. Regarding climate, we consider scenarios of potential alterations of the flow regime due to climate change. In that case, the most likely scenario is an alteration corresponding to a slightly wetter future.
- **Policy scenarios**, on which dialogue 2 focused, aim at describing hypothetical future situations that are shaped by specific policy decisions and interventions. They are constructed to explore with stakeholders the potential desirable and undesirable impacts of various courses of action. The evaluation of policy scenario is first conducted in qualitative terms during workshops, before being evaluated with the river basin model and again discussed with stakeholders on the basis of modeling results.

Table 2 : Description of the different types of scenarios

Scenario	Climate	Global socio-economic change	Policies
Baseline (BS)	Current climate with historical variability	2023 economic activity, population, water and energy demands	Current policies and management rules / practices
Business as usual (BAU)	slightly wetter	Most likely evolution of water / food / energy demands (extension of current trends)	Same as above
3 policy scenarios (PS)	slightly wetter	Same as above	Policy and management options described in the policy scenario

3.2.2 Developing policy scenarios

In the Senegal case study, the development of policy scenarios was based on two successive stages.

The first stage consisted of analyzing the dynamics of the WEFE, represented as a complex system. This **system dynamic analysis** had three main objectives:

(i) To identify the main external factors of changes (drivers) that are likely to significantly impact the different components of the WEFE nexus in the Senegal river basin;
(ii) To characterize the potential impact of those external changes on the state of the WEFE nexus;
(iii) To identify potential adaptation measures (or "solutions" using the GoNEXUS terminology) that can be implemented to mitigate the undesirable impacts of external changes.

The case for Food Security is shown as an example in Figure 6. It provides an illustration of how this approach was applied to the Food security challenge in the Senegal basin. The main drivers identified through interviews and during dialogue 1 (shown in red) are climate change, geopolitical instability and growth (economic, urban, demographic). Their main impacts are shown in green, and the solutions proposed by stakeholders appear in blue. A similar analysis was conducted for the energy, water supply, navigation and ecosystem protection.

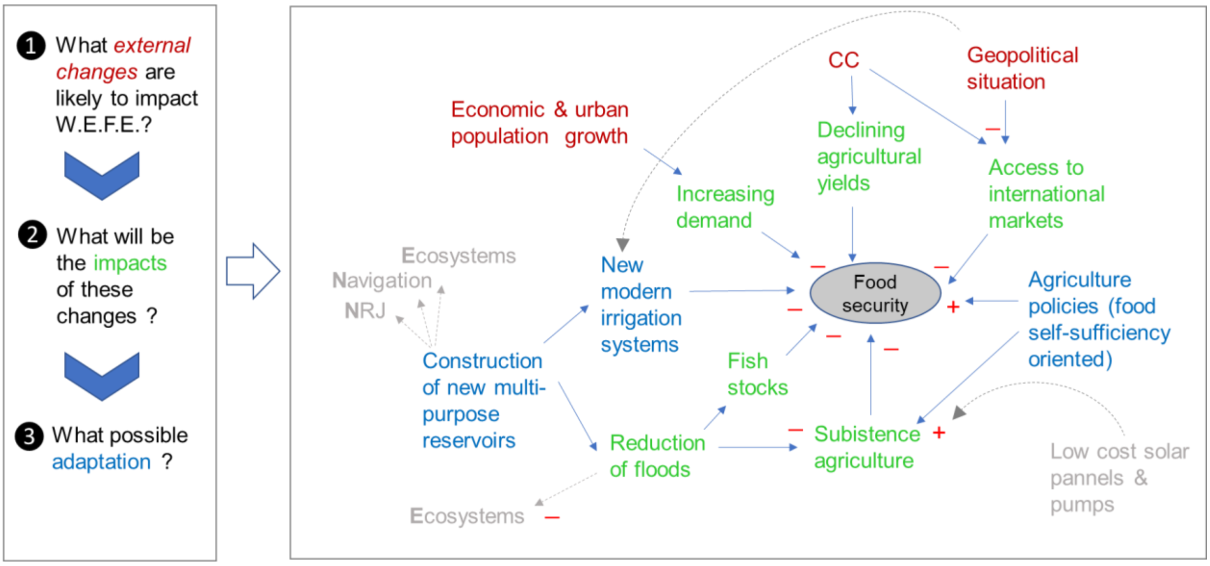


Figure 6 : General approach to develop policy scenarios: illustration with the Food Security component of the WEFE.

In this initial exploratory phase of the analysis, complexity arises from the formulation of numerous hypotheses concerning the future evolution of the WEFE nexus. Specifically, for each change factor, such as climate or geopolitical instability, we had to delineate multiple hypotheses, and therefore qualifying various levels of impact associated with these scenarios. Additionally, we identified several relevant adaptation strategies to address these potential impacts. This process broadens the scope of possibilities, encompassing both "what can happen to us" and "what we can do about it." A comprehensive treatment of this complexity would theoretically generate hundreds, if not thousands, of scenarios to encompass all conceivable futures. However, recognizing the limitations of the human mind in handling such a multitude of scenarios, we needed to streamline and reduce this complexity.

To address this complexity, we made the deliberate decision to distill it into **three contrasted scenarios** presented as narrative storylines. Each scenario outlines the causal relationships among change factors (drivers), their impacts, and potential solutions. The selected hypotheses within these scenarios aim to capture the key processes and broadly depict the diversity of possible solutions. The primary motivation behind this simplification is to enhance the efficiency of dialogue, especially considering that these scenarios will undergo testing in workshops involving stakeholders.

3.2.3 Summary of narrative scenarios developed in the Senegal basin

Based on the results of preliminary interviews with stakeholders and the first dialogue, we developed three policy scenarios which are briefly presented below. The three corresponding narrative storylines are also provided in annex 1.

Scenario 1: “Total business: full speed ahead”

In this scenario, it is assumed that governments of riparian countries are adopting a coordinated policy to construct new reservoirs for the purpose of enhancing food, hydroelectric production and river shipping. The management of reservoirs and water resources is guided by the overarching goal of maximizing economic productivity. Water is primarily allocated to hydropower production and large-scale agricultural private projects, at the expense of rural populations and ecosystems. Reservoirs are altering the natural hydrology of the river, eliminating phenomena such as flooding and leading to the decline of flood-recession agriculture and traditional fishing. Access to water is becoming more unequal, heightening numerous conflicts. Ecosystems associated with water are deteriorating, manifesting in issues such as estuary salinization, pesticide pollution, and the aridification of the valley. The main assumptions of this scenario are graphically depicted in Figure 7.

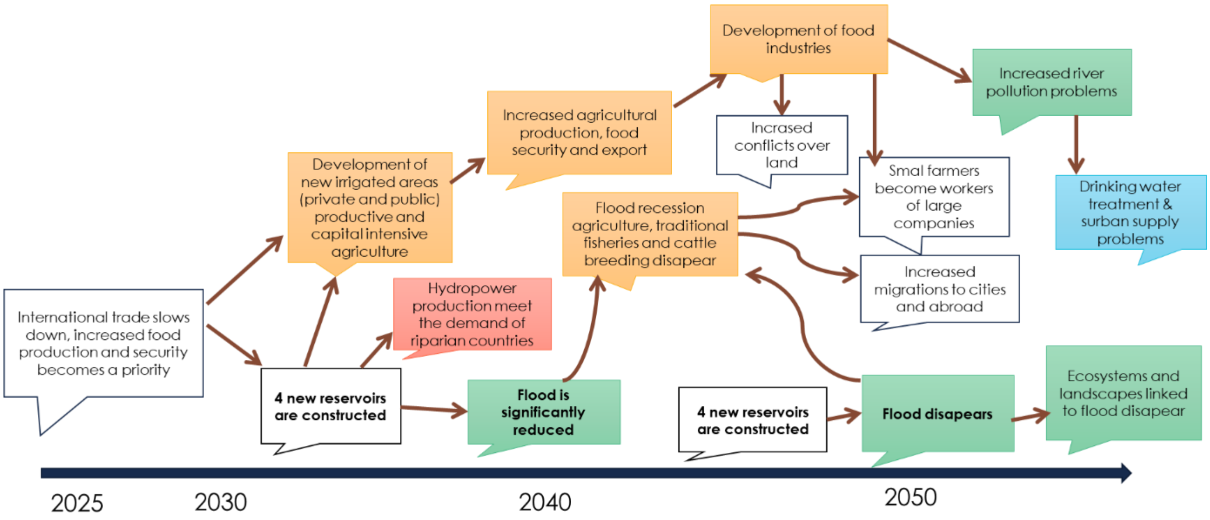


Figure 7 : Graphic representation of the main hypothesis underlying scenario 1 (Senegal case study).

Scenario 2: "Water: the heart of the social model"

In this scenario, it is assumed that the primary concern of the governments is socio-political stability. However, this stability is threatened by the impoverishment and marginalization of rural areas, whose means of livelihood (flood recession agriculture and artisanal fishing) are jeopardized by large hydroelectric development projects upstream in the basin. The downstream countries (Mauritania and Senegal) are therefore putting their veto on the construction of certain dams upstream to make sure that partial flooding of the flood plain is still possible in order to support traditional food production activities and essential riverine ecosystems. The downstream countries, benefiting from this artificial flood, must nevertheless make concessions to those upstream who are experiencing losses in hydroelectric production. A new agreement regarding the sharing of hydroelectric production is reached within the framework of enhanced international cooperation. The downstream countries compensate for the decrease in their electrical supply by exploiting new offshore gas resources and developing solar and wind energy. The main assumptions of this scenario are graphically depicted in Figure 8.

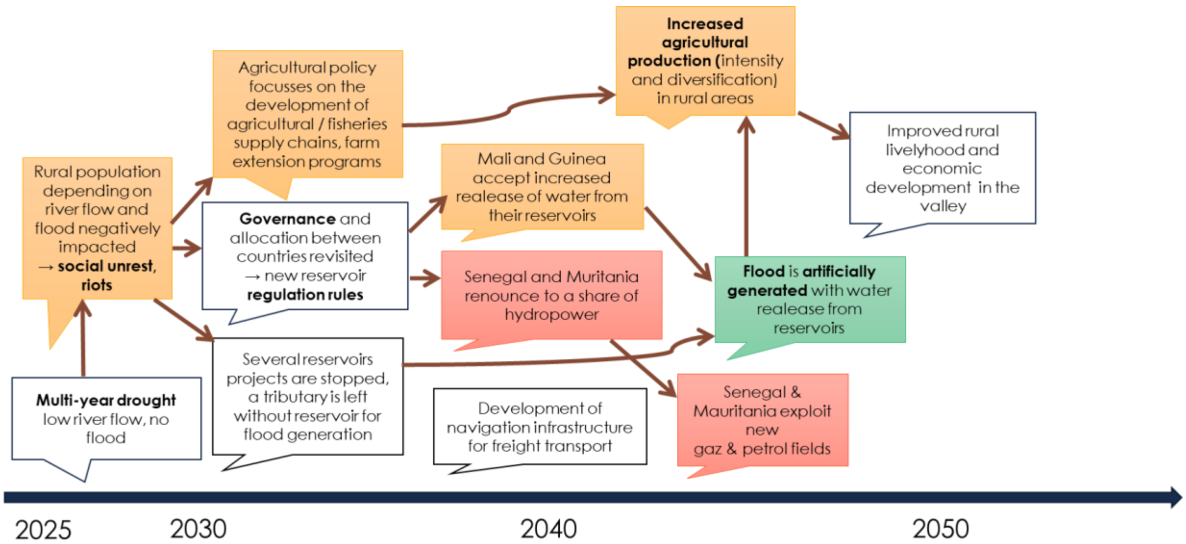


Figure 8 : Graphic representation of the main hypothesis underlying scenario 2 (Senegal case study).

Scenario 3: "The solar revolution"

This third scenario assumes that governments leverage technological advances in solar energy production at two levels. At the national level, they invest in the creation of large-capacity solar power plants connected to a fully integrated West African Power Pool (WAPP). At the local level, governments support the development of small-scale irrigated agriculture powered by river-pumped photovoltaic installations. Freed from uncertainties related to floods, agriculture in the middle valley transforms, moving towards forms that are better integrated into the market, more productive, and contributing to local economic development. It coexists with more intensive agriculture and aquaculture driven by private capital, whose production capacity ensures the food security of the countries. However, in this scenario, the overexploitation of surface and subsurface water bodies combined with the intensification of agriculture leads to pollution, resource depletion, intensifying conflicts between water users regarding water rights and land tenure. The main assumptions of this scenario are graphically depicted in Figure 9.

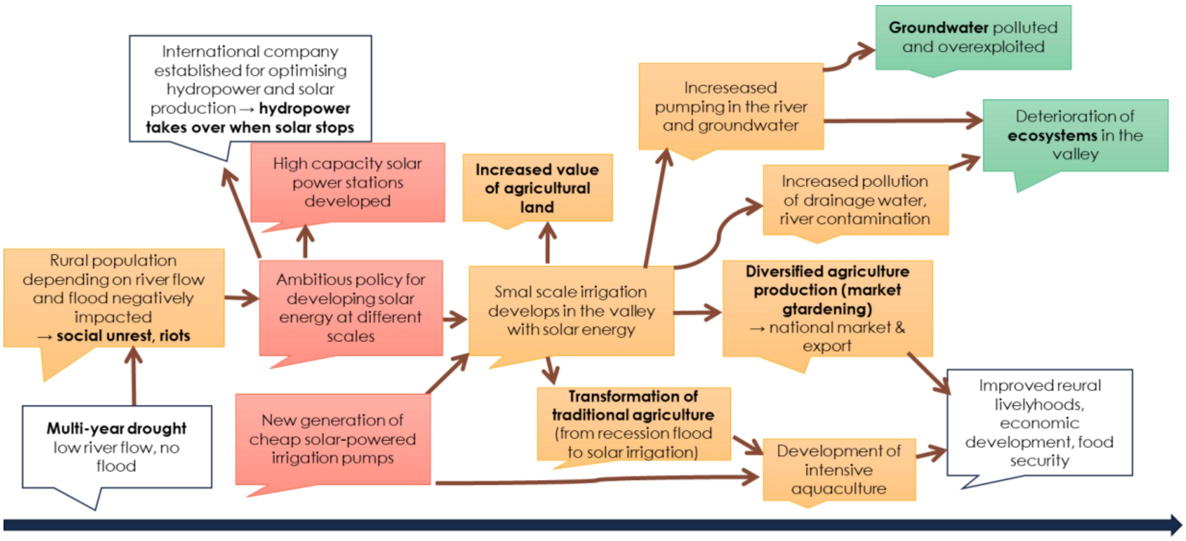


Figure 9 : Graphic representation of the main hypothesis underlying scenario 3 (Senegal case study).

3.2.4 Debating scenarios with stakeholders

The three narrative storylines were presented and debated with stakeholders during a one-and-a-half-day workshop. The workshop was pursuing two objectives:

- The first one was to collect stakeholders' points of view on the scenarios, paying attention to their evaluation of relevance and credibility of underlying hypotheses, their consistency and their judgements in terms of desirability. Our intention was to allow stakeholders modifying the scenarios in a way that they can become more relevant to them. They were also offered to create new scenarios if needed.
- The second objective was to enable stakeholders to assess the strengths and weaknesses of these scenarios in the face of major changes or external shocks, such as climate change, economic shocks (in the agricultural or energy markets, etc.) or changes in international relations. The aim of this exercise is to get stakeholders to think about the possibility of crisis situations so that they can then work on the actions to be taken to avoid them or limit their impact (workshop 3 on solutions).

At the end of the workshop, the aim is to obtain scenarios modified and validated by the participants, ready to be simulated with the hydroeconomic model.

The outcome of this participator activity is described in Deliverable 6.3.

3.3 Assessing scenarios with river basin model

This section provides further details how steps ❺ to ❽ were conducted.

3.3.1 Specification of model inputs for scenario

Table 3 : Model inputs per scenario for the Senegal case study

	Scenario 0 - Baseline	Scenario 1 – Business full speed ahead	Scenario 2 – water, the heart of the social model	Scenario 3 – the solar revolution
Number of reservoir and storage capacity	2 (11 km3)	+ 8 new reservoirs (+30 km3 storage capacity)	+3 new reservoirs (+10 km3)	+4 new reservoirs (+12 km3)
Number of hydropower plants and capacity	3 hpp (400 MW)	+9 new hpp (+814 MW)	+4 new hpp (+642 MW)	+5 new hpp (+660 MW)
Irrigated area in ha	150kha	+200 kha	+100 kha	+250 kha

Figure 10 to Figure 13 display the schematic representations of the baseline scenario (scenario 0), scenario 1, scenario 2 and scenario 3 respectively:

- Scenario 1 involves the construction of all planned reservoirs and hydropower plants as well as the extension of irrigated areas to more than 350ka. We assumed that all irrigation demand sites will increase by the same factor and that the cropping pattern would not change. However, crop water requirements do change with the hydroclimatic conditions.
- In scenario 2, only the Bafing is dammed while the other two major affluents (Bakoye and Faleme) remain essentially free-flowing rivers contributing to the flooding of the lowlands and hence to flood recession agriculture, fisheries and the preservation of riverine ecosystems.
- In scenario 3, irrigated agriculture is more massively developed thanks to solar pumping, flows in the Bakoye are unaltered while Gourbassi is constructed in the Faleme, primarily to sustain low flows for navigation purposes.

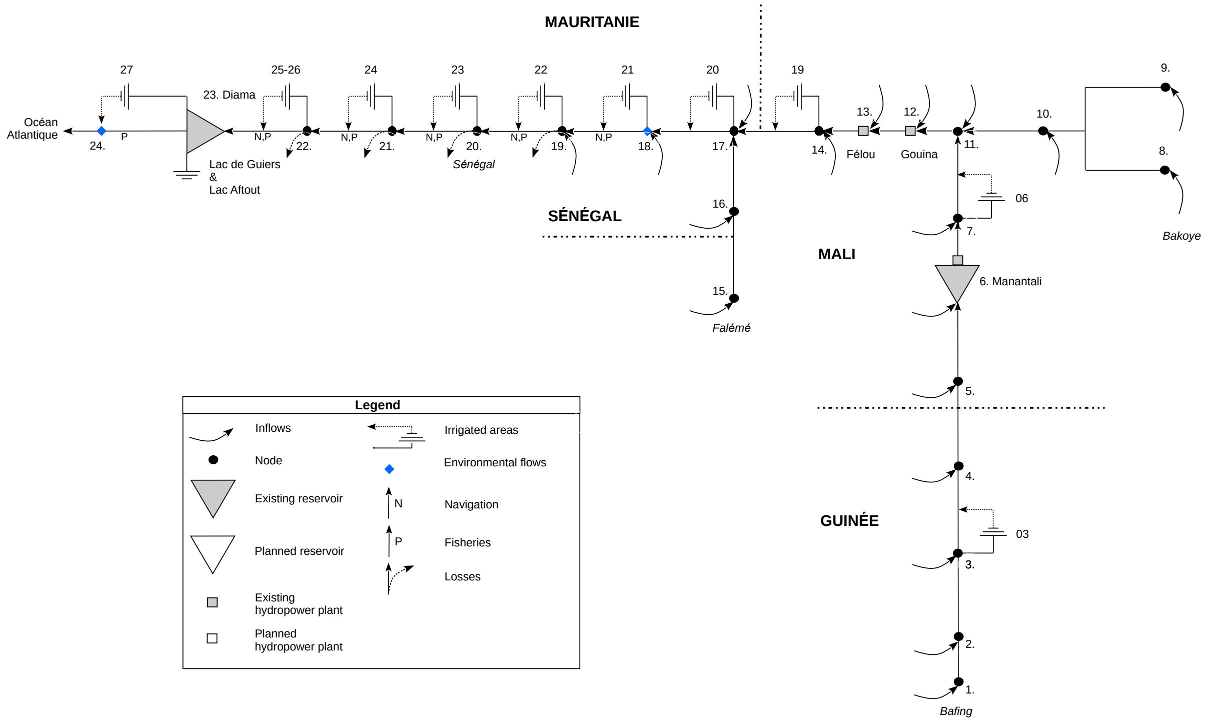


Figure 10. Use of the Senegal hydroeconomic model to simulate the baseline scenario

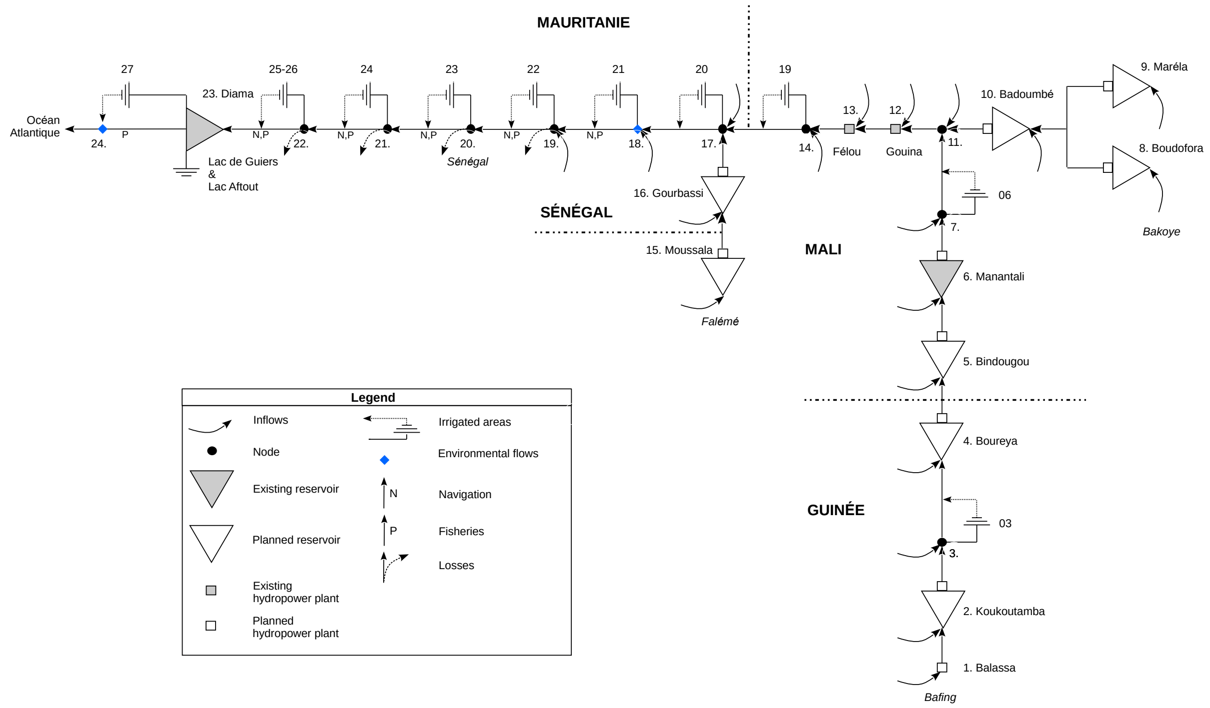


Figure 11. Use of the Senegal hydroeconomic model to simulate scenario 1

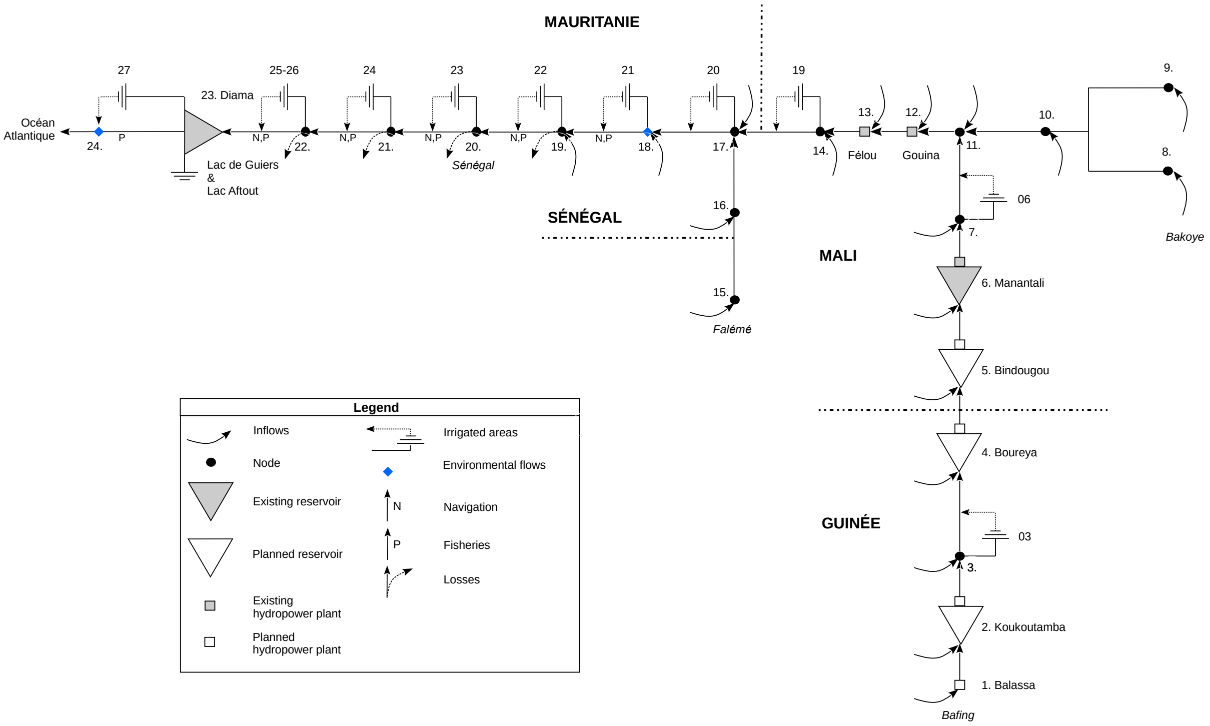


Figure 12. Use of the Senegal hydroeconomic model to simulate scenario 2

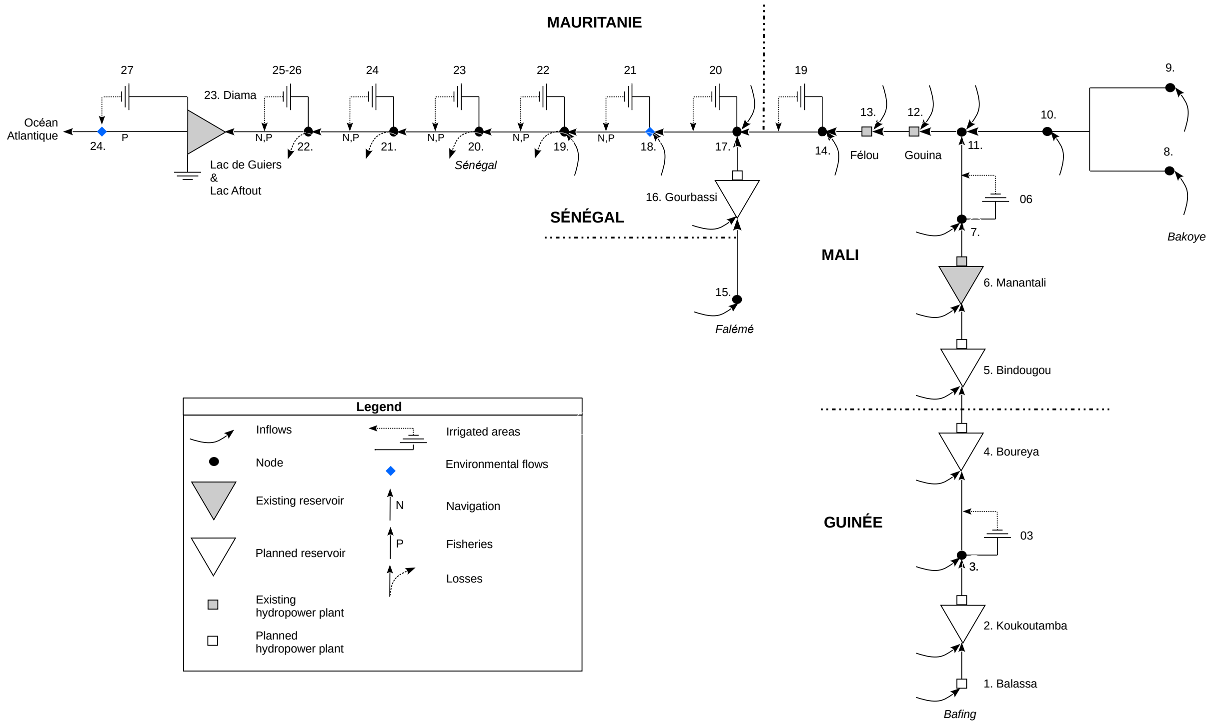


Figure 13. Use of the Senegal hydroeconomic model to simulate scenario 3

3.3.2 Accounting for climate change uncertainty

To effectively assess the performance of the system under climate change, it is crucial to test it over a wide range of climate stressors, which can be challenging with a limited number of GCM-based projections. We use CORDEX-AFRICA climate ensemble simulations (55 P and 22 ET) as inputs to a hydrological model, resulting in a large set of 1210 hydrological simulations over the 2020-2100 period. An exhaustive combination of these scenarios with the local socioeconomic scenarios previously described was done to analyse the impact of the global planetary trends on the local strategies, which are mainly independent on global drivers.

The use of a large ensemble of hydrological projections captures as much as possible the uncertainty attached to future climatological conditions. In principle, members of this large ensemble could be directly processed by the hydroeconomic model to determine the adapted allocation policies and the corresponding performance indicators. By doing so, one implicitly assumes that there must be a link between adapted policies and the climate drivers behind GCMs simulations, i.e. mainly greenhouse gas emission scenarios. But water operators are more familiar with the hydrologic regime of their system and less with the emission scenarios that will affect the regional climate. Linking adapted policies to potential alterations of the flow regime due to climate change is more meaningful to water operators as it triggers experiential knowledge. To achieve this, hydrologic projections are clustered based on relevant hydroclimatic statistics characterizing the flow regime in the river basin.

Here, the eight relevant hydrologic properties that characterize the flow regime are:

1. The mean annual volume

2. The mean of the peak flow of the annual flood (in September)

3. The standard deviation on the peak flow of the annual flood (in September)

4. The peak volume of the ten-year flood

5. Average low flows (from February to May)

6. The standard deviation of low water flows (from February to May)

7. The number of months of low flows

8. The number of months of high flows

With these eight hydrologic attributes and using the K-MEANS clustering method, the 1210 projections are grouped into five clusters denoted C1, C2, ..., C5, each representing a potential alteration of the flow regime due to climate change. For the 2050 horizon, cluster C1 is a set of dry hydrologic projections comprising 23.1% of all hydrological projections; C2 is an intermediate dry scenario represented by 13.1% of all hydrological projections; C3 includes projections characterized by a moderate alteration of the flow regime compared to the baseline scenario (34.0% of all hydrological projections); C4 is made of moderately wetter hydrologic projections (19.3% of all hydrological projections); Finally, cluster C5 consists of the most wettest projections (10.4% of the original ensemble).

3.4 Downscaling scenarios at village level

3.4.1 Purpose of downscaling scenarios at village level

The river basin scenarios were designed to trigger debate between stakeholders operating at the national and international levels. Those stakeholders are however unlikely to be able to evaluate the consequences of the changes assumed in those scenarios on population at the local level. This is why the Senegal case study project team decided to organize local debates at village levels. This however requires designing a different methodology to engage local stakeholders in future thinking. To be locally meaningful, global scenarios described in the previous sections should be downscaled, i.e; transformed into a description of changes that are likely to occur at the local level.

The objectives of the local dialogue are:

1. To involve elected representatives and local populations in the discussion of scenarios for the development and management of the river, through a discussion of the local consequences of strategic decisions that would be taken at river-basin level.
2. Articulate the two scales of dialogue (watershed and local) and create interactions between the visions of institutional and local stakeholders.
3. Describe and assess the local consequences of scenarios designed on a river basin scale: how do scenarios translate locally, and what are the socio-economic consequences for local populations?

4. Contribute to the emergence of alternative scenarios and solutions, to be presented to the institutional stakeholders involved in river management during Dialogue 3 at river basin level.

The local dialogues will involve various parties:

- Representatives of local authorities and local communities (usually with little or no involvement in water management decisions);
- Representatives of various socio-economic sectors:
  - drinking water,
  - energy,
  - flood recession agriculture,
  - irrigated agriculture,
  - livestock,
  - fishing,
  - Forestry
  - etc.
- Local associations, youth, women's groups, etc.
- Local NGOs.

Example of possible participating groups in local dialogues

- Economic interest groups (which are the basis for various activities in the area).
- Women's economic interest groups.
- "Chiefs" of fishermen, stockbreeders, farmers, etc. (different from the previous one, as defined here as social categories and not as activities).
- Other associations to be identified.
- Borehole manager.
- + NGOs potentially if projects located in villages.

The "*Moyenne Vallée" (*Figure 14*)* is chosen for the local dialogues because it is the region where major challenges of future water management are concentrated: *(i)* there are still many potential development areas (in contrast to the "Delta") and *(ii)* this is where flood-related activities are concentrated.

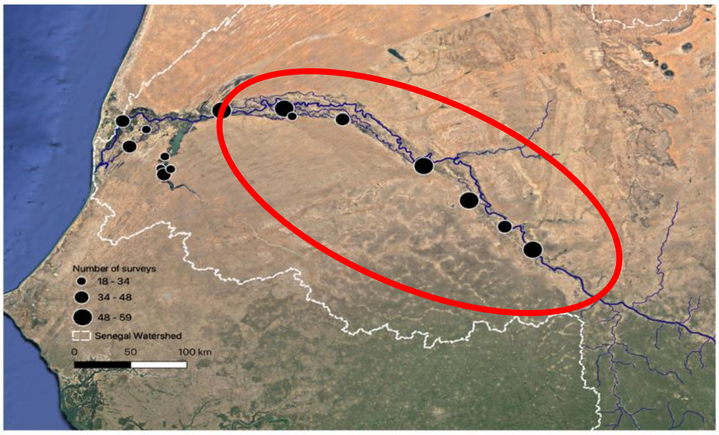


Figure 14 : Targeted region for local dialogues

At the local level, and given the targeted groups identified for these dialogues, discussions will take place exclusively in local languages (Pular, Soninke and Wolof) to enable the various groups identified to communicate easily.

According to the specificities noted in each of the target localities, discussions will take the form of focus groups for each of the stakeholder groups and targeted interviews with stakeholders considered as key by their community. These interviews will be based on an interview guide drawn up based on the scenario chosen to be presented for each selected village.

The audience for these local workshops is largely illiterate, with groups of people who can neither read nor write. The main difficulty here is to organize discussions on future scenarios with these people, who do not read or read very rarely, and who are above all unfamiliar with the notion of a scenario.

Our initial ideas and analyses, cross-referenced with information gathered from people involved in similar projects, point us in the direction of translating the different scenarios into the three local languages used in the "Moyenne Vallée" region: Pular, Soninke and Wolof.

These translations will take the form of stories and/or tales in these local languages, which will be used in simulated radio broadcasts and videos simulating TV spots that can be shown to the local population. Drawings and schematic maps will accompany these tools to enable communities to grasp the scenario presented to them and, above all, to assess the impact it could have on their respective activities.

3.4.2 Presentation of the village level case study areas

As a first step in presenting the scenarios for each village (Figure 15), and to guarantee the reliability of the analyses and the expected results, it is necessary to:

- Document in detail each of the targeted villages with detailed mapping and a review of socio-economic data, preferably using data collected as part of GoNEXUS activities in WP4 in 2022-23 and the data from the 2023 general census (Table 4 : Socio-economic data of the selected villagesTable 4).
- Validate with key stakeholders the representation at local system scale of the major nexus sectors and water management issues.

Donaye ***Diomandou*** ***Nabadji***

Figure 15 : Location of selected villages for local workshops

Table 4 : Socio-economic data of the selected villages

Village	Concessions	Households	Men	Women	Population
Diomandou	112	155	963	1,017	1,979
Donaye Taredji	14	25	88	138	226
Nabadji Civol	374	500	2,786	2,911	5,697

3.4.2.1 Village 1: Donaye Taredji

Donaye Taredji is located 9 km from the City of Podor, in the Middle Valley of the Senegal River. The village belongs to the department of Podor and the region of Saint-Louis.

The village of Donaye Taredji was recently settled, in 1999 according to several sources. Traditionally, the 500-year-old village of Donaye in the Walo has been deserted by its inhabitants during the winter months, since the time of their ancestors, to practice rain-fed agriculture in their fields at Taredji in the Dieri, some 30 km away. The stay was at least three months long each year, for the purpose of farming. In 1999, when the Senegal River overflowed its banks, causing flooding, the population moved to their fields in Taredji. In migrating to Taredji, the population left behind almost 800 hectares of agricultural land, as well as basic social facilities including three 3 mosques, a twelve-classroom school, a fully equipped dispensary, three 3 wells, a village bank, etc.

The relocation of people to Taredji gave rise to Donaye Taredji, located 200 km from Saint-Louis and 21 km from Podor. Tomatoes, onions and gombos are grown irrigated over a relatively small area, with most of the produce destined for local consumption. The population also practices livestock breeding and fishing. This new village is equipped with a medical center, a twelve-class elementary school serving as an examination center, a middle school, a borehole and 400 hectares of uncultivated arable land. But despite all this potential, the village of Donaye Taredji still faces major agricultural, environmental, and infrastructural challenges.

3.4.2.2 Village 2 : Diomandou

The village of Diomandou is located on the banks of the Doue River, about 60 km east of Podor and 15 km from the village of Aere Lao. The village is divided into two hamlets: Diomandou Walo and Diomandou Dieri, separated by an irrigated perimeter with a total surface area of 1100 ha, half of which is cultivated. The perimeter was flooded for the first time in 1989, after the start of the implementation of the Manantali dam. This locality has been affected by water-borne diseases in the past, particularly malaria and schistosomiasis.

3.4.2.3 Village 3: Nabadji Civol

The village of Nabadji Civol, located in the commune of the same name, belongs to the department of Matam (Matam region); it had 3,740 inhabitants in 2003, according to its PLD (Local Development Plan). Situated along the Senegal River, close to the Mauritanian and Malian borders, the commune of Nabadji Civol comprises 35 official villages and 30 hamlets. In 2013, the population of the Nabadji Civol increased up to 5000 inhabitant according to ANSD. This is a village where many basic social infrastructure projects have been developed, mainly through decentralized cooperation. In the water and sanitation sector, for example, the village has reached record levels, with access rates of +90% for water and +60% for improved sanitation.

3.4.3 Narratives for the 3 village level scenarios

3.4.3.1 Reformulation of scenario assumptions at local level

The implementation of **Scenario 1** implies the construction of all the reservoirs and hydropower plants planned under the OMVS program. It would also promote the development of irrigated areas throughout the basin, covering more than 350,00 km². The result would be an explosion in the demand for irrigation water, with a high risk of increasing crop water requirements due to hydroclimatic conditions. Scenario 1 promises rapid development with the OMVS dams, leading to potential agricultural boom and access to energy. However, the villages will have to navigate increased competition for water and adapt to a fully irrigated future, leaving behind their flood recession farming past. The following table describes how the general assumptions included in the three policy scenarios defined at basin level will be downscaled and reformulated at village level, for discussion with stakeholders.

Table 5 : Scenario 1 implications for village level

Assumption	Formulation in river basin scenario	Formulation in village level scenario
Completion of the OMVS hydroelectric and storage program	Economic and social development of riparian states based on the potential of the basin	Access to social and economic development for the village

Assumption	Formulation in river basin scenario	Formulation in village level scenario
Increased hydropower production in the basin with +9 new hydroelectric plants, representing an availability of +814 MW	Rising stakes for energy from the Senegal River and potential for increased tensions between riparian states over access to these energy resources.	Access to affordable energy for households and local socio-economic activities, particularly irrigated agriculture.
Increasing water availability in the basin with +8 new reservoirs and +30 km3 of storage capacity	-	Opportunity/Possibility to irrigate larger areas for commercial use and for socio-economico-environmental development
Increased irrigated area to +200 ha	Achievement of OMVS and Senegalese government objectives in terms of agricultural development of the basin and thus food self-sufficiency	No more flood recession cultivation and extension of irrigated cultivation
Deterioration of climate conditions and changes in the hydrological regime	Rising global water demand for human activities	Abandonment of rain-fed farming and conversion to 100% irrigated farming

Scenario 2 corresponds to limit the damming to the Bafing and continue the flooding of the lowlands, giving free rein to flood recession agriculture, fishing and the preservation of river ecosystems. With only three new reservoirs and four new hydroelectric plants, irrigated crops would cover a maximum of 100,000 ha. This is a resolutely social option aimed at protecting local communities and their traditional socio-economic practices. Scenario 2 champions villagers' way of life, promoting continued flood recession agriculture and river ecosystem protection. The village might see renewed fishing and traditional practices flourish, but economic growth could be slower compared to dam-focused scenarios. The following table describes how the general assumptions included in the three policy scenarios defined at basin level will be downscaled and reformulated at village level, for discussion with stakeholders.

Assumption	Formulation in river basin scenario	Formulation in village level scenario
Reduction of hydraulic and hydro-agricultural development in the basin	Natural flooding of recession basins	Resumption and intensification of flood recession cultivation around Diomandou
	River fishing development	Renewed fishing activity in the village, especially seasonal fishing
	Protection of the basin's aquatic ecosystems	-
Continued reliance on flood recession agriculture as the primary farming practice.	Prioritization of policies and investments that support and improve flood recession farming techniques, such as seed distribution, soil conservation, and rainwater harvesting.	Maintenance of traditional knowledge and practices related to flood recession farming. Potential increase in the cultivation of flood-adapted crops like rice and millet.
Decline of irrigation perimeter development policy	Decreasing irrigated perimeter	Gradual return to floodplain agriculture to support socio-economic development
Potentially slower economic growth	Diversification of economic development strategies beyond large-scale hydropower projects, focusing on areas like sustainable agriculture, ecotourism, and handicrafts.	Reliance on traditional livelihoods and potentially slower accumulation of wealth compared to villages benefiting from Scenario 1's irrigation boom. Increased importance of community cohesion and self-reliance.

Scenario 3 represents the massive development of irrigated agriculture using solar energy. Solar pumping flows in the Bakoye, and the construction of a series of dams, including Gourbassi on the Faleme, support low flows and allow commercial navigation in the river channel. Solar energy and irrigation advancements could bring

prosperity at village level, but managing population growth and resource allocation will be crucial. Balancing traditional river uses with commercial navigation presents another challenge.

Assumption	Formulation in river basin scenario	Formulation in village level scenario
Growth of the village population due to economic opportunities and improved living conditions	Regional development plans that prioritize investments in rural infrastructure and social services. Capacity building programs for local authorities to manage population growth effectively.	Expansion of healthcare facilities, schools, and sanitation systems to cater to the growing population. Potential strain on natural resources like water and firewood, requiring sustainable management strategies like rainwater harvesting and reforestation.
Increased access to solar-powered irrigation pumps empowers small-scale farmers.	Basin-wide investment in solar panel production and distribution programs. Development of micro-credit schemes specifically for solar irrigation technology.	Increased availability of affordable solar pumps leads to higher adoption rates among farmers. Diversification of crops beyond traditional varieties like rice and millet, with vegetables and fruits becoming more common.
Development of green energy sources and energy revolution in the basin	Construction of large-scale solar power plants in different areas of the basin	Access to a low-cost, renewable source of energy for household use and for irrigation water pumping.
Implementation of the OMVS river navigation program	Improving upstream-downstream trade from the river	Reduction of river fishing due to the arrival of boats in the river
Expansion of the policy of large agricultural schemes	More and more large-scale irrigation schemes	Small-scale village irrigation replaces flood recession farming

3.4.3.2 From assumption to narrative storylines

While each village faces its own set of opportunities and challenges, their fates are ultimately intertwined. Water management decisions in the basin will ripple through their lives, impacting farming practices, energy access, and even cultural traditions. The narrative for these villages remains unwritten. The chosen scenario will paint the canvas of their future, shaping their economies, ecosystems, and social fabric. The choices made today will determine whether they adapt, thrive, or face unforeseen consequences in the years to come.

This narrative also extends beyond these three villages. It serves as a microcosm of the broader challenges and opportunities facing the entire Senegal River basin. The decisions made on its future will impact millions of lives, livelihoods, and the delicate balance of this vital ecosystem. The narrative concludes with an open ending, inviting further exploration and discussion. It highlights the importance of engaging stakeholders, considering diverse perspectives, and finding solutions that benefit not just individual villages but the entire basin and its people.

4 Local socioeconomic and land use scenarios: lake Como case study

Authors: S. Ricart, M. Giuliani, A. Castelletti (POLIMI)

4.1 Overview of the methodology

In the Lake Como case study, a multifaceted bottom-up approach was adopted to create and assess the proposed climate and policy scenarios. This encompassed (i) incorporating knowledge from previous research projects (e.g., ADDAPT, INWOP or SO-WATCH), as well as (ii) conducting a comprehensive review of scientific documents and technical reports to update and refine scientific data, together with (iii) highlighting inputs from engaging key stakeholders through interviews, questionnaires and workshops, and (iv) combining all in an integrated hydrological and operational model to test robustness and to search for more efficient solutions. The overall approach is graphically depicted in Figure 16 and summarily described in the following paragraphs.

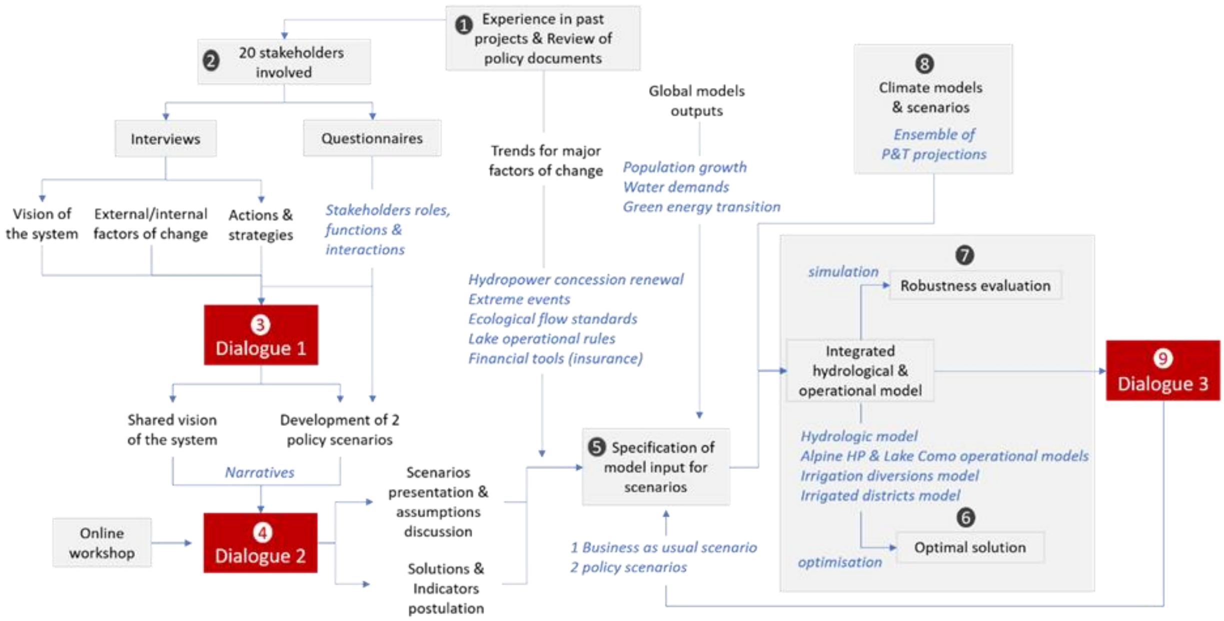


Figure 16. Overview of the multifaceted approach used to establish and test scenarios in the Lake Como case study.

The multidisciplinary approach aims to connect those outputs from dialogues as inputs for the integrated hydrological and operational modelling approach. The process was structured in nine main steps. The first step (❶) consisted of a review of the main results of previous projects that work in the Lake Como and the Adda river basin, such as, for example, the recently concluded ADDAPT project (Regione Lombardia 2020), which aimed to develop planning and control strategies for water resources and evaluate their contribution to building climate risk-resilient communities. Previous projects also provided social learning inputs, such as INWOP project (Water JPI 2018), which explored how advanced many-objective optimization approaches contributed in enriching the solution space with alternatives that better reflect the diverging perspectives of stakeholders, and align better with ethical concerns; or the SO-WATCH project (Fondazione Cariplo 2016), in which a novel decision-analytic framework was developed and tested to assist decision-makers in designing and assessing alternative soft-path measures for improving the overall water productivity at the river basin scale and, more precisely, in the Lake Como system. Furthermore, we conducted a review of existing policy documents and technical reports related to the different dimensions of the WEFE nexus, as well as a scanning process of local and regional newspapers and specialized newsletter information updating current social and political debates and discussions about some of the dimensions of the WEFE nexus (e.g., hydropower concession renewal, extreme events frequency and intensity, ecological flow standards, lake operation rules, financial tools discussion). Altogether, this information contributes to identify the main challenges that condition the Lake Como system, as well as the main factors of change that can potentially increase the pressure on the WEFE nexus considering the coexisting water demands and different climate projections, especially related to the food and energy production, environmental protection, and water management sectors.

To complement this secondary data information, we conducted a participatory process based on a series of semi-structured interviews and questionnaires with key stakeholders representing the four dimensions of the WEFE nexus by combining different interests, profiles, and scales (❷). The semi-structured interviews allowed us 1) to delve into the individual vision of the system, 2) to identify the main internal and external drivers of change and compare them with those previously identified in the review process, and 3) to recap preliminary examples of actions and strategies that could be applied to reinforce the WEFE nexus in the case study. Similarly, the questionnaires provided key information on the roles, functions, and interactions of stakeholders, also insights from the different stakeholders' perspectives on governance when managing the dimensions of the WEFE nexus (❸).

The results of these three steps were central to identify a shared vision of the Lake Como system and to develop contrasting local policy scenarios to integrate the possible long-term evolution of the WEFE nexus in the Lake Como case study. These policy scenarios aimed to reinforce the comprehension and awareness of different global/regional and external/internal changes, and which would be their impact to the nexus in the near future. Each scenario is presented to encourage stakeholders to consider possible actions and strategies across the four dimensions of the nexus that can be implemented to achieve a more climate resilient future. Therefore, the scenarios cover constructed hypotheses related to the main challenges encountered during the interviews (Dialogue 1) that may be intensified according to external and internal variables, such as climate and socioeconomic changes. Scenarios are described through a narrative to facilitate their understanding and discussion during a second dialogue (❹). A list of assumptions defining each scenario will be discussed with stakeholders to check its relevance and priority (considering its alignment with the WEFE nexus dimensions) and internal coherence and feasibility (valuing its capacity to achieve the target of each scenario). The discussion process with stakeholders will also be opened to refine the predefined assumptions if they are not considered valid to argue the hypotheses that motivated each scenario.

The Dialogue 2 will take place on Feb. 13-14th, 2024 as an online workshop, and is key for the social learning and local knowledge exchange processes, allowing stakeholders to share and contrast knowledge but also overcome the boundaries of their respective sectorial interests and demands. This dialogue will also allow participants to prioritize among different possible solutions to increase the adaptive capacity of the WEFE nexus and identify preliminary indicators to be then transferred as input for the modelling approach (❺). This is a key point in the nexus methodology: Scenarios are developed to engage stakeholders in a future-thinking exercise but also as input for the integrated model (hydrological and operational) simulations. This transition from forecasting narratives and expectations to quantitative simulation requires quantifying, in some way, the assumptions used to characterize each policy scenario. This scenario quantification is based on the results from global model simulations performed in the project (focused on e.g., population growth, water demands, green energy transition). At this step, the two policy scenarios were defined as 1) hydropower maximization and 2) risk management; while the Business as Usual (BAU) scenario was considered as the reference scenario.

Once the assumptions are defined in quantitative terms (based on the indicators previously identified), the integrated model (combining a hydrological model, different operational models for the alpine area and the Lake Como system, irrigation diversion models for the Adda river, and irrigated districts model) evaluates the scenarios. Two different evaluation methods are used: optimization (❻) and simulation (❼). Optimization is applied to identify those management strategies that can accomplish the objectives of each policy scenario (e.g., increasing hydropower energy production). The optimization is carried out for the reference period (BAU) and the two local policy scenarios. Subsequently, simulations will evaluate the performance of each optimal strategy under various hydro-climatic conditions, serving as a robustness test. Both the optimization and simulation tasks will explore a range of possible hydro-climatic conditions (❽), providing an ensemble of future hydrological regimes. A final dialogue, Dialogue 3, is planned to present and discuss, with stakeholders, the results of the modelling process (simulation of solutions) and to validate how each local policy scenario will respond to the challenges of the WEFE nexus in the Lake Como system (❾).

4.2 Developing policy scenarios

3.2.1 Types of scenarios

Different types of scenarios are developed to achieve two distinct objectives:

- A **Business-as-Usual scenario** (BAU), which assumes a continuation of current practices, policies, and socio-economic trends without significant changes. However, this BAU also assumes some change in the external context, considering the most likely evolution. Regarding climate, we consider scenarios of possible alterations of the alpine snow storage and river flow regime due to climate change patterns. In that case, temperature does not seem to be characterized by intra-annual shifts, following a similar trend (but greater in magnitude) to that observable in the control period, and some uncertainty is observed in terms of precipitation, with changes in rainfall inflows (e.g., it can be expected higher inflows in the first six months of the year, and consistently lower inflows between June and September, corresponding to the irrigation period; this will likely be reflected in an increase in winter-spring floods, and an increase in the deficit and low summer levels). This scenario will be used as a reference scenario to be compared with the policy scenarios outputs.
- **Two policy scenarios**, on which dialogue 2 will be focused, aim to describe hypothetical future situations that are shaped by specific policy decisions and interventions. They are constructed to explore, with stakeholders, the future of the system considering potential changes and (un)desirable impacts resulting from different assumptions conditioning the dimensions of the WEFE nexus. The basis of each policy scenario is first conducted qualitatively from narratives during stakeholders' semi-structured interviews and questionnaires (Dialogue 1) and knowledge exchange through the online workshop (Dialogue 2), before being evaluated with the integrated hydrological and operational model and again discussed with stakeholders based on simulation results (Dialogue 3).

3.2.2 Developing policy scenarios

In the Lake Como case study, the development of policy scenarios was based on two successive stages.

The first stage consisted of analyzing the dynamics of the WEFE nexus, represented as a complex system in which dimensions are interconnected and mutually influenced. This system dynamic analysis has two main objectives:

1) To identify the main challenges and external/internal factors of change (drivers) that are likely to significantly impact the dimensions of the WEFE nexus in the Lake Como system and the Adda river basin;
2) To identify potential adaptation measures or solutions that can be promoted to mitigate the impacts of these changes and delve into the interaction between solutions and the WEFE nexus dimensions.

Figure 17 provides an illustration of how this tripe-loop approach (challenges, drivers, and solutions) was applied to provide an overview of the framework that will be used to define each policy scenario in the Lake Como system considering the interaction between the four dimensions of the WEFE nexus. The main input was the content of the semi-structured interviews conducted in Dialogue 1, in which key concepts and narratives were combined to identify main challenges (shown in red, e.g., more frequent extreme events – flood and droughts, tensions between food and energy production), external and internal factors (shown in blue, e.g., ecological flow standards, hydropower concessions renewal) and tentative solutions (shown in green, e.g., irrigation methods modernization, forecast-based reservoir operation). During Dialogue 2, this framework will be discussed, asking for stakeholders' validation regarding elements and potential interactions between them.

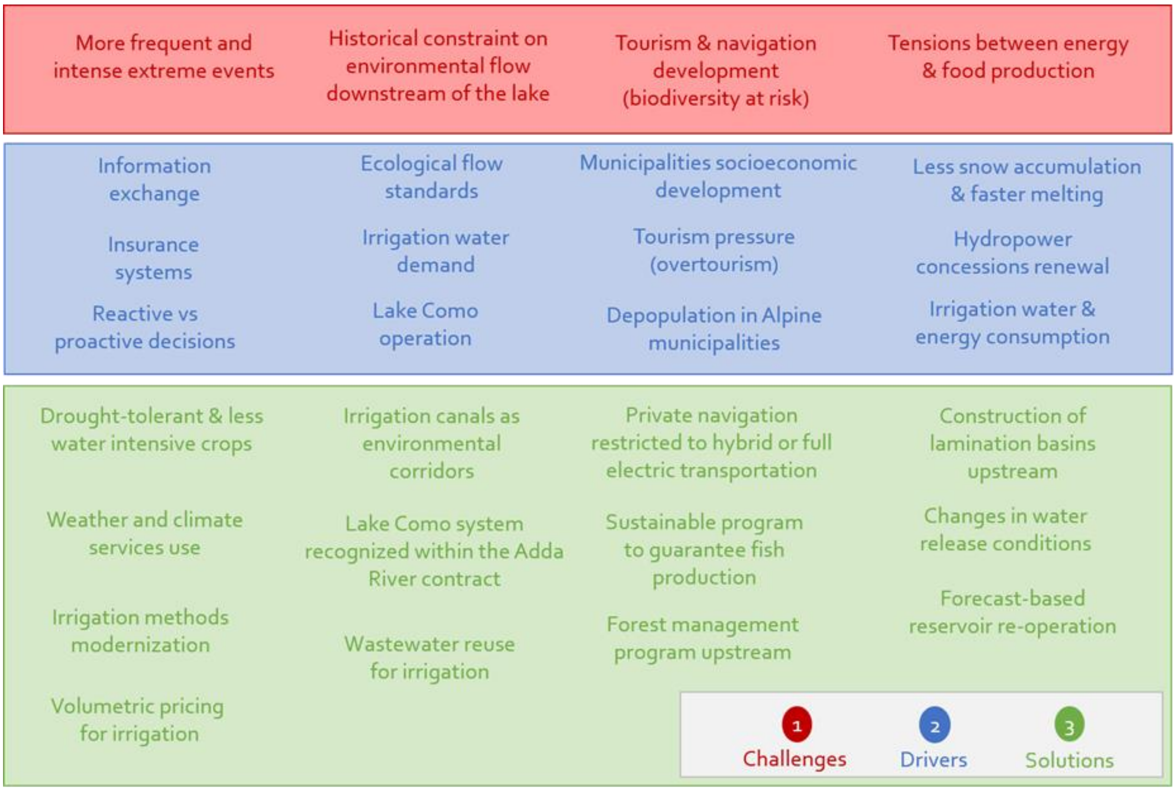


Figure 17 : Example of narratives combining challenges, drivers, and solutions from Dialogue 1 inputs (semi-structured interviews) to be used for developing policy scenarios.

This first phase of the analysis, exploratory in nature, defined the key elements for a comprehensive analysis of the complexity involving the management of the WEFE nexus by formulating different hypotheses concerning the future evolution of the WEFE nexus dimensions. The main challenges, drivers (factors of change), and potential solutions were captured from stakeholders, testing how they differ considering the diversity of stakeholders' interests. For each challenge, different drivers have been distinguished, some of them connected with different challenges (e.g., hydropower concession renewal is associated with the existing tension between food and energy production but also a key factor when discussing the environmental flow standards downstream of the Lake Como system). Several hypotheses explaining their evolution (considering climate scenarios but also socioeconomic patterns) have been shared with the stakeholders to identify potential and relevant solutions (conceived as adaptation strategies) to deal with them. This brainstorming process was useful to remark a range of possibilities, both in terms of which will be the impacts of these challenges, which circumstances (internal or external and considering both sectorial and holistic issues) could add more pressure to the system (increasing the unbalance between dimensions or even the collapse of the system), and how about the tentative actions (individual or in common) to take in the present time thinking about the future of the system by 2030 or 2050.

After identifying the main challenges, drivers of change and potential preliminary solutions, the second stage involved the formulation of tentative scenarios (local policy scenarios) to help stakeholders imagine the possible future of the system closely tied to the results of the exploratory analysis. We created **two policy scenarios** presented as a compound of three main issues: 1) the target of each scenario ("what do we aim at?"), 2) the plausible actions to accomplish with the target ("what to do?"), and 3) the aftereffect of these actions on each dimension of the WEFE nexus ("what to expect?"). The motivation behind this simplification in three steps is to facilitate stakeholders' feedback during the dialogues and enhance their efficiency, especially considering that these scenarios will undergo testing in workshops involving stakeholders which are different in nature, backgrounds, and interests, requiring an effort to provide clear key messages for later discussion.

The scenarios will be presented in a narrative format by adapting the storyline methodology to reinforce stakeholders' connection and validation of the shared content. Storylines provide context and a holistic view of the scenarios, which are described highlighting the main characteristics, relationships between key driving forces, and the dynamics (results) of their evolution.

3.2.3 Summary of narrative scenarios developed in the Lake Como case study

Based on the results of the Dialogue 1 (semi-structured interviews and questionnaires with stakeholders), we developed two policy scenarios that will be presented during Dialogue 2 (13-14 February 2024), being briefly presented below. Policy scenarios differ on target and WEFE nexus dimensions priority (Figure 18), which can be relevant for further discussion during the second dialogue.

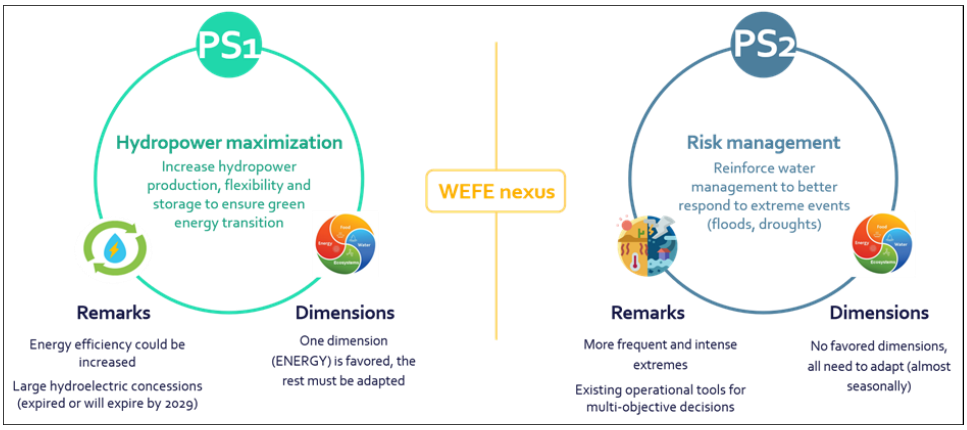


Figure 18 : The two policy scenarios described considering targets and priorities.

Scenario 1: "Hydropower maximization"

In this scenario, the target is to increase hydropower production, flexibility, and storage to maximize green energy transition and reinforce renewable energy self-sufficiency at the regional and national scale. It is assumed that particular actions need to be promoted by the public (regional administration, Regione Lombardia) and the private sectors (energy business) to boost the capacity of the energy system to respond to sectorial demands. Three main actions are presented to achieve this goal: 1) Increase public investment to expand renewable energy security and self-production (focusing on hydropower but also complementary green sources, e.g., solar energy through floating solar panels installed in main reservoirs), 2) Support small hydropower plants (mini hydro) construction for production and self-consumption downstream of the lake (including irrigation supply), and 3) Renew large energy concessions currently expired or to be expired before 2030 by assigning them to the current beneficiaries (to guarantee energy efficiency investments). To advance this triple strategy, it is presumed that the regional government (Regione Lombardia) and the energy sector led a coordinated strategy to define how to encourage hydropower production as part of the green energy transition. In this context, energy efficiency will be encouraged by conducting a technological upgrade of the large hydropower plants, while small hydropower plants (mini hydro) will be constructed downstream to increase upstream-downstream energy balance and increase self-production and self-consumption downstream (mainly from irrigation and urban demands). A regional land policy is approved to maximize land use for green energy production, and a comprehensive zoning scheme is defined. Likewise, financial instruments for transferring agricultural land to solar panel production are considered to complement hydropower production. A list of predefined assumptions to achieve hydropower maximization is provided in Table 6 and will be discussed during Dialogue 2.

Table 6 : Assumptions to achieve the target of the policy scenario on "hydropower maximization" considering the four dimensions of the WEFE nexus

ID	PS1. Hydropower maximization – Assumptions
1	A regional land policy to maximize land use for green energy production is approved and a comprehensive zoning scheme is defined
2	Financial instruments are offered to convert agricultural land to energy land (solar panel production) to complement hydropower production
3	In the reassignment of hydropower concessions, the Regione Lombardia has included forest management as a new responsibility for the energy sector: This presents an opportunity to increase water storage upstream for energy production
4	The Regione Lombardia encourages the technological upgrade of the large hydropower plants to increase by almost 10% the amount of energy generated each year
5	Proliferation of small hydropower plants (mini hydro) for production for self-consumption downstream (mainly from irrigation and urban demands) reduces upstream energy dependency
6	The competitive reassignment process of the hydropower concessions leads to asymmetry between foreign and Italian operators, increasing the risk of losing sovereignty in the production of green energy
7	Water conflicts between the energy and food production sectors increase due to the reduction of water supply for irrigation during the summer period, including impacts on the ecosystem (groundwater recharge)
8	Private navigation on Lake Como is restricted to hybrid or full electric transportation, which improves water quality and biodiversity
9	The surplus of hydropower production is offered downstream for irrigation (pumping water) and urban use (municipalities/tourism) at reduced cost as compensation for economic losses during the summer period
10	The energy sector establishes a sustainable program to guarantee fish production for the Lake Como system, including a specific program for activities led by the Fiumelatte fish nursery

As water storage is primarily allocated to hydropower production, impacts on the other dimensions of the WEFE nexus are expected. Land for agricultural use can be pressured by a new land policy aiming to maximize land use for green energy production, particularly if the zoning scheme includes highly productive soils. Likewise, tensions between the energy and food production sectors will increase due to the reduction in water supply for irrigation during the summer period, including impacts on the ecosystem (groundwater recharge). The water licenses in the basin are guided by the overarching goal of maximizing energy production in the Alpine hydropower reservoirs, dismissing downstream interests along the lake (e.g. recreational and tourism needs impacted by low lake levels during the summer) as well as the irrigation requirements of the farmers. The main expected outputs of the assumptions (most of them perceived as impacts) are depicted in Figure 5.

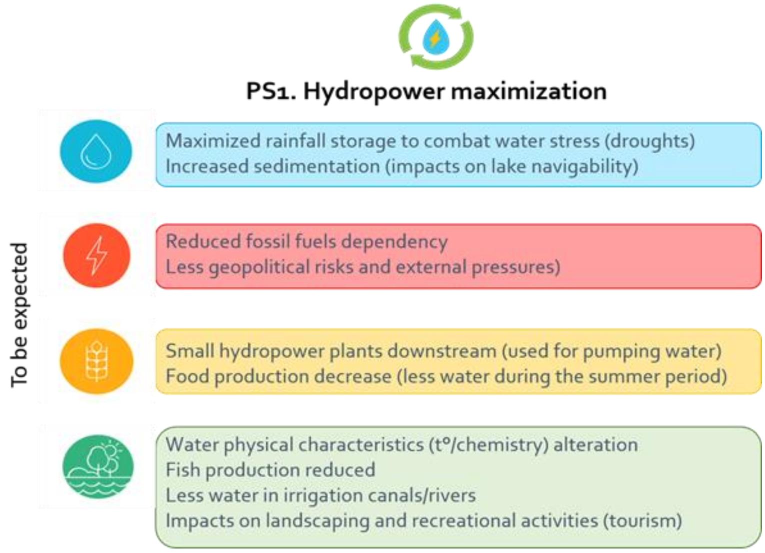


Figure 19 : Main expected impacts of the policy scenario on "hydropower maximization" considering the four dimensions of the WEFE nexus.

Scenario 2: "Risk management"

In this scenario, the target is to strengthen water management to better respond to extreme events emphasized by climate change, which are projected to be more frequent and intense, particularly regarding flood events and drought periods. In this scenario, it is assumed that the primary concern of the regional government is to address the consequences of climate variability by promoting technical but also decision and policy-making responses from the near- to long-term to increase the resilience of the system. As no WEFE nexus dimension is maximized above the rest, actions tend to consider the whole spectrum of the nexus by: 1) Updating operational tools for multi-objective decisions (e.g., to respond to erratic rainfall patterns, seasonal water stress), 2) Enlarging water storage capacity (e.g., to increase energy production upstream and food production downstream, but also to reduce flood risk), 3) Investing in irrigation systems water efficiency, subsidize the implementation of drought-tolerant and less water-intensive crops, 4) incentivize risk-hedging tools, such as insurance services, and 5) Promoting technological advancements to increase risk response (e.g., climate-weather services and monitoring). To advance on this multi-focused strategy, it is assumed a cooperation and coordination role between the Regione Lombardia and the Consorzio dell'Adda (as the lake operator) to strengthen the existing decision support systems (e.g., introducing changes in water release conditions to standardize the mechanism to regulate the Alpine reservoir systems, guarantee downstream water demands and improve drought risk management). Furthermore, they are expected to lead actions affecting upstream and downstream areas, potentially causing cost-benefit unbalance (e.g., promoting wastewater reuse for irrigation and ecosystem needs provides a) more water supply for energy needs upstream and b) more water supply for environmental requirements downstream; but c) food production could be limited if environmental, agronomic and health risks are not assumed, without ruling out the yuck factor among farmers. In this context, transversal assumptions able to increase the system's governance and multi-objective assumptions are planned. For example, the inclusion of the Lake Como system in the Adda river contract, which responds to a negotiated planning tool that aims to promote active involvement of all agents of the system to mitigate climate risks. A list of predefined assumptions to achieve hydropower maximization is provided in Table 7 and will be discussed during Dialogue 2.

Table 7 : Assumptions to achieve the target of the policy scenario on "risk management" considering the four dimensions of the WEFE nexus

ID	PS2. Risk management – Assumptions
1	The construction of several lamination basins upstream (for energy) and downstream (for irrigation) reduces flood risk (9 out of 10 years)
2	Treated wastewater reuse is maximized for irrigation and ecosystem needs as an alternative water source independent of climate patterns
3	The Regione Lombardia includes the Lake Como system in the Adda river contract to promote water governance downstream
4	Farmers adopt more efficient irrigation systems (moving from surface to localized and drip irrigation), reducing the need for derivation from surface water by approximately 15%
5	The introduction of drought-tolerant and less water-intensive crops increases groundwater recharge and preserve biodiversity associated ecosystems (river and irrigation canals)
6	The Regione Lombardia provides financial incentives to farmers to take out risk insurance services through which reinforcing protection from adverse meteorological events (floods and droughts)
7	Changes in water release conditions (e.g., the threshold on the level of Lake Como is +20 cm) are approved to standardize the mechanism to regulate the Alpine reservoir systems, guarantee downstream water demands and improve drought risk management
8	A regional program to face invasive alien species affecting the Alpine forests is approved: this will protect the system in terms of biodiversity, economic activities, CO_2 mitigation function, and flood risk
9	Changes in snow accumulation and melting reduce the seasonal water storage, exacerbating tensions (energy and food production sectors)
10	Nature-based solutions (e.g., water-controlled retention areas) are encouraged by Regione Lombardia, which intensifies pressure on land management and alluvial forests, putting at risk their ecological benefits

However, this holistic strategy is not exempt from impacts on the system. Introducing more efficient irrigation systems (moving from surface to localized and drip irrigation) reduces water demand but increases groundwater stress, as irrigation canals contribute to a less relevant way to the recharge of aquifers. Likewise, changes in snow accumulation and melting patterns impact seasonal water storage, exacerbating tensions across the WEFE nexus dimensions (e.g., energy and food production sectors). Other initiatives, as nature-based solutions (e.g., water-controlled retention areas) are encouraged by the Regione Lombardia, which intensifies pressure on land management and alluvial forests, putting at risk their ecological functions and the benefits for the nexus. The main expected outputs of the assumptions (most of them perceived as impacts) are depicted in Figure 20.

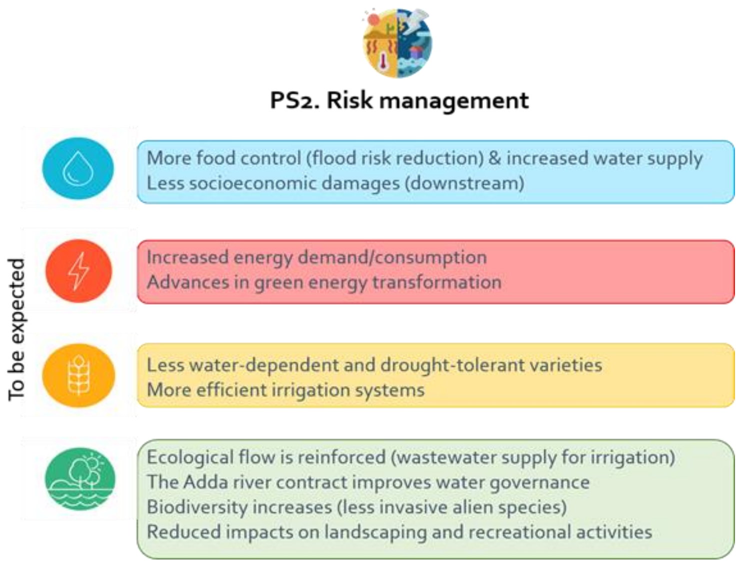


Figure 20 : Main expected impacts of the policy scenario on "risk management" considering the four dimensions of the WEFE nexus.

3.2.4 Debating scenarios with stakeholders

The two policy scenarios will be presented and debated with stakeholders during an online workshop that will take place in two sessions in mid-February 2024. The workshop pursued three objectives:

- To display the different visions of the WEFE nexus (identified in Dialogue 1) to highlight which elements and arguments have been used to describe the system and a potential shared vision of the WEFE nexus.
- To collect stakeholders' perspectives on predefined policy scenarios, focusing on their ability to evaluate the relevance and credibility of underlined assumptions, assess their strengths and weaknesses in the face of different factors of change, and their consistency and judgments in terms of desirability. A list of potential indicators able to evaluate the status and progress of each assumption will be discussed as a preliminary exercise to quantify assumptions as input for the integrated model. Likewise, the intention is to allow stakeholders to modify the scenarios in a way that reflects what is expected and how relevant it is for the management of the nexus. The possibility of creating new scenarios is also considered if needed.
- To identify potential solutions as actions capable of improving the resilience of the system and the coexistence of the WEFE nexus dimensions. Solutions will be widely discussed in Dialogue 3 as a previous step for their consideration as input for the modelling of the policy scenarios.

At the end of the workshop, the aim will be to obtain policy scenarios modified and validated policy scenarios from the participants, ready to be simulated with the integrated (hydrological and operational) model.

4.3 Assessing scenarios with model simulating

This section provides further details of how steps ❺ to ❽ will be carried out.

3.3.1 Specification of model inputs for scenario

A High-resolution WEFE model combining Stochastic climate downscaling and Hydrological modelling has been developed for the Lake Como system (see full details in D4.1). For the Stochastic climate downscaling it has been developed the AWE-GEN-2d stochastic weather generator for the whole domain based on observed climate variables for the present/historical period (additionally, the climate scenarios developed in WP2 are analyzed to develop factors of change). To adapt the AWE-GEN-2d model of the present climate to the future climate scenarios of WP2, we extracted the lake Como domain from the global climate model projections, and computed factors of change for each grid cell in the domain. The change factors are based on a 30-year moving window, where the difference is relative to the present climate model simulations. We apply the factors of change to the AWE-GEN-2d model of present climate to develop simulations for the GoNEXUS future scenarios. Results identify how, in general terms, the temperature trajectories are consistent with the global average. However, for precipitation there is little to no trend evident in the case study domain, compared with the very distinct trends and differences among SSP scenarios at the global scale.

For the Hydrological modelling, we have adapted the TOPKAPI-ETH model configuration to run using the new TOPKAPI-ETH version 2. The change to the newer model version allows the possibility to analyse the WEFE challenges assessed from spatially distributed indicators, using the optimized reservoir operation policies for the three largest hydropower schemes (A2A, Enel, and Edison). A particular aspect which we emphasize in the modelling work is the use of the glacier dynamics module in TOPKAPI-ETH to account for the impacts of the expected loss of glacier volume under a warming climate. We include the reservoir regulations in the upstream part of the catchment and force the model with higher resolution climate inputs.

In parallel, a simulation model of the reservoir operations at the daily time step, the Lake Como Design Model, has been developed to adopt a Multi-Objective Robust Decision Making approach in the case study. The model receives as input the water flow drained by the lake and computes its controlled storage dynamics. The water released from the lake is distributed to the agricultural districts for irrigation and to a few run-of-the-river hydropower plants. These processes have been modelled by means of a water distribution model of the main river steam and the canals that actually divert the flow to the districts and plants. In addition, the crop yield and production have been estimated by IdrAgra, a spatially distributed model for the simulation of irrigation and crop production of irrigated areas. The Lake Como Design Model allows the search for Pareto-optimal solutions that jointly consider planning and management actions, evaluating the robustness of each combination against present and future climatic conditions.

3.3.2 Model simulation and future scenarios robustness

Three WEFE indicators have been considered for the Lake Como Basin experiments in D4.1, namely the water deficit of the downstream users and the frequency of flooding events in Como as well as that of the lake low levels. These were formalized as follows:

- Flood control – number of days per year with an exceedance of the flooding threshold (h^f) in Como
- Low level prevention – number of days per year with lake level below low-level threshold (h^l = -0.2m)
- Downstream deficit minimization (in which water demand represents both the needs of the agricultural districts and of the hydropower plants).

The relevance and accuracy of these objectives will be discussed in Dialogue 2 considering the alignment with assumptions, indicators and solutions.

In order to anticipate future scenarios, a simulation model of the reservoir operations at the daily time step, the Lake Como Design Model, has been developed to conduct Many-Objective Robust Decision Making for the Lake Como Basin. The model receives as input the water flow drained by the lake and computes its dynamics. The water released from the lake is distributed to the agricultural districts for irrigation and to some existing hydropower plants. These processes have been modelled by means of a water distribution model of the main river steam and the canals that actually divert the flow to the districts and plants. In addition, the crop yield and production have been estimated by IdrAgra, a conceptual model for the simulation of irrigation and crop production of irrigated areas. Further details are provided in deliverable D4.1.

In the experiments reported in D4.1, three alternative actions were explored regarding the modification of the Lake Como active capacity:

- Alternative 0 (A0), that represents the current situation with operating space limits (h^{lb} = -0.4m and h^{ub} = 1.1m);
- Alternative 1 (A1), that considers the new flooding threshold (h^f = 1.73m) established after the installation of the barriers in Como. This allows to restore the operating space (h^{lb} = -0.4m, h^{ub} = 1.3m) set by the legislation, which have been lowered in the past decades due to the subsidence affecting some areas in the city of Como;
- Alternative 2 (A2), that takes advantage of the new barriers in Como to increase the flooding threshold as in A1 and does not fix h^{lb} and h^{ub} a priori but optimize them as two additional parameters to be added to those defining the policy (vector θ).

Focusing on the application results and considering an historical horizon (2000-2021), the optimization produced three sets of Pareto optimal solutions (Figure 21) for the three actions introduced above; each Pareto optimal set includes different operating policies for the lake's regulation for a given lake's active capacity. The figure shows that A1 and A2 clearly dominate A0: both allow to obtain better solutions in terms of flooding (left), downstream deficit (bottom), and low levels (dark blue). The increase of the operating range upper bound to 1.3 m and of the flooding threshold to 1.73 m (A1) strongly reduces the conflict between the objectives (they span a relatively small range of values considering each objective). A2 is almost equivalent to A1. The main difference is that it is able to decrease the deficit indicator of about 10% with respect to A1, but with a concurrent increase of the frequency of the flooding occurrence. The presence of three sets of solutions provides a rich context for supporting the identification of candidate compromise solutions during the dialogues with the stakeholders.

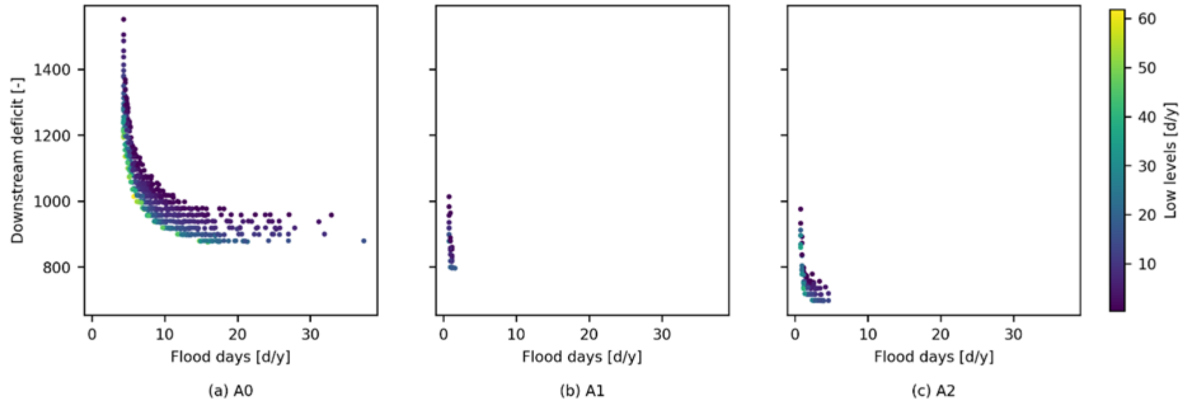


Figure 21 : Comparison of the Pareto fronts obtained for the three alternatives A0 (a), A1 (b), and A2 (c) on the historical horizon (2000-2021).

Lastly, the solutions found for the historical horizon must be evaluated on future scenarios to test their robustness to the variations of the hydro-meteorological regime caused by the climate change. A schematic representation of the future scenarios' features is reported in Figure 22. We specifically considered the following features to allow meaningful comparisons between the combinations:

- two horizons, one representative of the mid-term future (2039-2060), the other at the end of the century (2079-2100).
- three RCPs. A very stringent mitigation scenario (RCP2.6), an intermediate scenario (RCP4.5), and the one usually considered as a worst-case scenario (RCP8.5).
- three combinations of global and regional circulation models (ICHEC+RACM, ICHEC+RCA4 and MPI+RCA4). Comparing ICHEC+RACM and ICHEC+RCA4 we can isolate the contribution of the regional model, while the comparison between ICHEC+RCA4 and MPI+RCA4 quantifies the contribution of the global model.
- three planning and management alternatives (A0, A1 and A2).

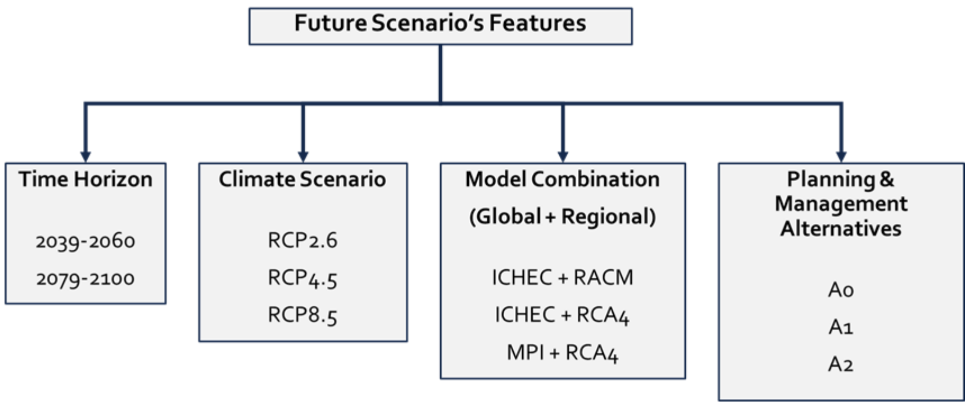


Figure 22 : Aspects of the future scenarios considered in the study: two horizons, three RCPs, three combinations of global and regional circulation models, three planning and management alternatives.

In general, this framework allows to quantify the response of the system (in terms of stakeholders' satisfaction) considering a comprehensive set of future hydroclimatic conditions (combining different temporal horizons, RCPs, global and regional circulation models) as well as synthetically generated scenarios spanning a wide range of droughts features. The challenges, drivers, and solutions identified in Dialogue 2 could support model simulations by identifying the range and severity of different hydro-climatic conditions and extreme events after considering the list of assumptions affecting upstream and downstream water management patterns. Likewise, Dialogue 2 will be useful to discuss with stakeholders which scenario or time horizon they prefer to go further considering the expected outputs of the compromised operating policies.

5 Local socioeconomic and land use scenarios: Spanish river basins

Authors : E Gómez Martin, D. Martínez Domingo, V Mónico González, A Rubio Martin, M Pulido Velázquez (UPV)

5.1 Overview of the methodology

A multidisciplinary bottom-up approach was employed to develop and evaluate the scenarios proposed in the case studies of the Spanish River basins (Jucar, Tagus, and Segura). This approach included the review of documents and scientific data derived from external studies and global models, engaging various stakeholders through interviews and workshops, and utilizing different simulation and optimization models for each of the considered watersheds.

The methodology used is outlined in Figure 23 and is briefly described in the following paragraphs.

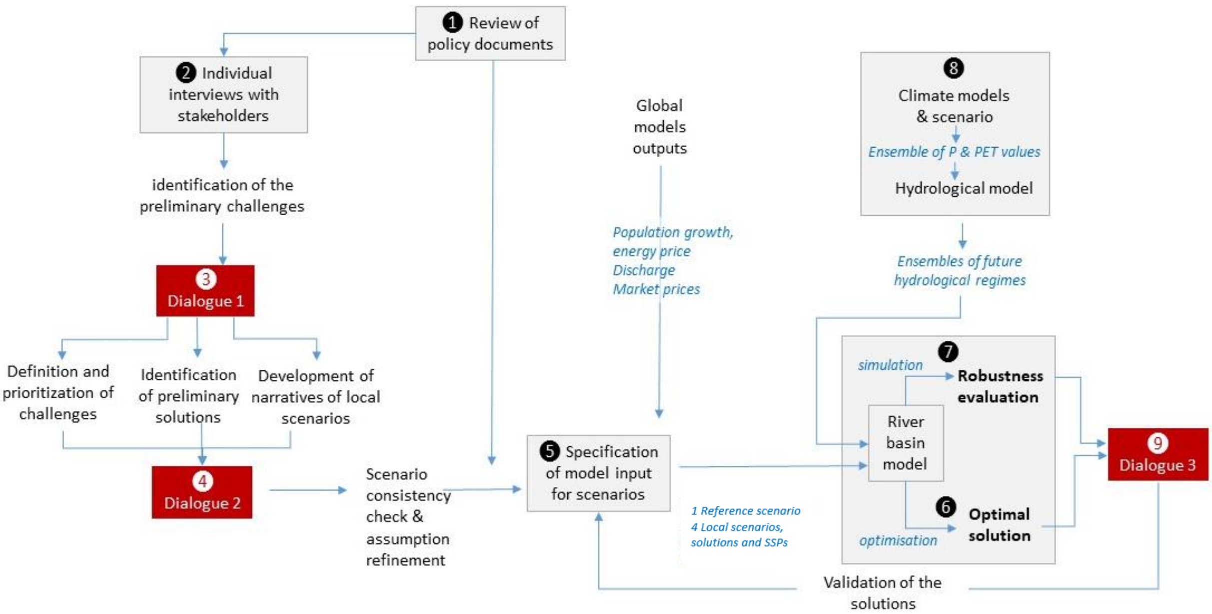


Figure 23 : an overview of the inter-disciplinary approach used to develop and assess scenarios in the Spanish case studies.

The first step consists of a review of the existing policy documents related to the different dimensions of the WEFE Nexus, as well as the hydrological basin plans, developed by the corresponding River Basin Authorities (RBA), the national organizations in charge of basin management (❶).

The documents help and give an idea about the main challenges and problems of the basin, as well as the characterization of the demands and different future projections, especially related to the environmental, food security, energy consumption and production, and water resources management sectors.

To obtain more information, we conducted a series of interviews with various stakeholders representing the different sectors and institutions involved in the four dimensions of the nexus (❷). These interviews allowed us to preliminary identify the challenges that the basin presents from the different components of the nexus and from different perspectives.

Once the documents were reviewed and the interviews were conducted, the stakeholders were brought together in four participatory dialogues (two for the Júcar basin, at the subbasin level, one in the Segura basin, and one in the Tagus basin) (❸). The goal was to encourage the exchange of perspectives, allowing participants to gain knowledge from each other and transcend the boundaries of their respective sectors. This dialogue also allowed participants to build a common understanding of the challenges of each basin and their prioritization, as well as possible solutions. Both the challenges and the solutions are essential for developing the local scenarios. Some of the visions collected during the workshops are presented in the videos below:

Júcar: https://www.youtube.com/watch?v=E7lmcWzRBXQ

Tagus-Segura: https://www.youtube.com/watch?v=sVkbjoKVyns

The results of the previous three steps allowed the research team to develop contrasting local scenarios that represent a possible long-term evolution of the WEFE nexus in the Spanish case studies (❹). These scenarios aimed to increase stakeholders' awareness of the variety of global and regional changes that could affect their future. The intention is to encourage them to consider possible adaptation strategies across the four dimensions of the nexus that they can implement to design desirable futures. Therefore, the scenarios cover hypotheses related to the main challenges encountered in the first dialogue and the changes that may be produced by external variables such as climate and socioeconomic changes. The scenarios are described through a narrative to facilitate their understanding by interested parties. They are then discussed with stakeholders in a workshop (Dialogue 2) to check their internal coherence and refine the hypotheses that motivated each scenario.

But scenarios aren't developed just to engage players in a future-thinking exercise. They should also serve as a basis for running river basin model simulations. This transition from qualitative forecasting to quantitative simulation involves quantifying the assumptions of the scenario (❺). This scenario quantification is based on (i) existing global change studies, (ii) results from global model simulations performed in GoNEXUS), and (iii) existing policy documents. In general, different types of scenarios are considered: the reference period, the local scenarios discussed in Dialogue 2 and socio-economic future trajectories (SSPs). More details are provided in the modelling section below.

Once the quantitative hypotheses are defined, the river basin model evaluates scenarios. Two different evaluation methods are used: optimization (❻) and simulation (❼). Optimization is applied to identify management strategies that allow for achieving objectives defined in the scenario (for example, minimizing the demand for surface resources). This also considers assumptions about the general socioeconomic context. The optimization is carried out for the reference period and local scenarios. Subsequently, simulations (❼) are carried out to evaluate the performance of each optimal strategy under various hydro-climatic conditions, serving as a robustness test. Details on the approach used to define the range of possible hydro-climatic conditions (❽) are presented in the section below.

A third dialogue is organized to present and discuss the modeling results (solutions) ❾ with stakeholders.

5.2 Developing scenarios

5.2.1 Types of scenarios

Three types of scenarios are developed, described below:

- <u>The reference period</u>: This scenario refers to the historical period simulated with Global Climate Models (GCM) in which the continuation of current conditions (climatic and socioeconomic) is assumed without any significant policy/management change or intervention. This scenario will provide a reference point with which it is possible to evaluate the impact of other scenarios.

- Local scenarios on which Dialogue 2 focuses aim to describe hypothetical future situations that are shaped by specific policy decisions and interventions. They are constructed to explore with stakeholders the potential desirable and undesirable impacts of various courses of action. The evaluation of the local scenario is first conducted in qualitative terms during workshops before being evaluated with the river basin model and again discussed with stakeholders on the basis of modelling results and solutions adopted.
- Scenarios will be run with and without solutions through the different SSPs available in the project (SSP1-2.6, SSP3-7.0 and SSP5-8.5)

5.2.2 Developing local scenarios

In the Spanish case studies, the development of local scenarios was based on two successive stages.

The first stage consisted of analyzing the dynamics of the WEFE, which is represented as a complex system. This dynamic analysis of the system had three main objectives:

1. Identify the main challenges that the basin presents and prioritize them according to the present and future needs of the actors in the system.
2. Identify possible adaptation measures or solutions that can be implemented to mitigate or counteract the challenges.
3. Identify the main variables that interfere in the system and how they are related to each other, as well as the state of these relationships (weak or strong).

To accomplish each of these objectives, various participation methods were implemented, with the involved actors actively taking part. Ultimately, this resulted in a system dynamic model that represents the relationships among all the variables considered within the system. (This process is explained in more detail in the Deliverable 4.1 - chapter 2.4).

Figure 24 illustrates how this approach was applied in the different case studies of the Spanish basins.

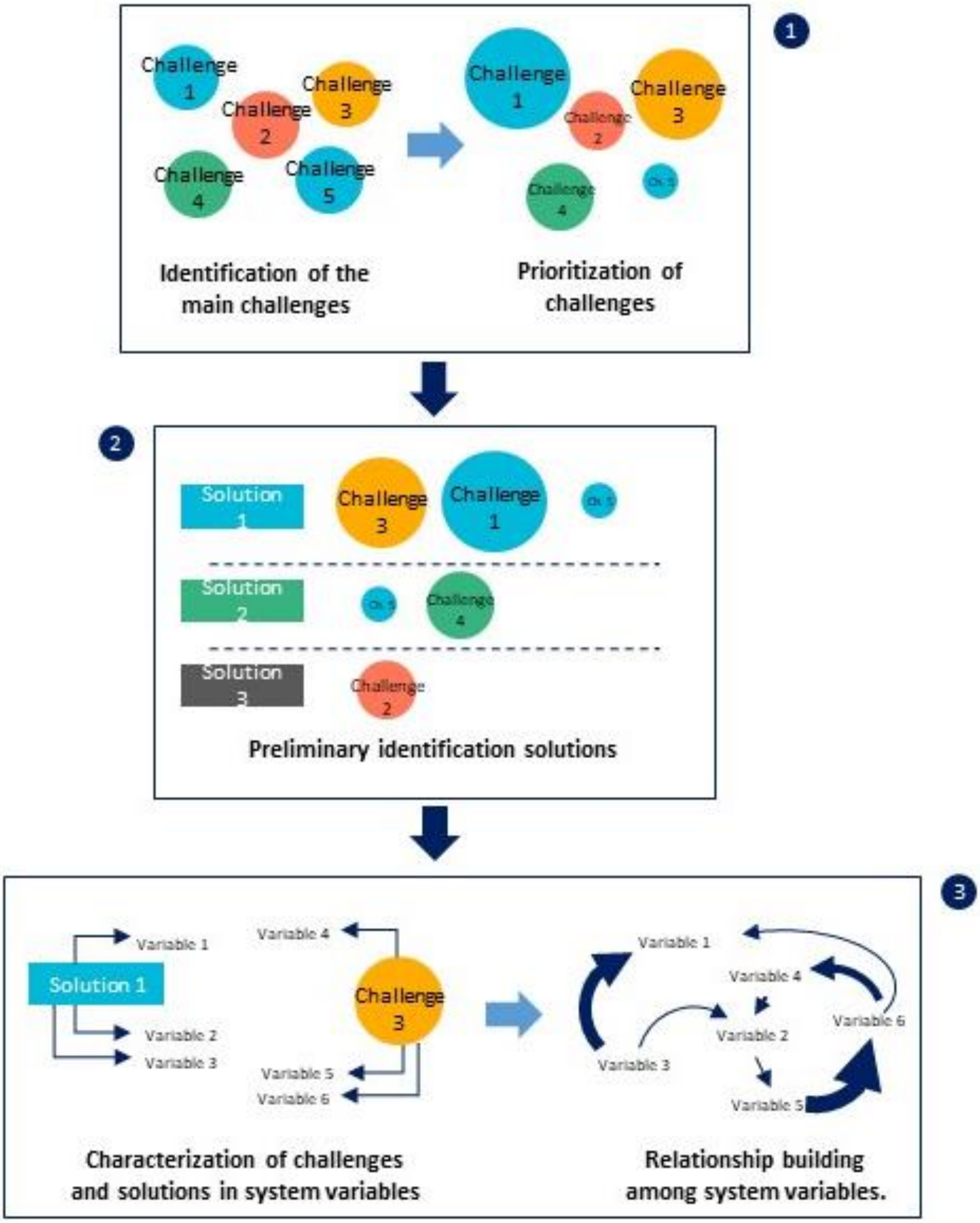


Figure 24 : General approach to analyzing the dynamics of the WEFE of Spanish river basins.

After identifying the main challenges, potential preliminary solutions, and the interaction among different variables in the system, the second stage involves formulating hypothetical scenarios (local scenarios) of the future closely tied to the identified challenges and the potential behavior of the system if any of the variables were altered. The hypothetical scenarios were chosen to address several of the primary challenges and solutions.

The selected hypothetical scenarios aim to capture the key processes and broadly depict the diversity of possible solutions. The primary motivation behind this simplification is to enhance the efficiency of dialogue, especially considering that these scenarios will undergo testing in workshops involving stakeholders.

Following the approach developed by the Senegal team, scenarios are then presented as **storylines**, written as **fictional press releases** which involve fictitious characters and relate facts supposedly taking place in the late 2050's.

5.2.3 Summary of narrative scenarios developed in Spanish River Basins

Based on the results of preliminary interviews with stakeholders and the first dialogue, we developed the local scenarios which are briefly presented below.

5.2.3.1 Scenarios developed in Júcar river basin

Scenario 1. Environmentalism, renewable energy, and agriculture come together in a successful collaboration

The Júcar region has implemented a visionary strategy that merges environmentalism, renewable energies, and sustainable agriculture to address the challenges presented by climate change. A collective groundwater management plan has been established, which has successfully maintained a balance in the levels of the Mancha Oriental aquifer and benefited crops with lower water demand. The Water Framework Directive has prioritized environmental uses over agricultural uses, and the region has integrated water-saving and modernization technologies to achieve a sustainable balance in the aquifer. Since 2030, the region has undertaken a dedicated commitment to renewable energies, providing employment in the construction, operation, and maintenance of wind farms, solar plants, and hydroelectric power plants, thereby consolidating a more sustainable economy. Although the implementation of renewable energy facilities has resulted in the loss of traditional landscapes, the region has addressed landscape alteration and loss of natural habitats in a balanced manner, prioritizing environmental sustainability. The Júcar region has established itself as a global benchmark in the harmonization of economic development and environmental preservation. The main assumptions are presented in a schematic way in Figure 25 and in a narrative way in Figure 26.

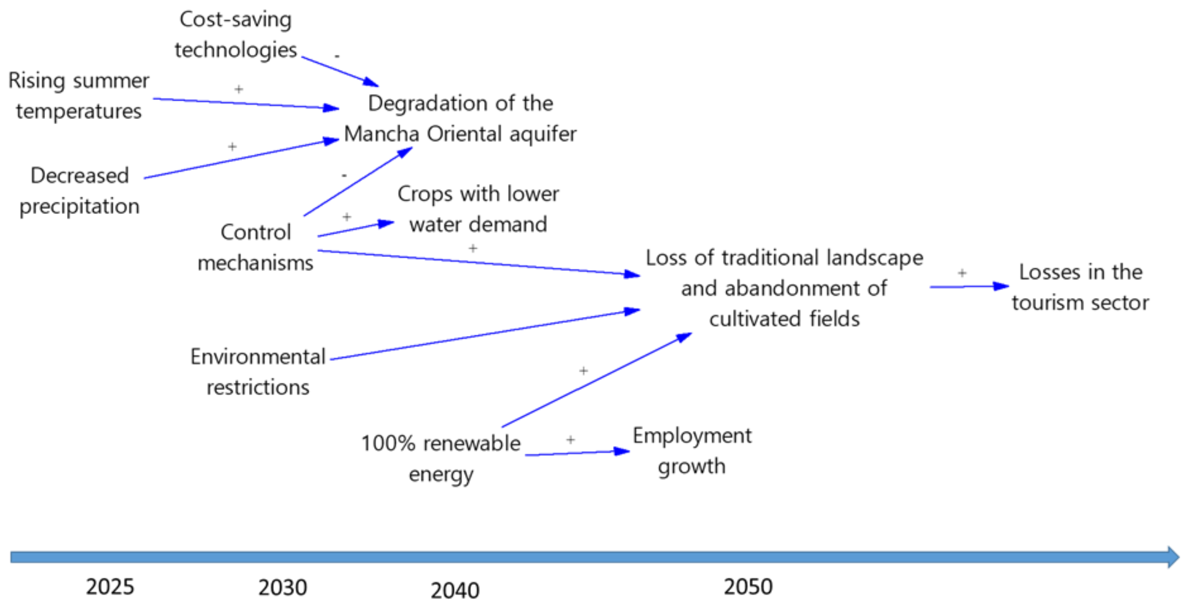


Figure 25 : Schematic representation of assumptions included in scenario 1, Jucar basin.

ALBACETE

La Tribuna

MIÉRCOLES 10 DE MARZO DE 2050. NÚMERO 118.094 DIARIO INDEPENDIENTE Precio: 16 euros

Revolución en la Gestión del Agua del Júcar: Ambientalismo, Energía Renovable y Agricultura se Unen en una Apuesta Ganadora

Transformación en la Gestión del Agua: El Júcar Prioriza lo Ambiental y Abraza las Energías Renovables en la Agricultura

A las puertas de 2050, la región del Júcar se posiciona como un ejemplo de resiliencia y adaptación frente a los desafíos del cambio climático. Durante dos décadas, caracterizadas por un aumento de 2°C en las temperaturas estivales, una disminución del 20% en las precipitaciones y una reducción del 40% en las entradas en Alarcón, impactando directamente en el acuífero de la Mancha Oriental, la región ha adoptado una estrategia visionaria que fusiona el ambientalismo, las energías renovables y una agricultura adaptada a los desafíos contemporáneos.

La gestión colectiva de las aguas subterráneas ha sido crucial en el proceso de transformación. Los mecanismos de control implementados tanto por los usuarios como por la administración han logrado mantener un equilibrio en los niveles del acuífero de la Mancha Oriental, beneficiando especialmente a los cultivos de menor demanda hídrica. Aunque esta gestión eficiente ha enfrentado desafíos al limitar la entrada de ciertos cultivos que podrían haberse beneficiado de la disminución de los días de frío, ha resultado esencial para garantizar la sostenibilidad de este recurso vital.

La Directiva Marco del Agua ha desempeñado un papel fundamental, priorizando los usos ambientales sobre los aprovechamientos agrarios. La región ha superado con éxito las restricciones ambientales mediante la incorporación de tecnologías de ahorro y modernización, logrando un equilibrio sostenible en el acuífero que sienta las bases para las generaciones futuras.

Desafíos y Oportunidades en la Apuesta por las Energías Renovables

Desde el año 2030, el Júcar ha emprendido un compromiso decidido con las energías renovables, a la par de su gestión del agua, motivado por el incremento en los costos energéticos y la ambición de alcanzar independencia económica en el sector agrario. La inversión en energías renovables ha generado empleos en la construcción, operación y mantenimiento de parques eólicos, plantas solares y centrales hidroeléctricas, consolidando así una economía más sostenible.

Aunque las energías renovables encarnan alternativas limpias y sostenibles, la construcción de sus infraestructuras ha planteado desafíos ambientales notables. Concretamente, la implementación de instalaciones para energías renovables, destacando la energía fotovoltaica en particular, ha ocasionado la pérdida de paisajes tradicionales, generando inquietudes sobre la preservación de la estética y la identidad visual de las zonas rurales.

Adicionalmente, las restricciones de la Confederación Hidrográfica del Júcar han conducido al abandono de campos de cultivo, generando incertidumbre sobre la viabilidad del agricultor tradicional y disminuyendo la importancia histórica de la agricultura en la región.

A pesar de estos desafíos, la región ha enfrentado de manera equilibrada la alteración del paisaje y la pérdida de hábitats naturales, priorizando la sostenibilidad ambiental. La competencia por tierras entre la agricultura y la generación de energía renovable se ha abordado con estrategias que buscan armonizar ambos sectores.

La industria turística local también ha sido contemplada en esta ecuación, con esfuerzos para mitigar los impactos visuales y paisajísticos de la infraestructura de energía renovable con el fin de preservar la atracción turística. Este enfoque equilibrado ha consolidado la región del Júcar como un modelo en la búsqueda de soluciones integradas para la agricultura, el medio ambiente y el turismo.

Con determinación, el Júcar avanza hacia un futuro sostenible en 2050, donde la gestión del agua, el ambientalismo y las energías renovables convergen para superar los desafíos actuales y construir un legado para las generaciones futuras. La región no solo ha resistido ante las adversidades climáticas, sino que ha prosperado, consolidándose como un referente mundial en la armonización entre desarrollo económico y preservación ambiental.

Figure 26 : Narrative description of scenario 1 in the Jucar basin as a press release.

Scenario 2: Improving agricultural productivity is a top priority

Despite the challenges arising from a 2°C temperature increase and lower rainfall, the region has successfully adapted, resulting in enhanced agricultural profitability. This transformation has been enabled by shifts in crop selection, technological advancements, and international trade reforms, which have turned previously crisis-stricken farms into large, competitive corporations. While the introduction of exotic, high-value crops has improved profits, it has adversely affected smaller farms that depend on subsidies for survival. Moreover, the implementation of renewable energy has lowered energy prices but created environmental concerns such as declining aquifer levels. The Júcar River Basin Authority is considering strict measures to address these issues, including restrictions on groundwater extraction. Although large agricultural companies have flourished, concerns about the sustainability of this model have arisen, considering potential economic losses from stricter controls. This scenario highlights the need for a cautious approach to achieve a sustainable balance amid environmental consequences and economic impacts. The main assumptions are presented in a schematic way in Figure 27 and in a narrative way in Figure 28.

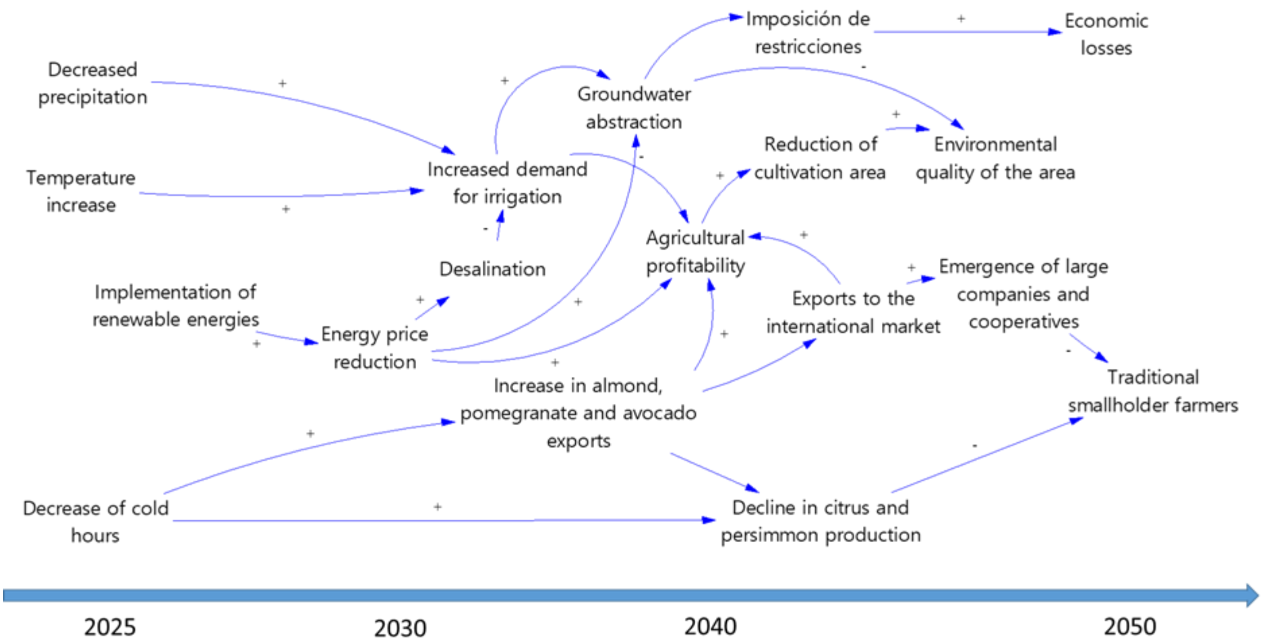


Figure 27 : Schematic representation of assumptions included in scenario 2, Jucar basin.

LAS PROVINCIAS

«La voz del país que quiere ser justa, prudente y económicamente gobernado»
MANIFIESTO FUNDACIONAL, 1866

ÚLTIMA EDICIÓN · Martes 10.03.50 · Año201 Nº158.094 · 16€ · www.lasprovincias.es

Transformación Agrícola y Desafíos Energéticos en la Cuenca del Júcar

Avances Agrarios y Desafíos Energéticos en la Región Valenciana

El año 2050 ha llegado marcado por transformaciones significativas en la Cuenca del Júcar, donde el cambio climático ha forjado nuevas realidades en la agricultura y la energía. A pesar de los retos, la región ha logrado adaptarse y prosperar, demostrando resiliencia y visión estratégica.

El calentamiento global ha dejado su huella con un aumento de 2°C en la temperatura, generando una mayor demanda de riego ante la disminución del 20% en las lluvias. Este escenario ha obligado a replantearse los cultivos tradicionales, y la agricultura valenciana ha visto reducida la producción de cítricos y caquis, afectados también por la disminución de las horas frío en la última década.

Sin embargo, a pesar de la persistente sequía, la cuenca del Júcar ha experimentado un aumento sostenido en la rentabilidad agrícola por tercer año consecutivo, gracias a la presencia exitosa de sus principales productos en el mercado internacional. Reformas estructurales durante la última década para liberalizar el comercio han llevado a un impresionante incremento en las exportaciones de almendra, granada y aguacate.

La transformación del sector agrario ha sido notable. Pequeñas explotaciones en crisis durante los años 2020-2030 han dado paso a grandes empresas, como Valencia Almond, líder nacional en la producción de almendras. Cooperativas de medianos y grandes agricultores han desplazado a los pequeños agricultores tradicionales, emergiendo como como competidores internacionales, y cultivos tropicales antes exóticos, como el aguacate, han florecido en la cuenca del Júcar.

La introducción de cultivos exóticos, con un alto precio en el mercado, no solo ha aumentado las ganancias en el sector agrario, sino que también ha permitido reducir el área de cultivo necesario para la viabilidad de las explotaciones agrarias. La alta competitividad, la innovación y la participación social han impulsado un rápido desarrollo tecnológico y su transferencia al sector agrario, disminuyendo los costos de producción para equipararse al mercado exterior.

Sin embargo, estas estrategias han tenido sus damnificados, principalmente las pequeñas explotaciones que aún sobreviven gracias a ayudas cada vez más reducidas, vinculadas a la protección del medio ambiente y la diversificación de la actividad.

La CHJ Observa con Preocupación el Impacto Ambiental y Evalúa Medidas Rigurosas

A pesar de la escasez hídrica, la implantación de energías renovables en la región ha propiciado una reducción significativa en los precios de la energía durante la última década. Este fenómeno ha permitido un aumento en los bombeos en toda la zona, sosteniendo así la productividad agrícola. Aunque estos beneficios son innegables, se han evidenciado efectos colaterales como la disminución de los niveles piezométricos de los acuíferos, la deterioración de la calidad del agua subterránea y un agravamiento de la intrusión salina cerca de la costa.

La Confederación Hidrográfica del Júcar (CHJ) observa con creciente inquietud estas tendencias y contempla la implementación de controles y restricciones más rigurosas en la extracción de aguas subterráneas para salvaguardar el recurso hídrico.

Aunque la nueva dinámica energética ha propiciado la creación de grandes empresas agrarias en las últimas dos décadas, la sostenibilidad de este modelo se ve cuestionada. La imposición de mayores restricciones en la extracción de aguas subterráneas podría poner en aprietos a estas empresas, generando preocupaciones sobre posibles pérdidas económicas que podrían afectar significativamente a la región valenciana.

La Cuenca del Júcar ha experimentado transformaciones notables hasta el año 2050, destacando la capacidad de adaptación del sector agrario frente a los desafíos climáticos. Sin embargo, las consecuencias ambientales y las posibles repercusiones económicas plantean desafíos cruciales que requieren una cuidadosa consideración para garantizar un equilibrio sostenible en el futuro.

Figure 28 : Narrative description of scenario 2 in the Jucar basin as a press release.

5.2.3.2 Scenarios developed in Tagus-Segura river basin

Scenario 1 (Segura): Energy and digital revolution

In this scenario, it is assumed that dialogue and collaboration are established between government entities and farmers to define a plan for the management and development of renewable energies. With this plan, the implementation of photovoltaic energy is increased as the main source for irrigation systems, promoting digitalization for both large agricultural expanses and small-scale farmers. This aims to reduce existing gaps and enhance production margins.

Simultaneously, a significant decrease in water contributions from the Tagus River is assumed, leading to an expansion of desalination capacity in the basin. To decrease energy costs, photovoltaic systems are implemented in the plants, resulting in increased pumping from aquifers and very high levels of overexploitation. Additionally, with the digitalization of agricultural production systems, aquifer recharge is reduced. The main assumptions of this scenario are graphically depicted in Figure 29 and Figure 30.

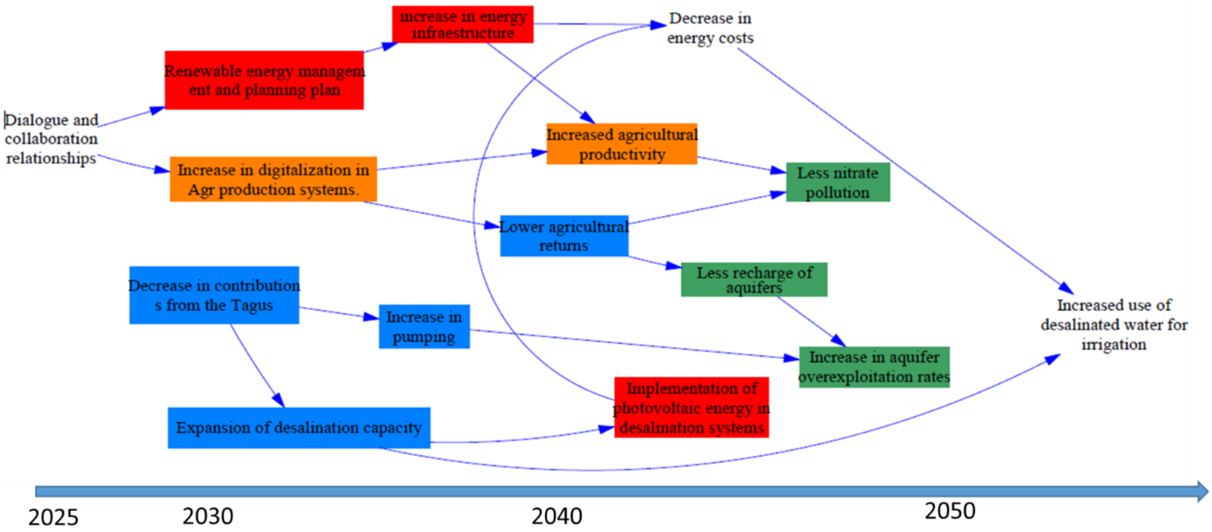


Figure 29 : Graphic representation of the main hypothesis underlying scenario 1 in the Tagus and Segura basins

La Opinión www.laopiniondemurcia.es DE MURCIA

JUEVES, 11 DE MARZO DE 2021 | AÑO XXXII | NÚMERO 11.822 | DIRECTOR JOSÉ ALBERTO PARDO LIDÓN PRECIO 1,40 € Este diario utiliza papel reciclado al 80,5 %

Transformación Sostenible en la Cuenca del Segura

Hace más de 25 años se establecieron relaciones de diálogo y colaboración entre las entidades gubernamentales y los agricultores en la Cuenca del Segura. Este compromiso visionario dio origen a un plan integral de gestión y ordenación de energías renovables que ha modelado una nueva era en la región.

ENERGÍA RENOVABLE Y DIGITALIZACIÓN: EL LEGADO DE UNA COLABORACIÓN FRUCTÍFERA

Desde la implementación de este plan, la energía fotovoltaica se ha erigido como la fuente principal para los sistemas de riego, transformando la agricultura y generando un modelo sostenible para grandes extensiones agrícolas y pequeños productores.

Energía fotovoltaica en la cuenca del Segura

La digitalización ha sido la herramienta unificadora que ha disminuido la brecha tecnológica, permitiendo un aumento significativo en los márgenes de producción y una gestión más eficiente de los recursos.

DESAFIOS EN LA GESTIÓN HÍDRICA: RESPUESTAS INNOVADORAS

En un escenario que se enfrenta a los desafíos del cambio climático, y en el que los aportes de agua desde el Tajo han disminuido considerablemente, la Cuenca del Segura ha respondido con audaces estrategias de gestión hídrica. La ampliación de la capacidad de desalación ha sido una medida clave, respaldada por la implementación masiva de sistemas fotovoltaicos en las plantas de desalación, reduciendo significativamente los costes energéticos de producción y consumo.

Adicionalmente, la gestión del agua ha experimentado una metamorfosis digital en la cuenca. Sistemas de riego avanzados, alimentados por datos en tiempo real y algoritmos inteligentes, han reemplazado los métodos tradicionales. Estos sistemas no solo permiten una distribución precisa y eficiente del agua y los fertilizantes, adaptándose a las necesidades específicas de cada cultivo, sino que también han optimizado el uso del agua mediante la combinación de sensores, inteligencia artificial y automatización.

SOSTENIBILIDAD DIGITAL Y SU IMPACTO AMBIENTAL

Sin embargo, La digitalización de los sistemas de producción agrícola y la disminución de los costos energéticos han sido una herramienta de doble filo. Aunque se ha mejorado la eficiencia y la precisión, disminuyendo los aportes de nitratos a los acuíferos, también se ha disminuido su recarga y aumentado los bombeos, resultando en índices de sobreexplotación que demandan atención inmediata.

Digitalización. Sistemas de riego digitalizados

En este cuarto de siglo de transformación, la Cuenca del Segura se encuentra en un cruce de caminos, enfrentando desafíos y celebrando éxitos. La colaboración continua entre el gobierno y los agricultores, respaldada por la innovación y la sostenibilidad, ha dejado un legado que trasciende el tiempo y establece un modelo para el futuro. La Cuenca del Segura se mantiene como un faro de resiliencia y progreso, donde la colaboración audaz y la visión a largo plazo han allanado el camino hacia un futuro sostenible

Figure 30 : Narrative description of scenario 1 in the Tagus and Segura basins as a press release.

Scenario 2 (Segura): "Transformative Sustainability"

In this scenario, it is assumed that, following the prioritization of environmental objectives in the Segura River Basin by government entities in 2025, ecological and forestry restoration actions have been implemented to enhance natural and scenic resources. These actions have aimed at increasing the areas designated as Special Conservation Zones and High Connectivity Zones (SCZ and HCZ), leading to the expansion of areas dedicated to ecological corridors, which have increased from representing 18% to 36% of the national territory, with a notable decrease in areas allocated for irrigation. This has resulted in a significant rise in the supply and demand for ecotourism activities, diversifying employment in the region and increasing the demand for labor in tourism and ecotourism-related activities.

Considering the decrease in contributions due to climate change, restrictions imposed on agricultural activities regarding fertilizer use, the increase in ecological flows to improve the ecological status of surface water bodies, and restrictions on groundwater use, along with the success of the compensation system (Restoration of agricultural lands) as a key tool for a paradigm shift, agricultural activities decreased considerably during the first decade. The remaining irrigation systems have adapted by changing some crops to those with lower water needs and primarily sourcing from desalinated and reused resources.

Although the economy was heavily impacted by the reduction in agricultural activities, it currently relies on ecological and scenic tourism and sustainable agriculture. Significant improvements have been observed since the lowest point in 2030. Another measure implemented in response to the economic recession was the issuance of carbon bonuses. Consequently, a percentage of lands used for agriculture now serve as large CO_2 sinks, enabling the collection of substantial carbon bonuses. The main assumption of this scenario is graphically depicted in Figure 31 and Figure 32.

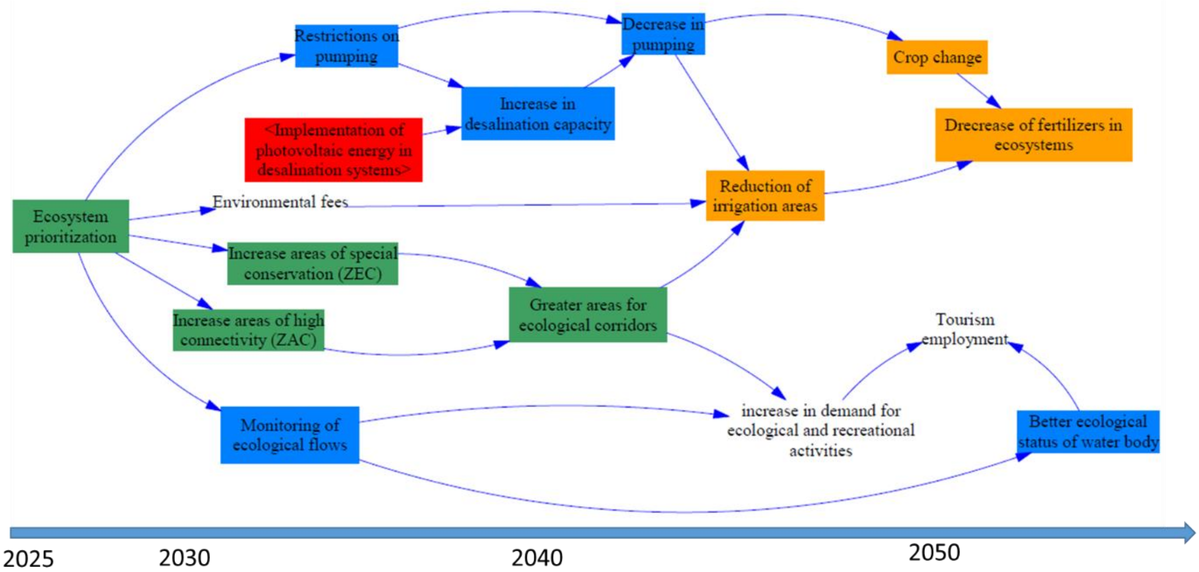


Figure 31 : Graphic representation of the main hypothesis underlying scenario 2 in the Segura basin

LA VERDAD

FUNDADO EN 1903. www.laverdad.es

Lunes
17.01.2050
Nº 38.725
1,80€
Venta conjunta e inseparable con AS en la Región de Murcia

120 ANIVERSARIO

Pepe Jara Fotógrafo, músico y veterinario

«NUNCA HAGO FOTOS CON EL TELÉFONO»

El polifacético artista expone una colección de imágenes tomadas en las calles de Murcia P34

LA JUGADA PERFECTA DE LOS LUNES: LA VERDAD Y AS POR 1,80€

El Segura: Una cuenca ecológica y sostenible

La cuenca del Segura ha emergido como un modelo para regiones en todo el mundo que buscan un equilibrio entre el desarrollo y la conservación del medio ambiente. En un hito trascendental para la cuenca, el compromiso gubernamental con los objetivos medioambientales que inicio con el ciclo de planificación 2027-2030 ha llevado a una notable transformación en la región, marcando un nuevo modelo de desarrollo que le apunta a la sostenibilidad y la ecología. A lo largo de las últimas décadas, se han implementado medidas que han redefinido la relación entre la comunidad, el medio ambiente y la economía.

Las acciones de restauración ecológica y forestal, enfocadas en la valorización de los recursos naturales y paisajísticos, han sido la piedra angular de esta transformación. La expansión de las Zonas de Especial Conservación (ZEC) y Zonas de Alta Conectividad (ZAC) ha resultado en la ampliación de los corredores ecológicos pasando del 18% al 36% del territorio nacional desde 2023. Aunque esto ha llevado a la disminución de áreas destinadas a regadíos, el impacto positivo se ha sentido a través de un aumento significativo en la oferta y demanda de actividades ecoturísticas, diversificando el empleo en la región y generando una creciente demanda de mano de obra en sectores turísticos y ecoturísticos.

Actividades turísticas en la cuenca del Segura

Por otra parte, las restricciones impuestas al uso del agua subterránea, las restricciones en el uso de fertilizantes y el aumento y seguimiento en los caudales ecológicos para mejorar el estado ecológico de las masas de agua superficiales han sido elementos cruciales en la transformación. Estas medidas, han contribuido al bienestar general del ecosistema, promoviendo la salud de los cuerpos de agua y preservando la biodiversidad.

Sin embargo, en las últimas décadas, la agricultura ha sido el sector que mayores retos ha encontrado en esta transformación ecológica de la cuenca. Sumado a estas nuevas políticas, la disminución de las aportaciones y el aumento de las temperaturas por efecto del cambio climático llevaron en la década del 2030 a una disminución productiva de este sector llevando a la economía de la región al borde de una recesión económica. Sin embargo, el éxito del sistema de compensación, centrado en la restauración de tierras agrícolas así como el pago de bonos de carbono emergieron como herramientas clave para hacer frente a este problema. Por otra parte, las superficies de riego que mantuvieron su uso después de esta transformación, se adaptaron optando por cultivos con menores necesidades hídricas y abasteciéndose principalmente de recursos desalados y reutilizados impulsados por energías limpias.

A pesar del fuerte impacto inicial en la economía, la región ha encontrado una nueva base económica sólida en el turismo ecológico y paisajístico, así como en la agricultura sostenible. Este enfoque innovador demuestra que la sostenibilidad no solo es ambientalmente responsable, sino también económicamente viable en la cuenca del Segura.

Figure 32 : Narrative description of scenario 2 in the Segura basin as a press release.

Scenario 3 (Tagus): Tagus is environmentally prioritized

It has been 20 years since the Tagus River was prioritized, leading to a significant transformation. The water transferred to the Segura Basin disappeared after decades of protests from the donor basin. This adjustment allowed the Tagus to meet its own needs, resulting in territorial development and partial mitigation of the effects of climate change. The upper stretch of the river, benefiting the provinces of Guadalajara and Cuenca, experienced growth in tourism, recreational activities, and a revival of the rural population. Regional development extended beyond tourism to include new agricultural industries, particularly in irrigated areas, leading to the emergence of new crops. However, challenges arise, as the Tagus Basin Authority acknowledges potential overexploitation of aquifers in the future. Groundwater user communities have expressed concern about the increasing pressure on the system due to irrigation development. The central axis of the Tagus, up to Talavera, has resisted the adverse effects of climate change and population growth, thanks to increased water flow. This ecological lifeline has restored the functionality and structure of aquatic and terrestrial ecosystems that previously suffered severe degradation. The middle and lower basin, prioritized since 2030, has earned appreciation from Portugal. Minimum continuous flows were established from the Azután reservoir to Cedillo, eliminating the excessive variability in the Tagus's flow that negatively affected its natural dynamics and disrupted water supply to Portugal. However, this decision, along with reduced reservoir releases, led to a decline in hydroelectric production, making way for other renewable sources such as photovoltaics. As of 2050, the reduction in water contributions raises questions about the Albufeira Treaty. Spain contends that the current figures are challenging to meet and anticipates tense relations with Portugal unless treaty points are reconsidered to align with the reduced contributions. The controversy surrounding the treaty's revision is evident. The main assumption of this scenario is graphically depicted in Figure 33 and Figure 34.

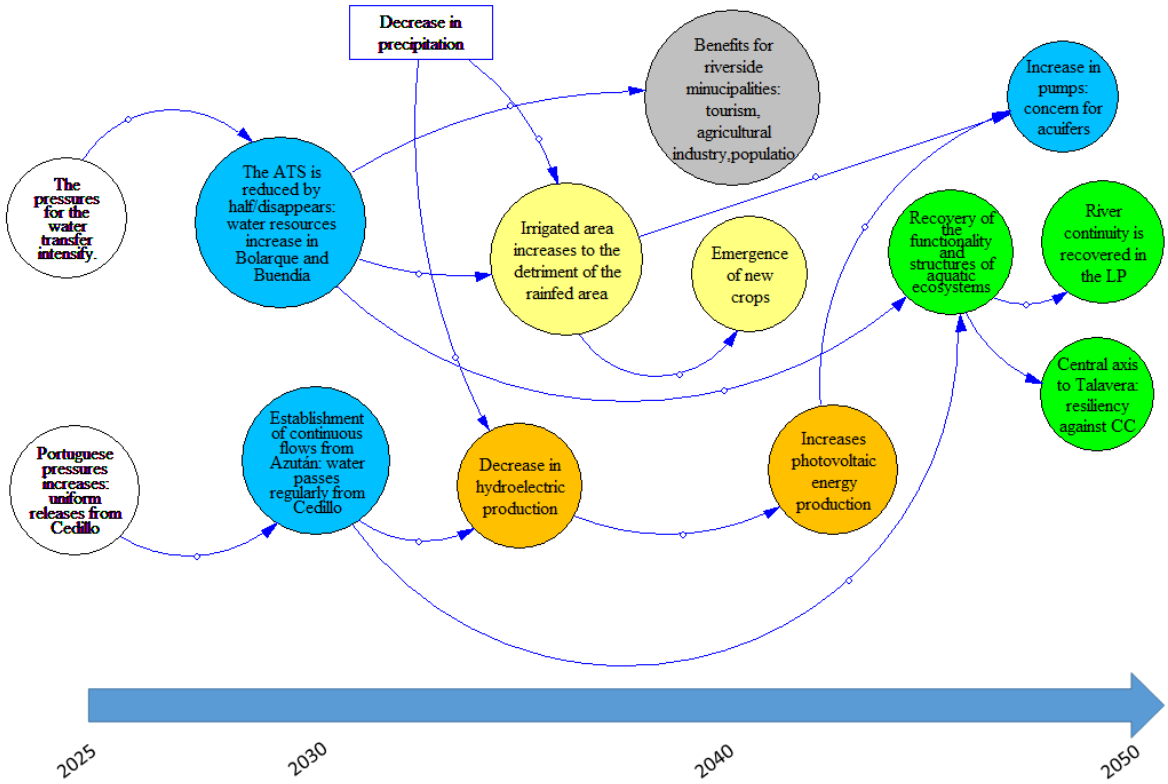


Figure 33 : Graphic representation of the main hypothesis underlying scenario 3 in the Segura basins

EL PAÍS

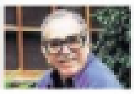
EL PERIÓDICO GLOBAL

www.elpais.com

MARTES 10 DE ABRIL DE 2050 | Número 16.252 | EDICIÓN MADRID | Precio: 1,80 euros

TENIS Roland Garros también le cierra las puertas a Djokovic P33

CULTURA Cómo se descubrió a Indira, la hija secreta de García Márquez P28



El Tajo: balance de los logros y desafíos tras 20 años de priorización

Han pasado ya 20 años desde que el Tajo se priorizase y haya experimentado desde entonces una profunda transformación: el **agua trasvasada a la Cuenca del Segura se redujo a la mitad** tras décadas de manifestaciones y protestas por parte de los usuarios de la cuenca cedente. El reajuste del trasvase ha conseguido que el Tajo pueda atender sus propias necesidades, algo que se ha traducido en un claro **desarrollo del territorio** y en la mitigación parcial de los efectos del cambio climático que empezaron a perjudicar a la cuenca a principios de siglo.

Uno de los principales beneficiados ha sido el tramo alto del río. La **mayor disponibilidad de agua** entre los embalses de Entrepeñas y Buendía ha supuesto una nueva oportunidad para las provincias de Guadalajara y Cuenca, sobre todo a los municipios ribereños y su revitalizado sector turístico ligado al atractivo paisajístico, y a las actividades de recreo, pesca y navegación. Actualmente la población rural que decreció entonces, se está recuperando. El desarrollo regional no sólo proviene del sector turístico, sino además de las nuevas industrias agrícolas que paulatinamente empezaron a asentarse en las provincias por el impulso que empezó a tomar la agricultura de regadío (fenómeno que se traslada también al resto de la cuenca). Esto también ha acarreado la aparición de nuevos cultivos en la cuenca.

Sin embargo, **no todo son ventajas.** Según el documento de Esquema de Temas Importantes de la Confederación Hidrográfica del Tajo (CHT) aunque todavía no recoge ningún acuífero sobreexplotado, no descarta que la situación cambie próximamente. Las comunidades de usuarios de aguas subterránea (CUAS) llevan tiempo advirtiendo que los datos recogidos son preocupantes. El desarrollo de **regadío** en la cuenca ha añadido **una presión extra al sistema.** Por otro lado, según se puede adivinar en el último Plan Hidrológico (PH), el eje central del Tajo hasta Talavera ha conseguido resistir a los efectos adversos del cambio climático y al aumento de población de Madrid (sin quitar mérito a la concienciación ciudadana y sus esfuerzos). El aumento de caudal ha sido el **salvavidas ecológico** que se necesitaba: se ha recuperado la funcionalidad y estructura de los ecosistemas acuáticos y terrestres del río, que habían sufrido una grave degradación.

Del mismo modo, la parte media y baja de la cuenca también se ha priorizado desde entonces y **Portugal lo ha agradecido.** Desde 2030, se establecieron caudales mínimos continuos desde el embalse de Azután hasta Cedillo, lo que eliminó la excesiva variabilidad del caudal del Tajo que afectaba negativamente a la dinámica fluvial natural del río y que hacía que el agua llegase a Portugal por rachas. Esta decisión no estuvo exenta de polémica. A causa de este cambio de gestión de las sueltas de embalses y a la reducción en las aportaciones, **la producción hidroeléctrica se ha reducido** y ha

Figure 34 : Narrative description of scenario 3 in the Segura basin as a press release.

Scenario 4 (Tagus): Water transfer suffocates the Tagus

In this scenario, the relationship between Spain and Portugal has never been as deteriorated in recent decades, primarily due to water, an increasingly scarce and contested resource on the Iberian Peninsula. The dispute revolves around the four shared river basins, becoming a major controversy. The main issue is Spain's non-compliance with the Albufeira Treaty, which regulates the flow of water to Portugal. The situation is particularly critical for the Tagus River, the longest in the peninsula, affected by water transfers to the Segura basin. While the amount of transferred water has decreased, the Tagus-Segura transfer remains a source of unacceptable pressure on the river system. The problem has intensified with the declaration of overexploited underground water masses in the latest Hydrological Plan of the Tagus River Basin Authority. Despite previous assessments stating no quantitative issues, the reality now is an increase in pumping to compensate for reduced precipitation and the expansion of irrigated land. Efforts by Madrid to improve water efficiency and raise public awareness have not been sufficient for the Tagus basin. The middle and lower parts of the basin face additional pressures, such as the negative impact of hydroelectric production on fish populations and riparian forests. Portugal complains about peaks caused by Spanish reservoir releases and demands continuous minimum flows from Cedillo to combat estuary salinization in Lisbon. Spain, in turn, calls for an immediate review of the treaty with climate-adapted limits. The possibility of a joint Hydrological Plan derived from a joint authority is raised as a potential solution. The main assumption of this scenario is graphically depicted in Figure 35and Figure 36.

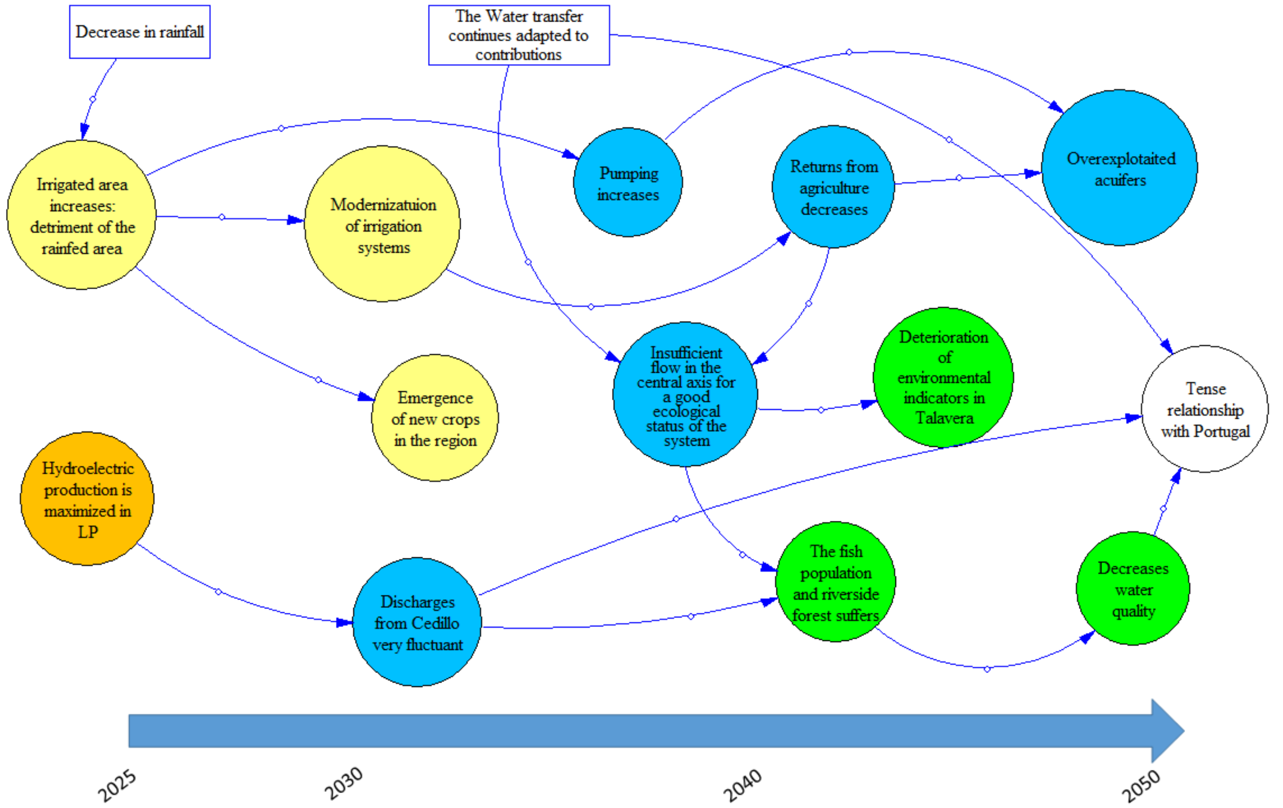


Figure 35 : Graphic representation of the main hypothesis underlying scenario 4 in the Segura basins

PAPEL Sidney Toledano, 20 años al frente de Dior: «El secreto del lujo es el detalle»

47 REDES SOCIALES Detenida la hija menor de edad de un imam de Madrid por incitar al odio contra gays y chiíes

EL MUNDO

MARTES 19 DE ENERO DE 205
AÑO XXVII. NÚMERO 10.20
EDICIÓN MADRID
PRECIO: 10.5

El agua, fuente de conflicto entre España y Portugal: el deteriorado Tajo en el centro de la disputa

Nunca las relaciones entre España y Portugal habían estado tan deterioradas en las últimas décadas. El motivo es el agua, un recurso cada vez más escaso y disputado en la península ibérica. La lucha por el agua está enfrentado a ambos países por las cuatro cuencas que comparten y se ha convertido en la gran controversia peninsular. La razón está siendo el **incumplimiento por parte de España de los objetivos del Tratado de la Albufeira** que regula el caudal que debe llegar a Portugal. El caso del Tajo, el río más largo de la península, es el más crítico, pues sufre las consecuencias del trasvase de agua hacia la cuenca del Segura.

Es cierto que la cantidad de agua trasvasada al Segura ha bajado en las últimas décadas debido a la disminución de las aportaciones en la cabecera del Tajo y que algunos años no ha sido posible trasvasar nada, pero a día de hoy, el trasvase Tajo-Segura es, más que nunca, una fuente de presión inaceptable sobre el sistema fluvial, pues la realidad es que esa agua trasvasada se revela esencial aguas abajo.

La situación se ha agravado con la aparición de **masas de aguas subterráneas declaradas sobreexplotadas** en el último Plan Hidrológico (PH) de la Confederación Hidrográfica del Tajo (CHT). Remontándonos al tercer ciclo del PH 22-27: "ninguna masa de agua subterránea se ha evaluado como en mal estado cuantitativo, aunque en algunas pudiera existir una situación que aconsejaría no seguir incrementando su explotación…". Pues bien, ahora mismo la realidad es que los usuarios se han visto obligados a aumentar los bombeos en los últimos años para compensar la disminución de las precipitaciones y la **transición de algunas tierras de secano a regadío**. Este aumento en superficie regada ha sido estrictamente alimentado mediante aguas subterráneas. Además, tanto por la modernización de los regadíos en la cuenca (ha disminuido los retornos), como por las demandas urbana e industrial, que tampoco han aflojado, se ha incrementado la presión sobre el sistema.

Los **esfuerzos de Madrid** por mejorar la eficiencia y depuración de sus aguas, así como los planes de concienciación ciudadana para no disparar la demanda urbana ante el aumento de la población, no han sido suficientes para la cuenca del Tajo. Tampoco los cambios en las últimas décadas en la normativa europea sobre la depuración de aguas en pequeñas aglomeraciones urbanas estableciendo límites cada vez más ambiciosos (actualmente poblaciones inferiores a los 200 habitantes deben instalar una EDAR). La **bajada de caudal** le da al eje central poca cuerda para diluir y la **calidad de sus aguas ha ido mermando** paulatinamente. El deterioro de los sistemas acuáticos que ha experimentado son una buena muestra de ello y los indicadores ambientales en Talavera de la Reina son preocupantes.

La parte media y baja de la cuenca también se enfrenta a otras presiones. La **producción hidroeléctrica, que se intenta maximizar** para paliar el aumento del coste de la energía ha afectado **negativamente** y de forma muy significativa, a las **poblaciones de peces y al bosque de ribera** (mitigador claro ante el cambio climático). Portugal sigue quejándose de los picos generados por los desembalses de las compañías españolas y sigue reclamando la imposición de caudales mínimos continuos desde Cedillo para luchar contra la salinización del estuario en Lisboa y no desfavorecer a sus usuarios. Mientras, España pide la revisión inmediata del Tratado con límites adaptados a la nueva realidad climática. ¿Podría ser finalmente una solución un PH conjunto derivado de una Confederación conjunta?

Figure 36 : Narrative description of scenario 4 in the Segura basin as a press release.

5.2.4 Debating scenarios with stakeholders

For each of the case studies, distinct workshops were conducted, as presented in the table below.

Table 8 :Dates and venues for the workshops conducted in the Spanish case studies

Case study	Workshop	Date
Júcar	Albacete	11/01/2024
	Valencia	12/01/2024
Tagus-Segura	Murcia	17/01/2024
	Madrid	19/01/2024

These workshops aimed at achieving two primary objectives:

1. Firstly, the goal was to listen to and consolidate the perspectives of participants regarding the watershed's outlook. In pursuit of this, local scenarios were presented and discussed with stakeholders in each workshop. These scenarios were validated based on the realism of each defined statement and their relevance within the basin's context. This analysis took into consideration all components of the nexus and their interrelationships.
2. The second objective focused on identifying potential mitigation and adaptation solutions in response to various changes that could arise in the basin. These changes could result from external conditions, alterations in socio-economic policies, or even a paradigm shift in society, all of which were linked to the key challenges identified in Workshop 1.

Through these exercises, modified scenarios were obtained, validated, and characterized for their relevance, realism, and adaptation to the diverse contexts within the basin and the system. This comprehensive approach ensures that both the scenarios and proposed solutions are robust and applicable to the specific complexities of the basin, with the added capability of being simulated in the available models.

The outcome of these exercises is described in Deliverable 6.3

5.3 Assessing scenarios with river basin model

For assessing scenarios, two different models are employed for each case study at the basin level: a hydroeconomic model and a system dynamics model. These models serve as essential tools to assess interactions between nexus components and economic variables within the basin, both quantitatively and qualitatively.

Initially, simulations are conducted using both models (targeting different indicators) to establish the project's baseline, providing an approximation of the current dynamics of the system.

This baseline serves as a starting point for modeling local scenarios that, as mentioned earlier, undergo rigorous validation and co-production with stakeholders. Through this approach, noteworthy variables have been identified that were not considered in the baseline but are crucial for the analysis of local scenarios.

These additional variables are derived from stakeholder discussions and have been cross-referenced with available literature, along with the knowledge and experience of the modeling team.

Modeling these local scenarios enables researchers to compare system behavior under various circumstances, encompassing changes in policies and social paradigms. This methodological rigor enhances their ability to understand the potential consequences and adaptive responses of the river basin to different changes, thereby contributing to a comprehensive and realistic assessment.

6 Local socioeconomic and land use scenarios: Zambezi case study

Authors :, S. Sinclair (ETHZ), P. Burlando (ETHZ), André Müller (Adelphi)

with a contribution from D4.1: POLIMI (Wyatt Arnold, Andrea Ficchì, Matteo Giuliani, Paolo Gazzotti, Giorgio Guariso, Matteo Sangiorgio, Andrea Castelletti)

6.1 Overview of the methodology

In the Zambezi Watercourse, river basin and local development scenarios[2] will be derived and assessed using an interdisciplinary approach that mobilizes (i) stakeholders' knowledge and expertise (through the Dialogues), (ii) scientific data sets derived from external studies and global models and (iii) the use of a two stage model simulation strategy, coupling a strategic system optimization model (MORDM) with a high resolution hydrological model (TOPKAPI-ETH) through a common set of optimal system operation policies (reservoirs, and irrigation allocations).

The approach for this case study focuses on refining and later simulating an existing set of high-level basin development scenarios developed by ZAMCOM as part of the Strategic Plan (ZSP) for the Zambezi Watercourse 2018-2040 (ZAMCOM, 2019). This ZSP aims to maximize value for the riparian countries, aligning with their interest in optimizing and building upon scenarios previously developed through a broad stakeholder engagement process.

The overall approach is graphically depicted in Figure 37 and the main components of stakeholder interaction, and scenario simulation described in sections 6.2 and 6.3.

[2] We refer to these as development scenarios to distinguish from the Shared Socioeconomic Pathways derived global forcing scenarios developed in WP2 (GoNEXUS D2.1, 2022).

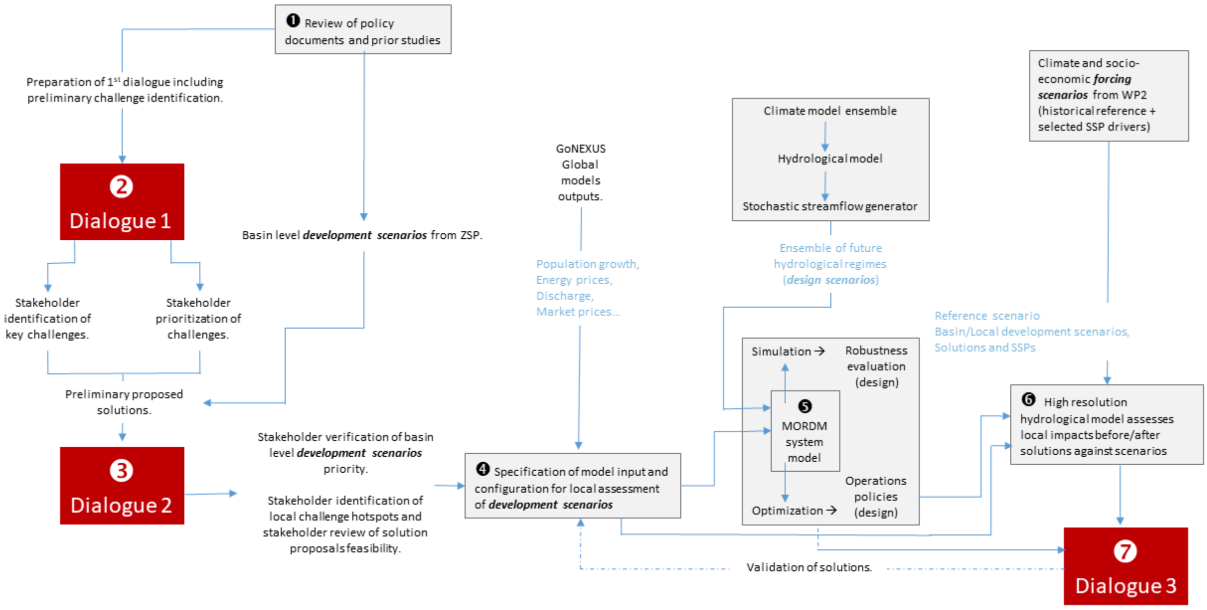


Figure 37 : Overview of the inter-disciplinary approach used to develop and assess scenarios in the Zambezi Watercourse case study.

6.2 Developing scenarios with stakeholders

6.2.1 Step 1: Assess existing basin status and development policies

In an extensive consultation process ZAMCOM (2019) undertook the following steps for the basin development scenario building:

- Explored 500 development scenarios based on a range of projects, priorities, and constraints
- Narrowed down the selection to seven preferred development scenarios
- Combined seven strategic development scenarios into one single scenario
- Developed basin investment scenarios to guide decision-making

The starting point for Dialogue 2 is with the seven development scenarios (ZAMCOM, 2019). They will be discussed and further refined during Dialogue 2, in order to translate them into model configurations, policy options and forcing scenarios[3] that will be used to explore by models possible local and technical solutions to the challenges, which are in line with the seven ZAMCOM development scenarios. These are:

- **Energy Security** – maximizing marketable firm energy from hydropower
- **Food Security** – maximizing calorie production to achieve the highest potential for food security, primarily through expansion of irrigated agriculture
- **Maximize Economic Benefits** – maximizing the net present value of the combined revenues from firm hydropower and irrigation expansion
- **High Environmental Flows** – a constrained maximization that reflects water allocation to maintenance of in-stream flows for ecosystems, and the maintenance of healthy wetlands, but with low allocations to flood and delta protection

[3] Compared to the Development Scenarios, the future forcing scenarios are based on global climate and socio-economic pathways.

- **High Delta and Flood Protection** – a constrained maximization with high allocations to delta and flood protection, but low allocations to instream and wetland ecosystem preservation
- **Moderate Environment and Delta/Flood** – balanced but moderate allocations to instream ecosystems, wetlands, flood, and delta protection
- **Ambitious Environment and Delta/Flood** – balanced by ambitious allocations to instream ecosystems, wetlands, flood, and delta protection.

6.2.2 Step 2: Stakeholder consultation at Dialogue 1

Stakeholders were brought together in a two-day workshop (Dialogue 1) in Harare, Zimbabwe, on 12-13 October 2022. The main goals of Dialogue 1 were a) introduce the GoNEXUS project, approach and objectives; b) understand the interests, concerns and perspectives of Dialogue participants; and c) explore and prioritize nexus challenges in the Zambezi Watercourse.

The highest priority challenges identified to be carried forward at Dialogue 1 and assessed in the context of the seven basin development scenarios identified by the ZAMCOM strategy plan (section 5.2.1) at the 2nd Dialogue (section 5.2.3) were:

- Flooding
- Droughts

Other challenges considered by stakeholders as highly important include:

- Land use conflicts
- Water scarcity
- Soil erosion
- Energy and water trade-offs
- Ecosystems health

6.2.3 Step 3: Stakeholder consultation at Dialogue 2

Stakeholders will be brought together in a two-day online workshop (Dialogue 2) on 13-14 March 2024. Here, the GoNEXUS team will interact with the stakeholders through the process outlined below to refine the strategic development scenarios e.g. in case of new information or priorities, as well as to define solutions targeting the key challenges identified in Dialogue 1. The refinement will start from some pre-developed examples to stimulate the discussion and will aim to agree on locally specific solutions and related model indicators for assessing the success of solutions in addressing challenges.

The scenario building exercise focuses on previously co-defined nexus challenges in Dialogue 1 using model outputs that depend on modelling maturity at the time of the Dialogue 2 and that describe the impacts for the reference scenario and for some preliminary future global forcing. Accordingly, stakeholders will address in Dialogue 2 the challenges listed in Section 5.2.2 that emerged at Dialogue 1.

Key aspects to be refined for each of the development scenarios during Dialogue 2 are:

- Locally impacted hotspots through key challenges and local or basin/sub-basin scale solutions
- Boundary "conditions" and assumptions / factors of change
- Indicators to assess WEFE nexus challenges and solutions

Dialogue 2 will be organised through three main sessions, as described here below.

Session I: Approach to refinement of ZAMCOM Strategic Development Scenarios (2019), e.g. with focus on floods and droughts (other challenges will be addressed in the same way)

Main Goal: Define local flood and drought impacted hotspots for each Strategic Development Scenario

Presentation:

- Introduce scenario building exercise, objectives and methods and provide overview on strategic development scenarios
- Present example modelling results for impacting strategic development scenarios (incl. climate impacts and SSPs), particularly regarding influence on floods and droughts to the extent model results are available at the time of the Dialogue 2

Group exercise:

- Reflect on relevant developments affecting each scenario, main assumptions, narratives, boundary conditions, concerning the scenario in the light of the impacts of climate / SSP forcing
- Define relevant hotspots in each scenario from perspective of future floods and droughts impacts and possible socio-economic and ecological knock-on effects: How could these places be affected?
- Test robustness of scenarios by looking at risks and opportunities: How resilient are the strategic development scenarios in the wake of future forcing? (e.g. using matrix with 3-5 criteria)
- Explore relevant metrics for each local hotspot needed for the modelling scenarios (starting basis for session on indicators)

Group presentations & discussions:

- Facilitate discussion on different strategic development scenarios, collecting additional information from all participants to complement them

Session II: Solutions to adapt to future forcing and/or to mitigate impacts of future forcing

Besides the scenario building, Dialogue 2 will also assess nexus solutions and indicators together with the participants, both of which are relevant for the scenario building.

Main Goal: Define relevant local flood and drought related solutions for hotspots in each strategic development scenario

Presentation:

- Summarise preliminary solutions for each scenario from Dialogue 1 and research incl. conclusions from the former EU project "DAFNE" (Start of from hotspots and challenges)

Group Work:

- Explore different types of solutions for the prior defined hotspots in each of the scenarios in relation to floods and droughts (incl. opportunities and trade-offs)
- Select high-potential solutions and evaluate key strengths

Discussion & Ranking:

- Present relevant solutions for each scenario and their key strengths (and perhaps weaknesses)
- Facilitate discussion on solutions, their strengths and weaknesses, redundancies, computability, local feasibility (where are they applicable, where not?)
- Agree on 3-5 priority solutions (out of all solutions selected by groups) in final step

Session III: Refinement/expansion of indicators

Main Goal: Define locally relevant flood and drought related indicators for hotspots in each Development Scenario

Presentation:

- Explain exercise and give small intro on indicators: What are they and why are they relevant for modelling exercise
- Share preliminary list of indicators (D5.1)
- Explain the use of criteria for indicators selection

Group Work:

- Continue exploring quantitative assumptions (from scenario building) and identify suitable local indicators to evaluate challenges and the impact of solutions
- Prioritise important indicators for each scenario
- Evaluate the suitability of indicators (e.g. on aspects such as data availability or computability)

Reflection:

- Groups hold a brief presentation on indicators to the other groups
- Other groups / moderators raise questions or add details

Following Dialogue 2, the case study team will synthesise and process the inputs and questions gathered at Dialogue 2.

6.3 Simulating scenarios

6.3.1 Step 4: Local (development) scenario specification

The previous steps function as the basis for designing and running the full set of model runs that include solutions. Specification of model input and configuration including local solutions representative of the selected development scenarios derived from stakeholder interactions at both dialogues, as well as other efforts within the project (e.g. the definition of global forcings such as SSPs scenarios and their prioritisation) are combined in this step.

6.3.2 Step 5: MORDM strategic system optimization

The strategic design model is intended to optimize bulk water trade-offs in the basin for the selected strategic development scenarios. In conjunction with an energy system model the POLIMI team also evaluated energy trade-offs of implementing floating solar voltaic generation in the major reservoirs to complement hydropower generation (Figure 38 and Figure 39). Full details of this modelling exercise are not repeated here, but described in GoNEXUS D4.1 (2023). The outcome was a set of systems operation policies targeting different objectives related to the different components of the nexus, which will be further analysed after Dialogue 2 in relation to the selected strategic development scenarios.

As outlined in the methodology sketch of Figure 37, a further robustness analysis of the operations policies against future stochastically generated streamflows under climate change was carried out to develop confidence in the optimized policies. The related outcome will be an additional element that Stakeholders will have available to discuss and select solutions.

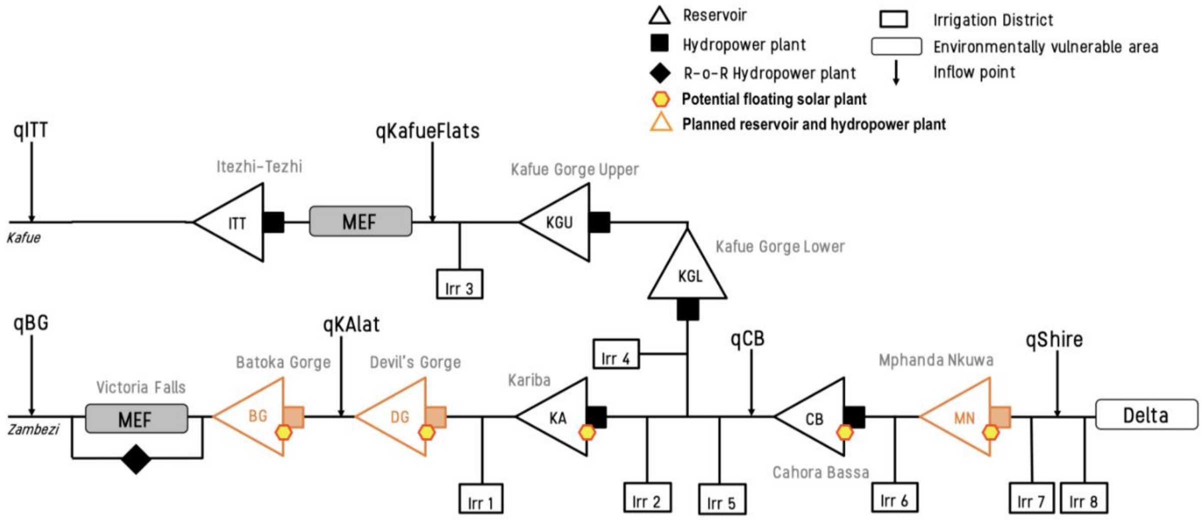


Figure 38 : Schematic of Zambezi Design Simulation-Optimization Model (after GoNEXUS D4.1, 2023) including the three planned reservoirs and potential floating solar installations. Minimum environmental flows (MEF) are enforced at Victoria Falls and below Itezhi-Tezhi reservoir at Kafue Flats.

6.3.3 Step ❻: High-resolution local impact assessment

In order to assess the impacts of forcing scenarios and evaluate the effectiveness of solutions at multiple hotspots around the basin, this step employs the high-resolution spatially distributed hydrological model TOPKAPI-ETH. The operation of bulk water transfers with TOPKAPI-ETH will be based on the optimal operations policies designed in step ❺ of the previous section 6.3.2and disaggregated in space to assess impacts at the scale of the hotspots identified in Dialogue 2. The climate and socio-economic forcing will be those derived in GoNEXUS D2.1 (2022), while the infrastructural configurations, assessment measures (indicators) with relevant ranges will be informed by the development scenarios. The solutions implemented in the high-resolution local impact assessment are the outcome of step ❸ (Section 6.2.3). As before the reader is referred to GoNEXUS D4.1 for a more detailed outline of the modelling strategy.

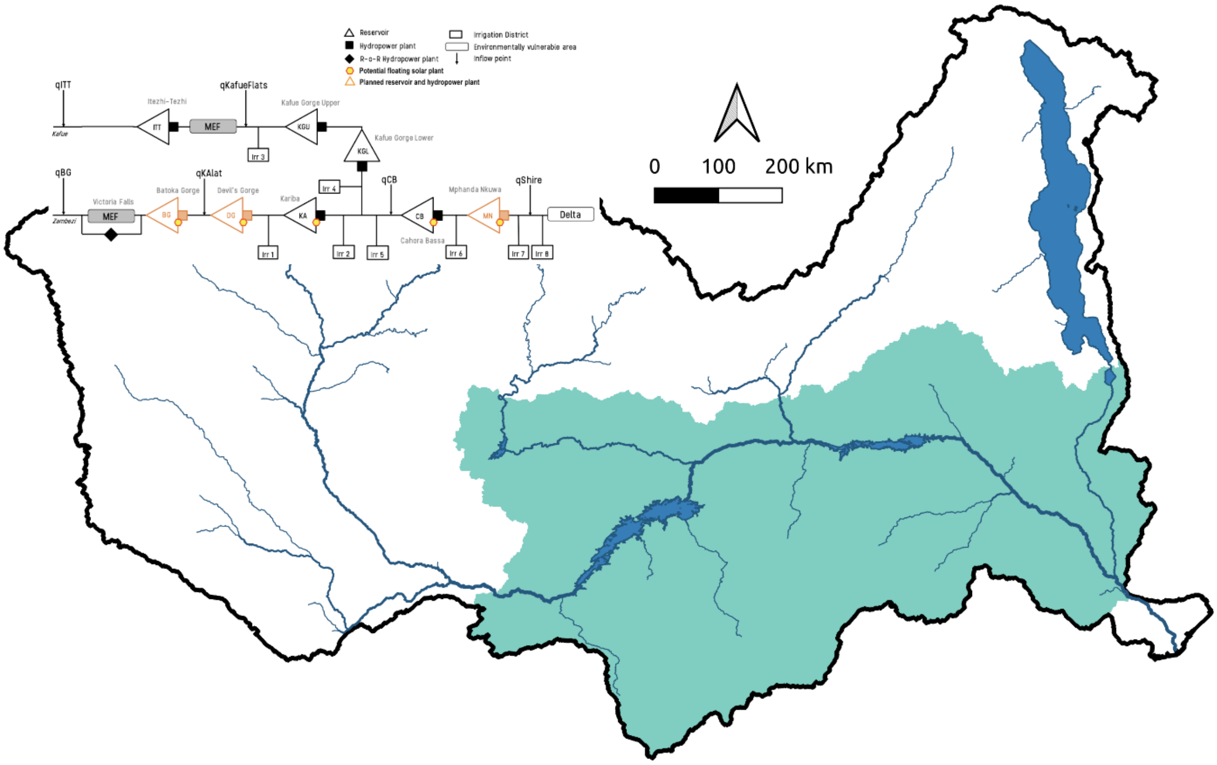


Figure 39 : An illustration of the implementation of MORDM designed infrastructure timing into the TOPKAPI-ETH model of the Zambezi Watercourse.

6.3.4 Step 7: Presentation and validation of scenario simulations and solutions at Dialogue 3

At the 3rd Dialogue, the full simulation results under all scenarios and forcing, both with and without solutions will be presented. The goal is to discuss and validate with the local stakeholders the main outcomes and solutions to address WEFE challenges in the basin. The validated and feasible solutions are to be carried forward as recommendations from the GoNEXUS team.

7 Local socioeconomic and land use scenarios: Danube river basin case study

Authors : Rens van Beek (UU)
with a contribution from:
János Fehér, Beáta Pataki (FAMIFE)
and Guido Schmidt (FT)

7.1 Overview of the methodology

The Danube River Basin (DRB) is the most international river basin on the Earth as 19 countries share the area of the basin. The Danube River Basin shows a tremendous diversity of habitats through which rivers and stream flow including glaciated high mountains, forested midland mountains and hills, upland plateaus and through plains and wet lowlands near sea level. Therefore, the basin is a challenging area from water management point of view. Due to its large extent from west to east, and diverse relief, the Danube River Basin also shows great differences in climate.

Climate change is the dominant factor driving a change in water resources in the Danube River Basin. The water, energy, food and ecosystem nexus in the region is highly dependent on water which is under significant pressures from pollutions by organic substances, pollutions by nutrients and hazardous substances, hydromorphological alterations, quality and quantity of sediment, invasive alien species as well as diffuse pollution on groundwater. Agriculture is the major water user in the basin, followed by domestic and industrial uses. A large number of small and medium size hydropower plants exists in the western part of the Danube Basin on both the main river as well as on smaller tributaries. In addition to climate change, other drivers that influence the water nexus are demographic changes, changes in agriculture (CAP, Farm To Fork), and changes in energy production (Green Deal targets).

Among the case studies in the GoNEXUS project, the Danube River Basin discerns itself by its size and the wide range of landscapes and the governmental and administrative units it encompasses. Moreover, a substantial part of the Danube River Basin is located within the European Union which imposes an additional layer of EU policies and regulations.

In the development of the local scenarios three steps were used that are linked to the three dialogues as outlined in Figure 40. As outcome of the first dialogue three main challenges for the Danube River Basin Case Study were identified that are listed here below.

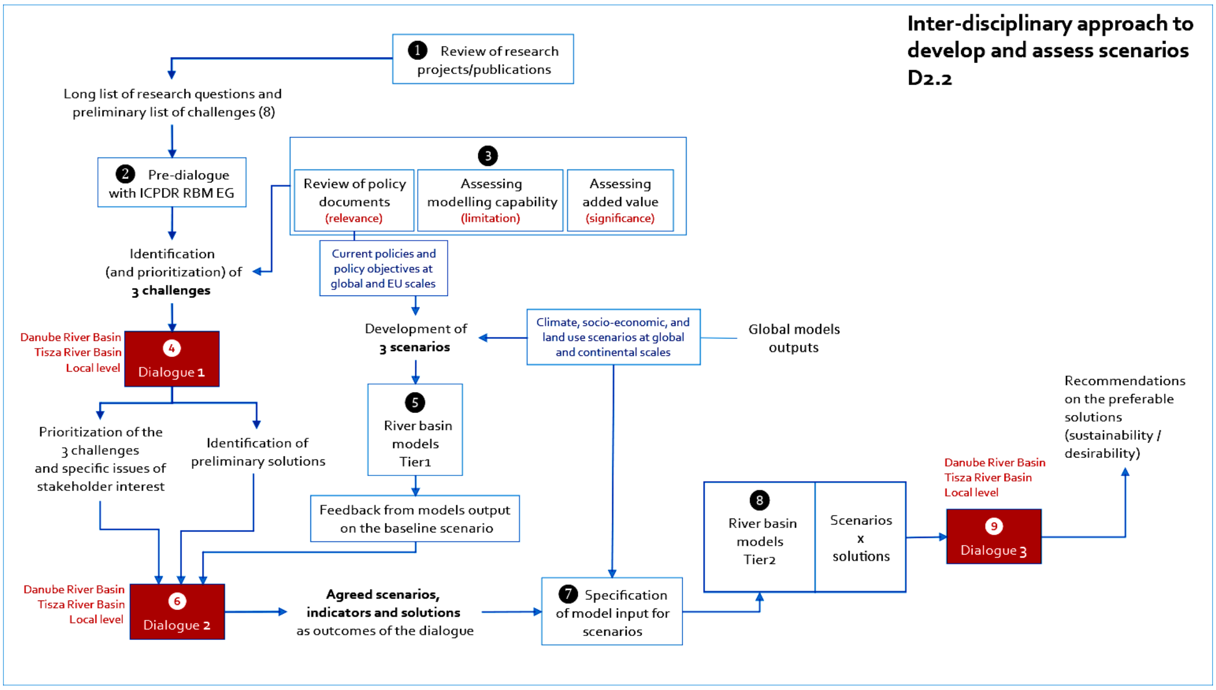


Figure 40 : Flow chart into the development of the local scenarios

The Danube River Basin Case Study identifies areas of interest at three spatial scales: (1) the river basin of the Danube as a whole; (2) the regional sub-basin level of the Tisza and (3) the local level, each requiring more detailed information.

For each of these levels, dialogues were held with stakeholders and the information compiled. Prior to these meetings, three challenges related to the impacts of climate change on the Water-Energy-Food-Ecosystem Nexus were defined (Figure 40., block 1, 2 and 3). The identification processes consisted of several steps in two phases as they are shown in Figure 41.

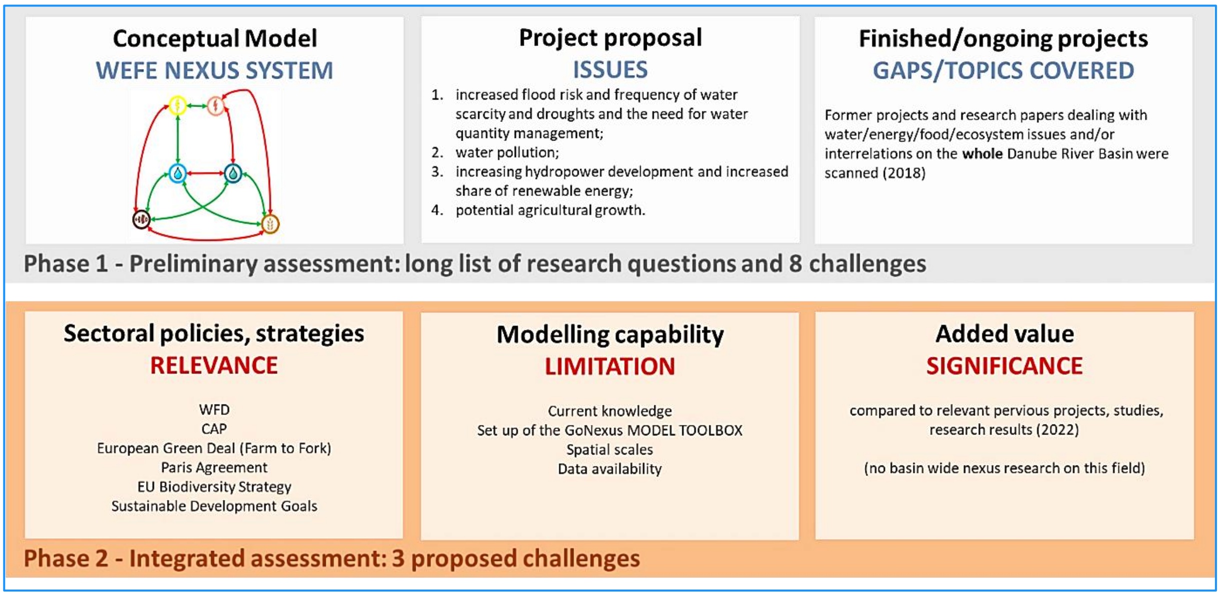


Figure 41 : Identification phases of WEFE challenges in the Danube Basin Case Study

Taking into account the WEFE nexus concept and the application goals of the GoNEXUS project, we conducted an extensive literature review of the WEFE challenges affecting the watershed. During the 1st phase assessment, we identified 8 significant challenges. In the 2nd phase assessment, the 8 challenges identified in advance were further evaluated according to the aspects of relevance (sectoral policies, strategies), limitation (modeling capacities) and significance (added value).

As a result, we identified 3 main challenges within the framework of the Danube Basin Case Study:

- Challenge 1: **Water scarcity and increased flood risk** due to climate change, which may require changes in land management. (*As a consequence of climate change and dramatic changes in land management, there are quite significant changes in surface runoff, water retention and storage, hence floods and water scarcity. These changes are going to influence the recent land management practices.*)
- Challenge 2: **Water scarcity due to growing irrigation demand** as a consequence of a warmer and drier climate. (*Agriculture is the major water user in the basin. In addition to climate change, other main drivers that influence the water nexus are the demographic changes and changes in agriculture (CAP, Farm-To-Fork). The pressure is increasing on water-intensive energy and food producers to look for alternative approaches due to the growing demand, particularly in water-scarce areas with large inter-sectoral competition for water.*)
- Challenge 3: **Vulnerability of riverine and terrestrial ecosystems (biodiversity)** due to water scarcity and land use changes driven by agriculture and energy. (*Agriculture and increasing energy demand transform(ed) the natural habitats and might need even more area and water for secure production, which can have direct and indirect impacts on rivers and land ecosystems. Water scarcity has direct and indirect impact on floodplains/wetlands, especially along freshwater bodies used for irrigation as well as the hydropower development has negative impact on the longitudinal connectivity of the water bodies, hence the ecosystems.*)

In the first round of dialogues, we proposed to the stakeholders to discuss the identified challenges and asked them to set priorities among them. The 1st dialogues (basin level, sub-basin level and local) did not show a clear preference to rank these objectives but the tendency is that on biodiversity vulnerability (Challenge 3) and that on hazards (Challenge 1) had a slight preference over that on water scarcity (Challenge 2). Whether Challenge 1 or Challenge 3 is more preferred varied, with Challenge 1 being preferred at the local level, Challenge 3 at the river basin and sub-basin level.

After this first round of dialogues, stakeholders expressed a desire to obtain scientific information from modelers involved in the project on the potential consequences of global change on their basin. This leads the Danube basin team to adopt a slightly different approach from other case studies, consisting in focusing on the assessment of a non-action scenario, which would serve as a basis for discussions in dialogue 3. Solutions i.e. adaptation) would then only be discussed in a third scenario.

7.2 Description of existing scenarios

This sections describe how the existing models are run to develop a scenario that will be presented in the second series of dialogues.

7.2.1 Climate

Because of the size of the Danube River Basin, simulations for the entire river basin will be performed at 5 arc minutes, the same resolution as the global simulations of WP3. Emphasis is placed on the hydrological trade-offs within the WEFE nexus as simulated with the large-scale hydrological model PCR-GLOBWB 2.

For the second dialogue, the results from the Tier 1 simulations of WP3 will be used. These results cover global scenarios in which the historical period is followed by three SSP-RCP combinations, being SSP1 – RCP 2.6, SSP3 – RCP 7.0 and SSP5 – RCP 8.5. Climate scenarios have been retrieved from ISIMIP3b (Inter-Sectoral Impact Model Intercomparison Project) and provides high resolution data (~50km) for five GCMs (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, and UKESM1-0-LL) and include future projections as well as the historical reference period, spanning 1961-2100. Globally reconstructed historical weather data have been taken from the GSWP3-W5E5 forcing of the ISIMIP3b.

7.2.2 Land use and socio-economic change

Land use change and water demand have been developed on the basis of the IAM IMAGE 3, developed by the Netherlands Environmental Assessment Agency (PBL) for the three SSPs linked to the climate change scenarios of the RCPs (SSP1, SSP3 and SSP5). Land cover changes are prescribed by changes in crop type and the extent of rainfed and irrigated crop land and pasture at 5 arc minutes and by changes in other land cover types (e.g., forest) at 30 arc seconds. This information has been blended into relevant land cover parameterization of PCR-GLOBWB 2 and used as a basis for the simulations.

In addition to land use changes, water demand has been included in the simulations. Non-irrigation water demands are imposed as an external forcing to PCR-GLOBWB 2 and comprise domestic and industrial water use and livestock. Irrigation water demand is calculated by the model on the basis of the extent of the irrigated area, crop mix, irrigation efficiency and climate and varies per scenario accordingly.

Other socio-economic variables are available as input or output of IMAGE 3; these are not explicitly considered in the preparation of the existing Tier 1 scenarios but can be included or replaced by relevant inputs to finetune local scenarios. Relevant variables comprise (*D* denotes drivers, *S* denotes spatial, i.e, gridded information, and * identifies post-processing, meaning the information is derived from the output of IMAGE 3 but not used by the coupled modules of the IAM)[4]:

- GDP (*D*)
- Population (*D, S**)
- Energy consumption
- Electricity production
- Water demand and consumption (S)
- Land use and land cover (S)
- Access to water (*)
- Fraction of population served by piped water (in major cities) (*)

7.3 Simulating scenarios

Tier 1 model results

In total 21 simulations have been performed as part of Tier 1 of WP3 and include:

- 1 simulation of the reconstructed historical climate of the GSWP3-W5E5 covering the period 1960-2019;
- 5 simulations using the five GCM members of the ISIMIP3b experiment, covering the historic period 1960-2014;
- 3 x 5 simulations comprising simulations for the three SSP-RCP combinations with the five GCM members, covering the period 2015-2100.

Model results from PCR-GLOBWB (UU) comprise a large number of hydrological variables that are mapped at 5 arc minutes and that are available over the period 1960-2100 at monthly and yearly resolutions. Broadly these model results can be subdivided into three broad categories in addition to the input data from the scenarios:

- Soil hydrology, including groundwater, at cell level;
- Water demand and withdrawal data per sector (domestic, industrial, livestock, irrigation) and per source (surface water, renewable groundwater, non-renewable groundwater and desalination);
- Surface water hydrology including discharge, water levels and water body storages (lakes, reservoirs).

In addition to the hydrological information, information is available from the agricultural model CAPRI of UPM, PROMETHEUS – PRIMES (E3-modeling) and GLOBIO (PBL) pertaining to the food, energy and ecosystem components of the WEFE nexus. These model results form the basis of the combined modelling of the WEFE nexus in Tier 2 of WP3 and both this information as well as the combined results can form the basis for the local scenarios for the Danube River Basin Case Study.

4 see Deliverable 2.1 for details

Information from the scenarios can be summarized per scenario and aggregated over space and time. As examples, time plots of the air temperature, precipitation and discharge at gauging stations (Figure 42 to Figure 44).

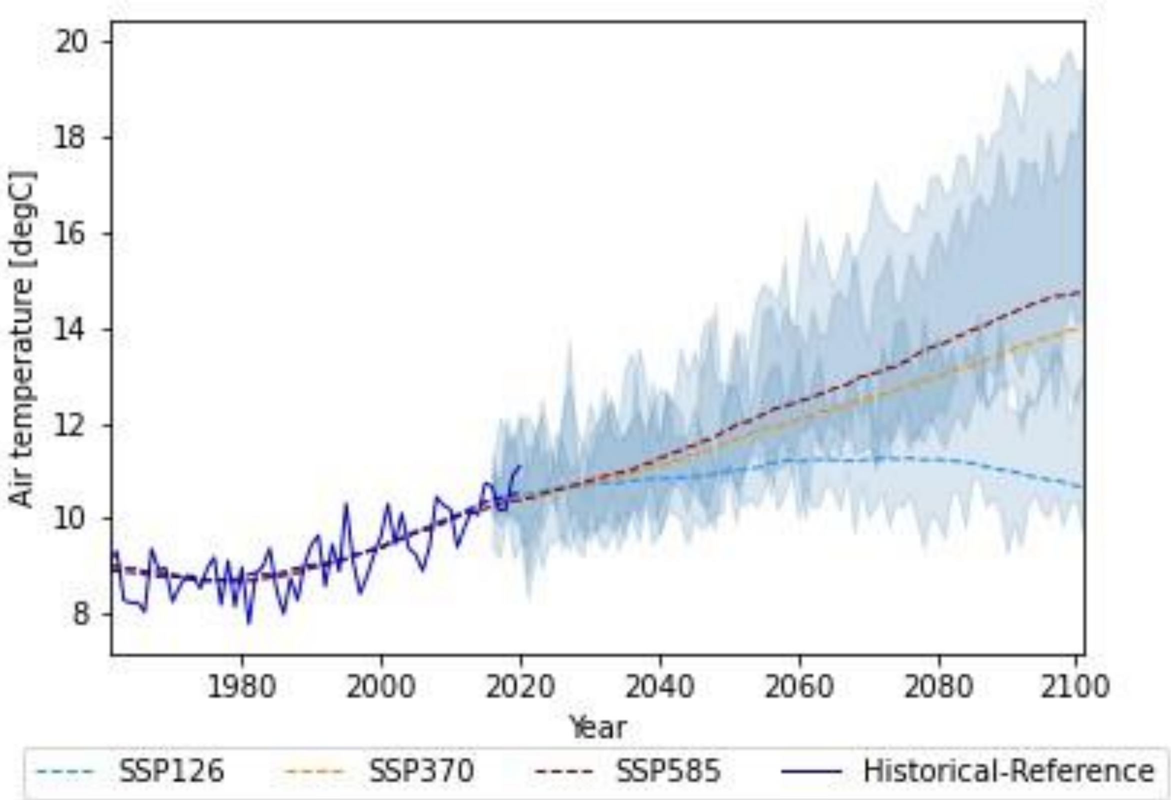


Figure 42 : Figure 3: Air temperature, yearly mean over the Danube River Basin
(Note: solid lines show the values of observed historical climate (Historical-Reference) as well as the median of the results of the five GCMs per SSP-RCP combination. The shaded area represents the range between the minimum and maximum across all five GCMs, the dashed lines represent the 30-year central running mean.)

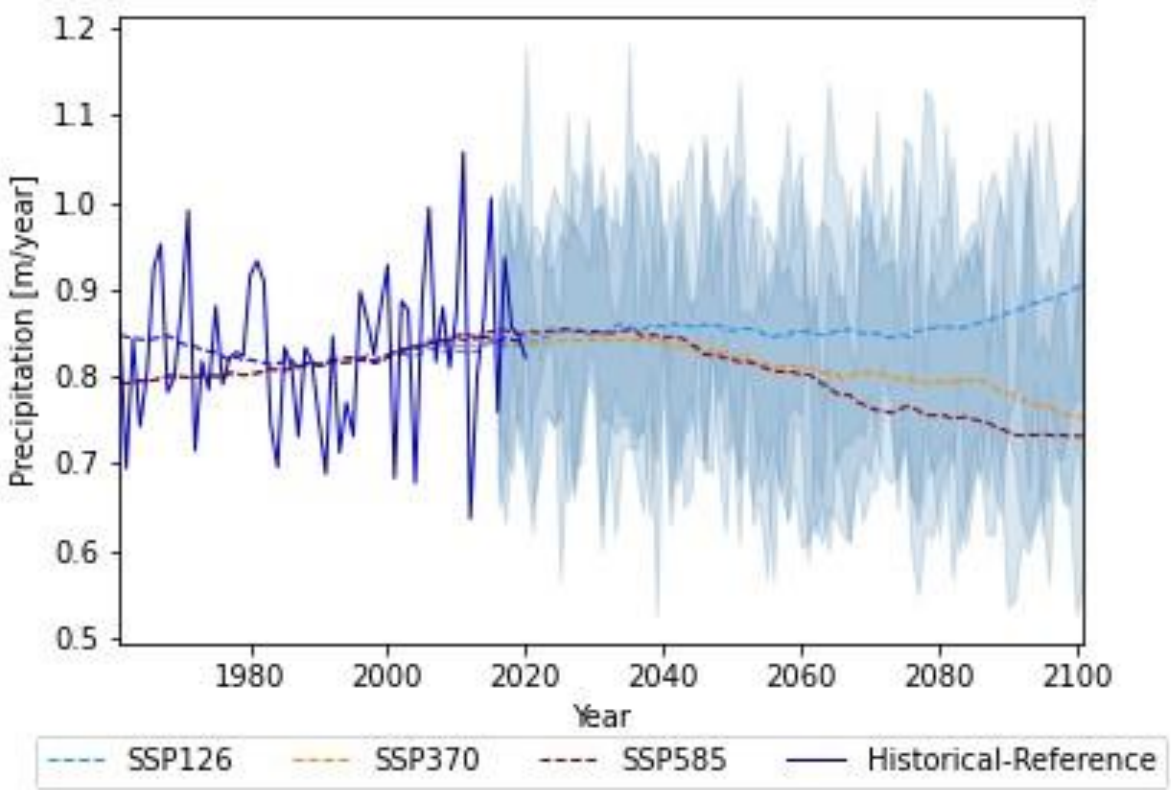


Figure 43 : Precipitation, yearly total over the Danube River Basin.
(Note: See Figure 38 for explanation.)

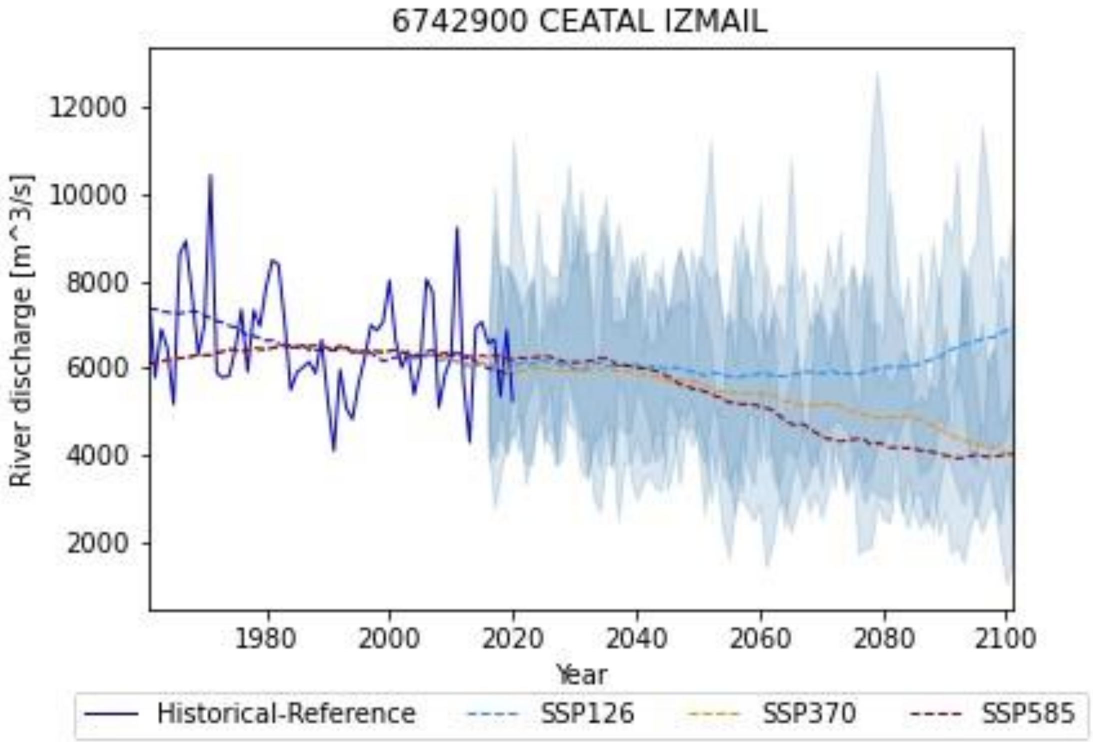


Figure 44 : River discharge, yearly mean at the station of Ceatal Izmail near the mouth of the Danube.
(Note: See Figure 38 for explanation.)

In addition to time series, results can be summarized to get statistics, such as the flow duration curves (Figure 45 : 41) and the total water demand (Figure 45).

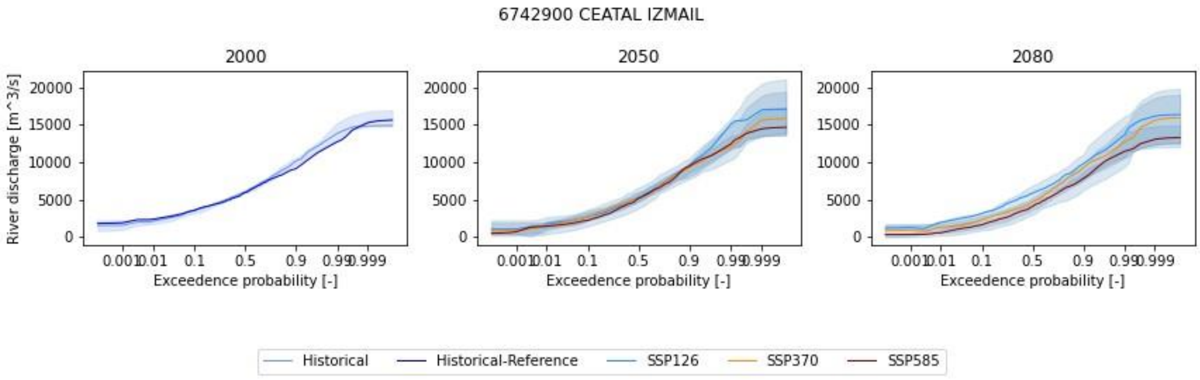


Figure 45 : Period-of-length flow duration curves (FDC) of the monthly river discharge (Note : Drawn lines are the median value from the five GCM members of each scenario. The shaded area show the range between the minimum and maximum FDC. The periods are based on 30-year normal periods, centred on the year indicated.)

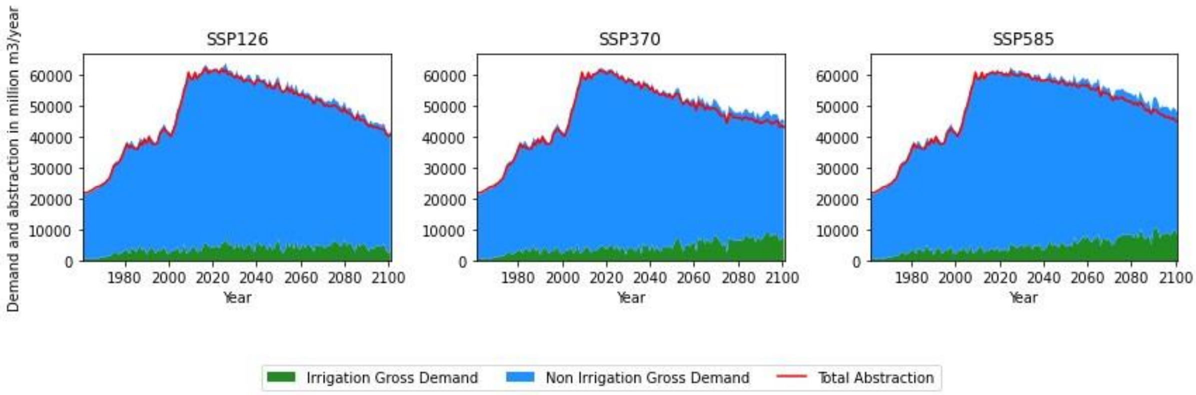


Figure 46 : Total water demand and abstraction for the Danube River Basin

(Note : Water demand is split between the water demand for irrigation and for non-irrigation purposes (livestock, domestic, industrial). Where the total abstraction is below the total demand, a water gap exists and the demand is not met.)

The scenarios show some interesting trends for the projections into the 21st century. First, the air temperature increases, leading to a larger evaporative demand, but the precipitation does not follow. There is some evidence for the intensification of the hydrological cycle but overall the tendency is that the Danube River Basin as a whole will become drier. Hence, low flow events will become more common but occasionally high-flow events above the current expected levels could occur. This creates additional challenges to navigation on the Danube and its tributaries. In terms of water demand, the overall tendency is for the irrigation water requirements to increase whereas the non-irrigation water demand decreases after 2030 as a result of decreasing population size and more efficient water use (Figure 46). The rate of decrease of the three scenarios, however, varies and reflects the narrative of the three SSPs used. Furthermore, the increase in irrigated water demand is larger for those SSPs that are combined with the more extreme RCPs. This reflects both the increase in irrigated area as well as the stronger drought signature, leading to greater irrigation water requirements per unit area of irrigated land. As a result, the water gap intensifies, increasing from almost imperceptible under the present-day conditions to an average of around 5% in 2080 for SSP5-RCP8.5. Overall, the developments in the results indicate that the scenarios will start to deviate more after 2050, with an overall drying for SSP3-RCP7.0 and SSP5-RCP8.5 and with a larger variability compared to SSP1-RCP2.6. These findings are largely consistent with the three challenges identified before.

7.4 Downscaling scenarios towards local scenarios

As part of the second dialogue, local scenarios will be presented and adapted to meet the concerns of the stakeholders involved. The global trends underline the major concerns and suggest both increased demands, with a consistent and relatively large increase in the irrigation water demand, an intensification of water scarcity and a larger climatic variability that reduces the reliability of the available water resources.

In relation to the challenges and reflecting on the questions that were raised by the stakeholders during the first round of dialogues, the following points are taken into consideration:

7.4.1 Effect of climate change on flood risk and water scarcity:

In addition to the CMIP6 climate change scenarios of ISIMIP3b, the more detailed (~11 km, 6 arc minutes) Coordinated Regional Climate Downscaling Experiment(CORDEX) data will be used.

As part of the workshop, the projected climate changes between the two datasets will be compared. All three available RCPs (2.6, 4.5 and 8.5) will be considered in the simulation. Note that the CMIP6 RCPs will be covered in any case by the global simulations in Tier 2 of WP3.

7.4.2 Effect of land use change on flood risk and water scarcity

In this case, SSP3 will be taken as the basis and used to get the projected changes in land cover and land use, as well as the associated water demands. To evaluate the effects, the change in runoff per land cover class will be assessed per sub-basin and for pre-defined periods. In this way, the effect of land cover / land use on the increased water scarcity / flood hazard can be explored locally and the aggregated effect at (sub)basin level assessed.

7.4.3 Water demand and water use per sector

In the local scenarios that will be based on SSP3 socio-economic developments and CMIP5 RCP climate change scenarios, the information on the sectoral water demand and use will be updated. First, industrial water use will be split into manufacturing and the energy demand for thermo-electric cooling. Also, environmental flow requirements can be defined a priori and will be included in the simulation, highlighting areas where river system health may be threatened by overexploitation.

Hydropower generation and the location of additional dams and in-stream turbines will be included in the simulations as well by identifying potential locations and capacity and implementing these in response to the projected energy needs for hydropower. For this, simulations of PRIMES-PROMETHEUS will be used. Similarly, irrigation water requirements will be based on the irrigated area, crop mixes and irrigation water efficiencies from the global projections of IMAGE3 in combination with the simulations of CAPRI of WP3 Tier 1 (envisaged as part of WP3 Tier 2 simulations). This will result in more locally tailored projections and gives the opportunity to develop policy scenarios linked to the *Green Deal* and the *CAP*.

Water withdrawals estimates in the simulations can be modified by the available groundwater pumping capacity. This essentially modifies the propensity of the water withdrawal to the different water resources with propagating effects on hydrological system from the local to the regional scale. Projections are included for the Tier 1 simulations but may be modified to better suit the local projections.

On the basis of the simulations, competition between the different sectors will be analysed and bottlenecks identified. In addition to the standard runs with PCR-GLOBWB also its water temperature component will be run for scenarios with hydropower and thermo-electric cooling water requirements in order to estimate the effect of thermal pollution for ecosystem functions (in combination with GLOBIO). At the moment, no other simulations of water quality are envisaged but simulations with the water quality model DynQual are available that are based on the global scenarios of Tier 1 of WP3.

7.4.4 Vulnerability of riverine and terrestrial ecosystems

Aspects of the effect of water withdrawal on river flow rate and the inclusion of environmental flow requirements were mentioned above. These aspects can be finetuned as part of the local scenarios and evaluated, bridging a first step towards the implementation of solutions, which will be part of the final step in the river basin modelling of GoNEXUS.

7.5 Scenario consistency check and assumption refinement

The second dialogue (Figure 40., block 5) is particularly intended to check the scenarios and their underlying assumptions and the suite of solutions. This means that the second dialogue will be used to query the stakeholders on the following points.

7.5.1 Definition of the local scenarios

It is intended that the local scenarios match the concerns identified in the three challenges. Whether this will be addressed by three unique narratives for the socio-economic developments on which the climate change of the RCPs will be imposed or whether more numerous scenarios are used, is something to develop in consultation with the stakeholders, bearing in mind that the number of possible simulations is limited because of the available resources and computation times.

We intend to develop the three narratives along axes that represent different needs of the challenges and span the actual scenarios within this. These axes are:

- Emphasis on agriculture; in this case a large but realistic area will be taken up by intensive agriculture, including irrigation;
- Emphasis on hydropower, in this case precedence is given to hydropower generation;
- Emphasis on ecology, in which case the priority is to protect vulnerable areas of biodiversity.

Within this space, several combinations can be made that give reasonable narratives for a scenario. For each axis, a division into a low/high category would result in eight scenarios but using four combinations for the first two axes and a high-protection scenario as well as a base line scenario results in a more manageable number of six scenarios (that need to be modelled for different climate conditions). A major step in the second dialogue, therefore, is the presentation of these combinations and soliciting feedback from the stakeholders to update them.

Stakeholders will also be consulted on the nature of the scenarios and the information that is used to create the scenarios eventually. This concerns the plausibility of maps of projected irrigated areas, protected areas (e.g., Natura 2000), dams etc. The outcome of this round of dialogues would be an agreed set of manageable narratives and relevant and vetted information that can be used to define the scenarios as outlined in stage 6 of Figure 40.

7.5.2 Identification of preliminary solutions

To a large degree the narratives predefine the types of solutions that will be considered (e.g. nature-based solutions as wetlands or river floodplain restoration, as part of the axis of ecological protection). However, a set of possible solutions were already identified as part of the model setup[5] for the Danube River Basin Case Study.

During the second dialogue, the nature of these solutions will be discussed and linked to the narratives. On the basis of the model evaluation on robustness and the optimal solutions (Steps 8 and 9 of Figure 1), the third and final dialogue will be organized.

Among others, the following solutions are considered and will be discussed:

- Implementation of protected areas in which certain human activities (irrigation, groundwater pumping etc.) are prohibited;
- Improved irrigation efficiency by considering more drought tolerable crops, increased irrigation water efficiency etc.;
- Environmental flow requirements to ensure river system health;
- Improved reservoir operations to mitigate the downstream impact of dams or restricted dam allocation;
- Prioritization of water withdrawals on the basis of sectoral demand;

[5] WP4_Danube_River_Basin_Case_Study_Model_Strategy.docx

- Improved water use efficiencies (other sectors than irrigation).

This list is not exhaustive but gives possible directions to consider and link to the narratives.

7.6 Intended outcome of the second dialogue

Preliminary scenarios have been drawn up as part of Tier 1 and Tier 2 of WP3 that can be amended to meet the requirements for the simulation of the Danube River Basin Case Study.

In preparation of the second dialogue, the Tier 1 results will be analysed and presented as well as the narratives linked to the challenges. To clarify the procedure to go from the narratives to actual local scenarios, one case (proposed: irrigated agriculture) will be developed, run and analysed prior to the presentation and linked to solutions. This information will be distributed among the stakeholders in advance and used to define a number of questions to be discussed during the dialogue meetings. All in all, this should result in the following at the end of the second dialogue:

1. A set of narratives to use as the basis for the local scenarios;
2. A background document of the views of the stakeholders to validate the assumptions that underpin these scenarios;
3. A list of solutions to be incorporated / evaluated with each scenario;
4. An updated list of indicators / guidelines on data presentation to be used for further analysis of the model results of the Danube River Basin Case Study.

References

GoNEXUS D2.1 (2022) Global and continental climate and land use scenarios, Lead by CMCC, Daniele Peano, Rens van Beek, Berny Bisselink, Hector Macian-Sorribes.

GoNEXUS D4.1 (2023) Final Synthesis on River Basin WEFE Models, Lead by POLIMI, Wyatt Arnold, Andrea Ficchì, Matteo Giuliani, Paolo Gazzotti, Giorgio Guariso, Matteo Sangiorgio, Andrea Castelletti (POLIMI); Hector Macian-Sorribes, Manuel Pulido Velazquez, Amparo Martinez-Domingo UPV); Adrian Gonzalez-Rosell (UPM); Scott Sinclair, Dennis Eberli, Matthias Häfliger, Luca Franzetti, Anna Costa, Paolo Burlando (ETHZ); Janos Feher (FAMIFE), Rens van Beek (UU).

Ouedraogo R, Seguin, L, Bruckmann, L (2022) Perceptions des acteurs sur le nexus Eau-Energie-Alimentation-Ecosystèmes dans le bassin du fleuve Sénégal. Rapport BRGM/RP-72354-FR. Brgm : Orléans. Available at : http://ficheinfoterre.brgm.fr/document/RP-72354-FR

ZAMCOM (2019) Strategic Plan for the Zambezi Watercourse, Zambezi Watercourse Commission (ZAMCOM), Harare.

Annexes

Annex 1: Narrative story line for Senegal river basin scenarios

Annex 2: Narrative story line for Segura river basin scenarios

….

Annex 1: Narrative story line for Senegal river basin policy scenarios

The following texts are English translation of the storyline presented and discussed with stakeholders during the second dialogue in Senegal.

Scenario 1

1

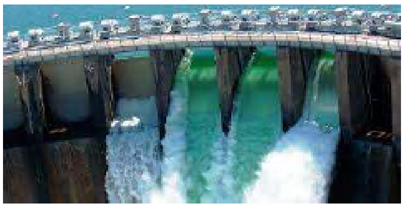
le soleil

June 25, 2045

Inauguration of the Balassa dam, symbol of the ambitious economic policy of OMVS member countries

Yesterday, in Fouta-Djalon, Guinea, the Guinean Prime Minister, Mr Camara, inaugurated the commissioning of the Balassa dam, in the presence of his Senegalese, Malian and Mauritanian counterparts, and the OMVS High Commissioner. This inauguration marks the end of a gigantic works program initiated by OMVS nearly 20 years ago, which has enabled riparian countries to strengthen their energy and food security. Not without significant social cost.

The event is historic. At the foot of the immense reinforced concrete wall, the four heads of government of the OMVS member countries shake hands after cutting the ribbon, and take turns at the podium to celebrate the mastery of water, the fuel of the economy. *"This inauguration is the culmination of twenty years' work,"* Mr Camara reminds us. The Balassa dam is the latest of 12 dams built in the upper basin over the last few decades, 70 years after Manantali. *"Let's not forget that they were initiated shortly after the Ukrainian crisis in the 1920s. At that time, the instability of energy and food markets had made our predecessors aware of our vulnerability due to overdependence on the rest of the world. Clear-sighted, our leaders of the time understood that only better control of our water resources would enable us to become more resilient. Today, we have done that".*



Dams have enabled a considerable increase in hydroelectric production, reducing oil imports, improving the country's trade balance and stimulating growth thanks to cheap energy. Dams have also boosted agricultural production, securing the water supply for large public irrigation schemes and enabling the development of private irrigation schemes, which have proved highly productive. Today, more than 300,000 hectares of land in the valley have been developed for irrigation.

"Today, almost 50% of food production in the Senegal River basin comes from this new intensive agriculture," explains Mauritania's Minister of Agriculture, Mr. Mohammed. *"This production has enabled us to reduce our food dependency: imports now represent only 30% of our needs, and in the event of a crisis we could easily transform export crops into food crops and become self-sufficient".*

The success of this ambitious policy highlights the exceptional quality of inter-state cooperation within OMVS. *"The real success we are celebrating today is a diplomatic and political one. OMSV member states*

Authors: Laura SEGUIN, Jean-Daniel RINAUDO (BRGM), Laurent Bruckmann, Amaury Tilmant (Université Laval), Awa Niang Fall, Khady Yama Sarr (UCAD)

have shown the world that they can work together. They were able to agree on an equitable sharing of the wealth created by the dams. Upstream countries recover more energy, while downstream countries benefit from more water for irrigation".

A thousand kilometers further west, in the middle valley of the Senegal River, the mood is far more gloomy. Monsieur Sow, mayor of Agnam, shows us the other side of the coin. *"What they don't say on TV is that we're the ones footing the bill for this success. As they built their dams, the flooding diminished and almost totally disappeared, and with it traditional fishing and flood recession agriculture. Thousands of families who had survived as best they could in the valley, here or in Mauritania, lost their livelihoods. Many migrated, both to the cities and abroad. Some of those who remained gained access to the new irrigation schemes or became workers for agribusinesses. There has been a lot of conflict over land, which has been sold to investors, some of them foreign, without recognizing our customary rights. Don't forget that it was China that financed the dams!"* Indeed, part of the production is now exported to Asia, in particular for the manufacture of biofuels.

NGOs are also concerned about the environmental impact. *"Upstream, the installation of the dams destroyed remarkable ecosystems and displaced many populations,"* explains Ms. Coulibaly of the Senegal River Initiative. *"Downstream, with the end of the flood, we saw the disappearance of what little riparian vegetation remained along the banks. Ecosystems have been seriously affected. Drainage water from irrigated areas is bringing more and more nutrients and pesticides into a river that flows less and less. This is beginning to pose problems for the production of drinking water in Lac de Guiers. We're in the process of making the whole valley uninhabitable: it's being sacrificed on the altar of productivity!"*

The initial program included five other dams on a tributary of the river. Increasingly contested, these projects are now at a standstill: *"The social distress of those left behind could generate political instability, fanned by the radical Islamist movements that have existed in Sahelian countries for 40 years,"* explains Ms. Coulibaly, *"It's time to take steps to improve their living conditions. One solution would be to release some of the stored water to generate a small artificial flood. Unfortunately, this runs counter to powerful interests"*. Will the political authorities have the courage to take this step? In the long term, its survival may depend on it...

Scenario 2

2

Sud Quotidien

March 27, 2050

Amadou Wade and OMVS honored for their social policy in managing the Senegal River

The prestigious Stockholm Water Prize was awarded yesterday to Amadou Wade, in recognition of his militant struggle and political action to protect the Senegal River. With this distinction, which is the equivalent of the Nobel Prize for water, the international jury highlights the success of the social water management policy implemented over the past 20 years by the 4 member countries of the OMVS.

A senior official in the Mauritanian administration, Amadou Wade resigned in 2025 at a time when OMVS was stepping up dam construction projects for power generation and private irrigation schemes. His close collaborator at the time, Ms. Sy, explains: *"He accused governments of privatizing water resources and sacrificing rural populations dependent on fishing and recession agriculture on the altar of energy and food autonomy"*.

"He understood that the risk of a social explosion was serious, as Islamist movements were already deploying their networks in the valley in Senegal and Mauritania, in conjunction with Malian groups".

He then joined a coalition of NGOs, academic researchers and international donors campaigning for more diversified river development that respects nature and local populations. Amadou Wade travels tirelessly around the world, organizing marches for the river, speaking at conferences and negotiating with political parties in 4 countries. As Mr. Sy explains, *"We had to wait until the social and climatic crisis of 2029 for him to be heard. The politicians were really afraid of being overwhelmed by the food riots in the valley. So they called him to the helm of OMVS. When he arrived, several major dam projects were halted"*. The Bakoye was protected from all dam construction to maintain a natural flood. The regulations governing the works were revised to allow water to be released at the time of flooding, in order to accentuate it. For the first time in 30 years, real investment has been made in navigation, both to revitalize the valley's economy and to meet Mali's demands. Above all, it was a signal to Mali and its rural populations.

"His genius was also diplomatic", explains Ms. Sy. *"The greatest challenge he faced was to build stronger governance between the OMVS countries, which were not pulling in the same direction. The upstream countries had no*

Authors: Laura SEGUIN, Jean-Daniel RINAUDO (BRGM), Laurent Bruckmann, Amaury Tilmant (Université Laval), Awa Niang Fall, Khady Yama Sarr (UCAD)

interest in releasing water for the flood, their priority being hydroelectric production. Downstream countries therefore had to give up part of their electricity production".

Regenerating the flood was of course not enough to develop the valley. Ambitious policies were implemented to organize the agricultural and fishing sectors. Major investments were made in processing, storage and marketing, as well as in farmer training. Yields have increased and a wide variety of agricultural products are now produced in the valley. Some, such as cowpeas, are exported and appreciated beyond the basin, and are considered among the best in West Africa.

"Many people today realize how visionary Amadou Wade was. Today, few people leave these lands to find a better future in Central Africa or Europe. The people of the valley are once again proud of their kingdom," adds Ms. Sy.

Business circles, meanwhile, are still critical of the fact that the planned dams and Chinese financing have been abandoned. In fact, our countries are still dependent on food imports. And even if the discovery of oil in Senegal and Mauritania has compensated for the loss of hydroelectric production, this is not conducive to the decarbonization of energy that is being promoted worldwide.

Water: fuel for the economy or cement for the foundations of our societies? The Stockholm Prize encourages us to continue along the path laid out by Amadou Wade in Africa and elsewhere in the world...

Scenario 3

3

Le Quotidien
www.lequotidien.sn

April 14, 2051

FAO: "The solar revolution has boosted food security in the Senegal River Valley".

Since the drought of 2028-2030, the territories of the Senegal River valley have been relatively unaffected by water shortages. This security is largely due to the decision taken at that time to develop photovoltaic energy on a large scale. It enabled farmers, who were dependent on flooding in the valley, to continue farming by drawing water from solar-powered pumping systems, thus freeing them from climate fluctuations.

In a report published by the Food and Agriculture Organization of the United Nations (FAO), the development of solar energy in the Senegal River Valley is highlighted as an example of food security and climate change adaptation. This has enabled many small irrigation schemes to be developed using solar-powered pumping systems.

Mr. Ba, a farmer in Oréfondé, remembers: *"In the 2020s, we were still hopeful that the flood would be maintained. But with the drought we realized that this was a utopia. Thanks to the new generation of pumps with cheap solar panels, everyone has been able to cultivate their land for market gardening".*

"This solar revolution has given rise to a class of small-scale agricultural entrepreneurs with diversified production, notably onions for the national market and for export," explains the FAO representative who presented his report at a meeting of the Basin Committee.

OMVS representatives were delighted to see their policy highlighted in this report. All the more so as it is based on extensive coordination between the four member countries. In addition to solar pumps for agriculture, photovoltaic technology has also developed on an industrial scale, with large-scale power plants now supplying electricity to towns and cities. While this development strategy has made it possible to reduce the number of hydroelectric dams built (6 in total out of the 12 initially planned for the 2020s), it also means that water releases need to be much more carefully managed: *"The solar revolution has been possible because it complements hydroelectricity, which is an easily controllable form of energy. Dams take over when solar power stops"*, as Mr. Ndiaye of OMVS explains.

Today, this cooperation is ensured by the Société Internationale des Barrages du Fleuve (SIBF), which brings together the former management companies (SOGED, SOGEM, SOGEOH): *"The SIBF has intensified cooperation between OMVS member countries. It enables us to optimize the management of all the river's structures in order to reconcile the objectives of electricity production and agricultural production"*, explains Mr. Ndiaye.

However, the development of solar energy has led to an increase in the price of

Authors: Laura SEGUIN, Jean-Daniel RINAUDO (BRGM), Laurent Bruckmann, Amaury Tilmant (Université Laval), Awa Niang Fall, Khady Yama Sarr (UCAD)

agricultural land, with new inequalities in access to land and water. Part of the population remains excluded from these new facilities. Ms. Sall of the Eaux Vives-Mauritanie association acknowledges the progress made by the development of this green energy, but points to a number of problems: *"The wetland ecosystems in the river valley have been degraded by the pumping and discharge of polluted water. Fishing has disappeared and been replaced by intensive aquaculture of fish such as tilapia"*.

Finally, the environmental activist warns of the risk of over-exploitation and pollution of the water table, which is already visible in certain areas: *"Having invested in photovoltaic panels, we now have free energy, and this easy access to water has led to an increase in the number of boreholes, but today we can see that the capacity of the water table to recharge itself annually has deteriorated considerably. Some farmers regularly have to lower their pumps to keep pace with falling levels"*. It's not out of the question that some boreholes could run dry in ten years' time, if the decline continues at the current rate.

Despite these positive developments, could water scarcity soon once again threaten the lands of the Senegal River valley? The solar revolution has certainly saved the local economy from drought. But have we been too quick to forget that water is a limited and fragile resource? Let's not kill the goose that lays the golden eggs: future generations will need it. Probably more than we do, given what scientists are saying about the impact of climate change on our region.