GoNEXUS

Tools and solutions for governing the nexus

Deliverable D5.4: Baseline EU WEFE nexus evidence

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WP5

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Lead by UPM

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Abstract

This deliverable will be the main results of task 5.3. It will provide a diagnosis of the WEFE nexus at the EU for the baseline scenario (current climate and policy) using the SAF and other quantitative methods to characterize the WEFE nexus from a multi-attribute perspective, revealing trade-offs and synergies existing in the baseline EU-scale scenario. The target audiences are the GoNEXUS partners, scientists working on EU-scale WEFE modelling, and EU bodies related to Water, Energy, Food and Environment (for the EU: Directorate-General of Agriculture and Rural Development, Climate Action, Energy, and Environment). It will also be relevant for WEFE EU directives such as the Water Framework Directive, the Common Agricultural Policy, the Energy Directive and the EU Green Deal. It will be used in Task 6.3

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V1	20/11/2023	Maria Blanco (UPM), Imen Arfa (UPM), Adrián González-Rosell (UPM), Berny Bisselink (JRC), Kristina Govorukha (E3M), Aafke Schipper (PBL)	Generation of first draft.
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1 Introduction

The GoNEXUS project utilizes a suite of thematic models addressing the Water, Energy, Food and Ecosystem (WEFE) nexus, which are integral to the European Union's assessment strategies. These models are not only operational but also actively applied in both research and policymaking. Among the users of some of these models are prominent institutions like the European Commission, the Organisation for Economic Co-operation and Development (OECD), and the World Bank. They employ these models for conducting impact assessments and exploring various policy scenarios. The model set includes operational climate-water, climate-energy, biodiversity, and land use-economic models (e.g. agroeconomic models), with most of them considering the interdependencies of only a few sectors. While these models are capable at capturing the interplay between several sectors, it is noteworthy that none of them currently encapsulate all four elements of the WEFE nexus in conjunction with climate change considerations.

This deliverable assesses the WEFE nexus at the EU level using the integrated water resource and crop model LISFLOOD-EPIC, the energy model PRIMES, the agro economic model CAPRI, and the ecosystems model GLOBIO. These models first provide a diagnosis of the WEFE nexus at the EU level for the baseline scenario (current climate and current policies). This will be obtained from analysing available observations at the EU level and simulations of the WEFE nexus performed by EU models under current climate, land use, infrastructure and policy forcing. For each model, this deliverable presents relevant evidence that corresponds with the baseline scenarios aligned with the challenges. Utilizing the GoNEXUS SAF developed in Task 5.1, the WEFE nexus is characterized through a multi-attribute perspective, revealing trade-offs and synergies. The outcomes of these simulations will inform and refine model configurations at the basin level, ensuring a tailored approach to nexus assessment.

2 Overview of EU Challenges

Climate change coupled with the escalating demands on natural resources poses significant challenges that will affect Europe in the coming decades. These challenges are anticipated to manifest in various forms, including migration pressure, volatility in food prices, water scarcity, irrigation inefficiency and imbalances in energy markets. These factors will become more impactful with time and represent the key elements of our EU GoNEXUS case study.

To address socioeconomic and environmental challenges from a nexus perspective, the EU case study team has identified the most critical WEFE challenges. These nexus challenges have been discussed and refined through dialogues with stakeholders. The all-encompassing challenge is that water scarcity and pollution will have major ramifications on other sectors, such as irrigation, energy prices, food security and biodiversity, among others. The main challenges are listed below.

Challenge 1: Growing water scarcity and water stress index due to increasing water demand related to macroeconomic trends (demographic pressure, increasing food demand...) and climate change (a warmer and drier climate in some European regions).

- **Specifics of the challenge:** Food and energy security require large amounts of fresh water. Water is one of the essential resources in both sectors, acting as a crucial component for irrigation. The demand for natural resources is likely to increase over the coming decades due to growing global population numbers and economic development. At the same time, climate change may lead to lower overall water availability. Consequentially, water scarcity, variability and uncertainty are becoming more prominent, which could lead to vulnerabilities within the energy and food sectors.

- **Why this challenge matters:** The EU is promoting initiatives to address water scarcity, such as investments to improve water use efficiency and the reuse of wastewater for irrigation. However, those solutions do not come without a cost. Energy requirements to transport reclaimed water from wastewater treatment plants to irrigated areas are high. While water reuse for irrigation may contribute to the reduction of water stress in coastal areas where irrigation is an important component of water demand, it may also contribute, in a more indirect way, to nutrient pollution migration. Addressing water scarcity requires paying attention to the impacts on energy demand, food security and ecosystems conservation.
- **Relevance:** This challenge is linked to the Water Framework Directive, the European Green Deal, the Circular Economy Action Plan (CEAP) and SDG 6.

Challenge 2: Green energy transition and the reduction of CO2 emissions

- **Specifics of the challenge:** Energy use accounts for 75% of EU greenhouse gas (GHG) emissions (European Commission, 2020), making energy system transformation an integral part of the EU's climate ambition. The green energy transition involves a higher share of renewable energy, replacing thermal and nuclear power generation vulnerable to water availability and temperature increases. Therefore, the transformation of the power sector can help mitigate the effects of water scarcity in a warmer and drier climate. However, greening the energy system can have negative economic impacts. Furthermore, hydro climatic scenarios also consistently show negative impacts on hydropower generation and biomass potential.
- **Why this challenge matters:** It is crucial to assess the impacts of climate adaptation strategies and energy policy measures from a nexus perspective, to account for the impacts not only on climate neutrality but also on water use and the agrifood sector. Additionally, assessing the ability of renewable sources to improve energy use efficiency is an essential aspect of the challenge that our work will contribute to. Through investigating this challenge, our main goal is to examine if the envisaged solutions to promote the energy transition are resilient in the context of the WEFE nexus, specifically focusing on climate neutrality, hydropower generation and biomass potential.
- **Relevance:** This challenge is linked to the European Green Deal, which sets an ambition for a climate neutral Europe in 2050, the Energy Efficiency Directive, Fit for Purpose, Renewable Energy Directive, and SDG 7.

Challenge 3: Reconciling water, energy and food security with ecosystems conservation (and other environmental effects)

- **Specifics of the challenge:** The agrifood system, which now accounts for almost a third of global GHG emissions, consumes large amounts of natural resources, contributes to soil and water pollution, and leads to biodiversity loss. Additionally, the energy sector is one of the major contributors to GHG emissions and the increase in water consumption reduces environmental flows and impacts freshwater ecosystems. Hence, we need to rethink our food systems, which now account for almost a third of global GHG emissions, consume large amounts of natural resources, lead to biodiversity loss. Promotion of sustainable agriculture may help to protect the ecosystem although yields might be negatively affected.
- **Why this challenge matters:** There are a number of areas that require further research. For example, we are investigating how the increase in energy use due to the growing energy demand for irrigation (and other related activities such as water transfers and pumping) will impact ecosystems. Also, we are looking into how irrigation water demand can be reduced to

protect natural ecosystems, how water scarcity affects the ecosystems and how we can achieve food security and sustainable agriculture production with ecosystem conservation and the sustainable use of natural resources.

- **Relevance:** This challenge is linked to SDG 13, 14 and 15, the Zero Pollution Action Plan (reducing pollution at source, e.g. pesticide use) and the European Green Deal (Farm to Fork Strategy, Biodiversity Strategy).

Challenge 4: Weak governance of the WEFE nexus

- **Specifics of the challenge:** Overall, cross-sectoral coordination of governance systems is insufficient. As a result, policy measures and regulations aiming at improving one part of the nexus often lead to overtaxing or affecting another part. The search for policies and governance mechanisms that are robust under changing conditions as well as economically and ecologically sustainable is crucial to minimize cross-sectoral trade-offs and promote synergistic actions.
- **Why this challenge matters:** Despite ambitious policymaking to improve resource efficiency and sustainable management of natural resources, the EU still faces complex sustainability issues at the nexus coherence among water, energy, food and ecosystems. It is important to identify the WEFE policy solutions that are effective as well as coordinated both from a sectoral perspective and a spatial perspective (from the EU to the subnational level)
- **Relevance:** This challenge is linked to SDG 17.

3 Baseline scenario

In this deliverable we will use three main scenarios for Tier 1 runs named "Sustainable Development," "Weak cooperation," and "Global Risk". These policy-relevant WEFE scenarios align with the climate, socioeconomic, and land use scenarios as follows:

- “Sustainable development” aligned with SSP1-2.6
- “Weak cooperation” aligned with SSP3-7.0
- “The wrong way” aligned with SSP5-8.5

The policy-relevant WEFE scenarios are baseline scenarios that represent future trends of the 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), therefore, they will serve to assess the nexus solutions (WP7) within the framework of the project. Figure 1 shows representative hypothetical trajectories of the three main policy-relevant WEFE scenarios and the reference period. In the scenario titled “Sustainable development” (depicted in green), more favourable impacts on the WEFE nexus indicators are expected, while in scenario labelled “The wrong way” (depicted in red), more negative impacts are expected.

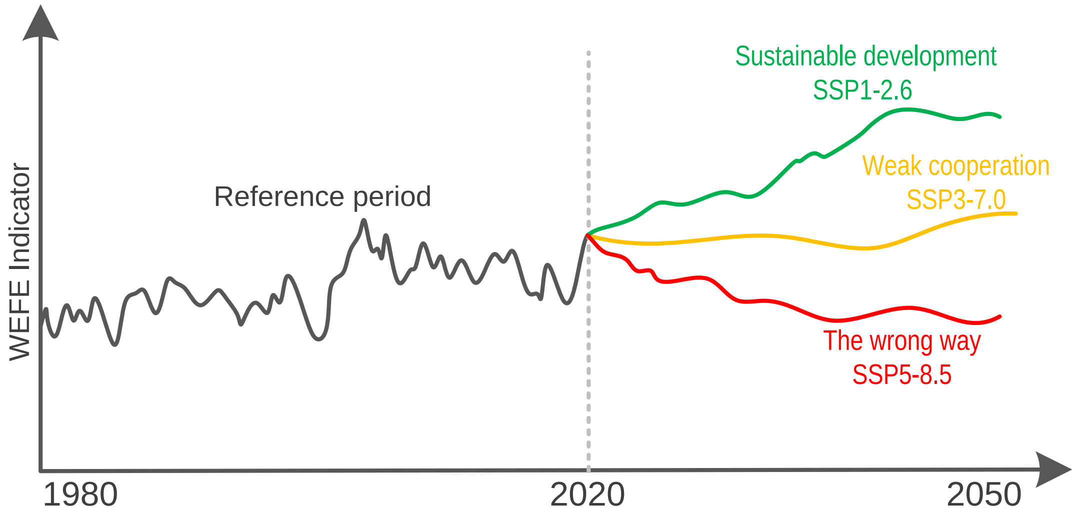


Figure 1. Illustration of the policy-relevant WEFE scenarios in contrast and the reference period. Source: own elaboration.

4 Process to generate evidence at EU level

4.1 Pool of models used at EU level

Four continental thematic models are used in GoNEXUS at the EU level. This template focuses on continental models that will provide detailed outputs for specific aspects of the Nexus. The main features of the thematic models are presented in Table 1. Furthermore, more details are provided in D3.1, D3.2 and D3.6 that describe the setup of the individual thematic models and models interlinkages.

Table 1. EU models in GoNEXUS

Model feature	LISFLOOD	CAPRI	GLOBIO	PRIMES
Model type	Hydrological rainfall-runoff model	Global agro-economic model with regionalized EU detail	Global biodiversity model	Global macro-econometric energy, environment and economy model
Main topics	- climate change impacts assessments - water abstraction - water availabilty	- agricultural trade, - bioenergy - water policies, -climate impacts	-freshwater fish species distributions and diversity	-energy balances -CO2 emissions -energy technology penetration, -prices and costs.
Nexus components	Water, land, food, climate	Food, water, bioenergy, environment, climate	Environment, biodiversity	Energy, climate, environment
Geographic coverage	Global	Global	Global	Global
Spatial resolution within EU	5x5 km	National and regional (NUTS2)	5 arcminutes (about 10x10 km)	National
Application to case studies	European	Global and European	Global and European	European
Time step	Daily	Annual	Decadal	5 years steps
Time frame	Until 2100	Until 2050	Until 2050	Until 2050
Partner	JRC	UPM	PBL	E3M

4.2 Reporting template

Simulation scenarios, defined in WP2, cover the climate, socioeconomic, land use and policy domains. The climate change scenarios defined and analysed are obtained from the Coupled Model Intercomparison Project (CMIP). The continental scales refer to CMIP Phase 6 (CMIP6). CMIP6 scenarios include two activities: The Scenario MIP (standard resolution) and the ISIMIP3b (Inter-Sectoral Impact Model Intercomparison Project, high resolution data). From the combinations between RCPs and SSP and according to deliverable 2.1, GoNEXUS has selected SSP1-2.6 (Sustainable development), SSP3-7.0 (Weak cooperation) and SSP5-8.5 (The wrong way). A first scenario run (Tier 1) has been established based on common inputs from WP2 (e.g. demographics, GDP, land use change, etc.) in order to have a homogeneous set-up for all the continental WEFE models. After tier 1 runs of baselines, the individual models will be interconnected. This entails including the interconnections between Water (LISFLOOD-EPIC), Energy (PRIMES), Food (CAPRI) and Ecosystems (GLOBIO). Interlinkages will be established by exchanging information between models for each simulation period. After that, a second scenario run (tier 2) will then be simulated based on common inputs from WP2 but also using the model linkages. For the Baseline scenario runs (tier 2 runs), the following scenarios are proposed: Sustainable development (SSP1-2.6) and Weak cooperation (SSP3-7.0) scenarios. The goal is to quantify the impact on the WEFE sectors and policies under the projected climate conditions.

Table 2. Summary of the scenarios used for Baseline Scenario by GoNEXUS project models under Tier 2

Simulations	***Socio-economic conditions***
2015 (2020) – 2100 Projections	
Policy relevant scenarios	***Projected WEFE nexus***
Sustainable development	SSP1-2.6
Weak cooperation	SSP3-7.0

We developed a **common reporting template** to:

- Jointly analyse model results from GoNEXUS models
- Ease the exchange of information across models that use different spatial and time scales.

Employing a “database type” reporting format is helpful to streamline the interaction between case study leaders and modellers. It also facilitates the identification of shared baseline outputs across various models, as well as specific outputs only available from some models. Furthermore, it will ease model linkages for Tier 2 scenario runs and policy scenario runs. As shown in Table 3, this reporting template includes eight dimensions (model, scenario, region, category, variable, unit, year and value).

Table 3.Common reporting template for model outcome

Model	Scenario	Region	Category	Variable	Unit	Year	Value

5 Baseline results

5.1 CAPRI

CAPRI is a global spatial partial equilibrium model for the agricultural sector developed for ex-ante impact assessment of agricultural, environmental and trade policies with a focus on the European Union. It is a comparative static model solved by sequential iteration between supply and market modules (for a detailed description see Britz and Witzke, 2014). The CAPRI Water version is an extended version of the model integrating water-food interconnections as it accounts for irrigation water use, irrigation efficiency, water use by other sectors and water related policy impacts, among others.

Scenario definition

In this project, the current climate scenario and three alternative baseline scenarios have been analysed:

- NoCC (no climate change effects): scenario with current climate and current policies.
- Baselines with climate change effects: SSP1-2.6, SSP3-7.0 and SSP5-8.5, all with current policies. Shifters on socioeconomic drivers have been processed at national level for all global regions and aggregated at the spatial scale in CAPRI for non-EU regions. Shifters on crop yield (irrigated and rainfed), crop water requirements, water availability and non-agricultural water withdrawal come from biophysical models.

CAPRI simulations have been run for 2020, 2030, 2040 and 2050.

Model results

From CAPRI results, under no climate change, EU total irrigated agricultural area is projected to increase under between 2020 and 2050. However, the total rainfed agricultural area is expected to decrease between the same period (Figure 2A and 2B). At country level, the irrigated area is expected to decrease mainly in southern European regions with limited water availability in 2050 compared to 2020 (Spain shows a decrease between 10 and 20% in the majority of regions). However, irrigated cropland is expected to increase in some less water stressed regions in 2050 compared to 2020 (for example Germany shows an increase of irrigated area approximatly between 0 and 10%) (Figure3).

Furthermore, production of the majority of crops is expected to increase between 2020 and 2050 under no climate change. This increase in production can be explained by increase in food demand following population growth. The increase in production compared to area (intensification) leads to an increase in crop yield. This increase in yields can be explained by an increase in technological factors and an increase in water withdrawals for irrigation (more water used for irrigation) between 2020 and 2050 (see figure 4).

Looking at scenarios under climate change, EU total irrigated agricultural area is expected to decrease between 2020 and 2050 (especially under SSP5-8.5). The total rainfed agricultural area shows a small decrease between 2020 and 2050 compared to irrigated area (Figure 2A and 2B). Under climate change scenarios, EU aggregated agricultural production mainly is projected to decline between 2020 and 2050 (especially under SSP5-8.5). Results confirm that the effects of climate change on EU production are a consequence of yield changes (mainly decrease of irrigated yield), increase in crop water requirements and less water availability for irrigation (less intensification and water use for irrigation).

Model results (figure 4) show that climate change will reduce total water withdrawal compared to no climate change. This reduction will affect water withdrawal for irrigation (less water availability for irrigation especially under SPP5-RCP8.5 in 2050).

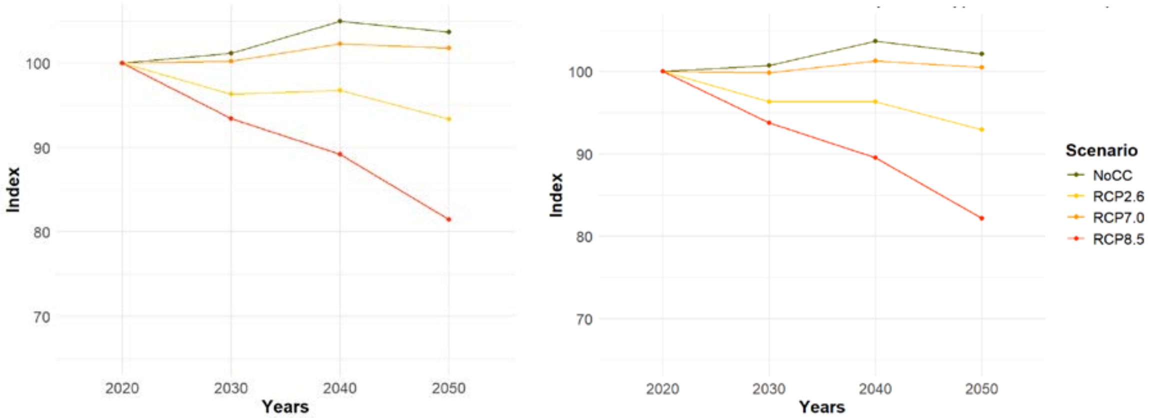


Figure 2. (A) EU trends in irrigated agricultural area (B) EU trends in rainfed agricultural area (1000 ha) (Index 2020=100)

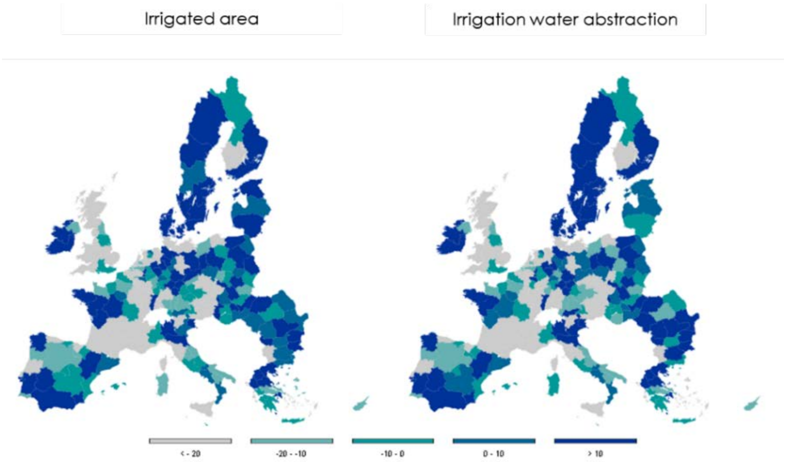


Figure 3. Irrigation trends under no climate change (% change in 2050 relative to 2020)

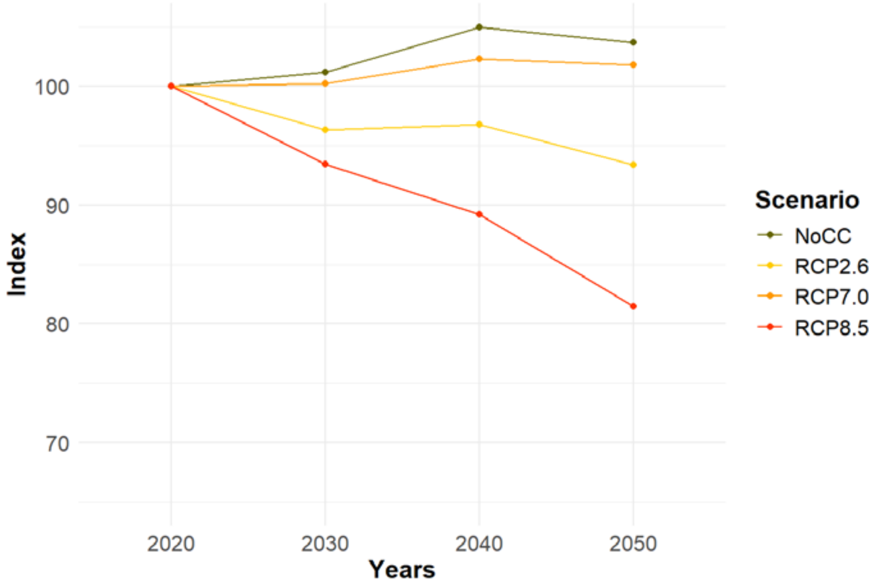


Figure 4. EU trends in water withdrawal for irrigation(1000m3) (Index 2020=100)

At crop level, in figure 5, we selected seven crops that produced more at EU level (barley, maize, potato, pulse, rape, sunflower and soft wheat) to assess the impact of climate change on irrigated and rainfed area in 2050. Under more climate change and with less water availability for irrigation, irrigated area of barley, rape, sunflower is expected to decrease by around 55%, 48% and 48% respectively for SSP5-8.5 in 2050 compared to no climate change. However, for the same crops, the rainfed area at EU level is expected to increase in 2050 compared to no climate change scenario (by around 7.5% for barley, 10% for rape and 6% for sunflower under SSP5-8.5). This can be explained by less water availability for irrigation, there is a shift from irrigated to rainfed area for some crops (especially winter crops). For summer crops such as maize (need water for irrigation), even with less water availability under climate change, the irrigated area increases compared to no climate change scenario in 2050.

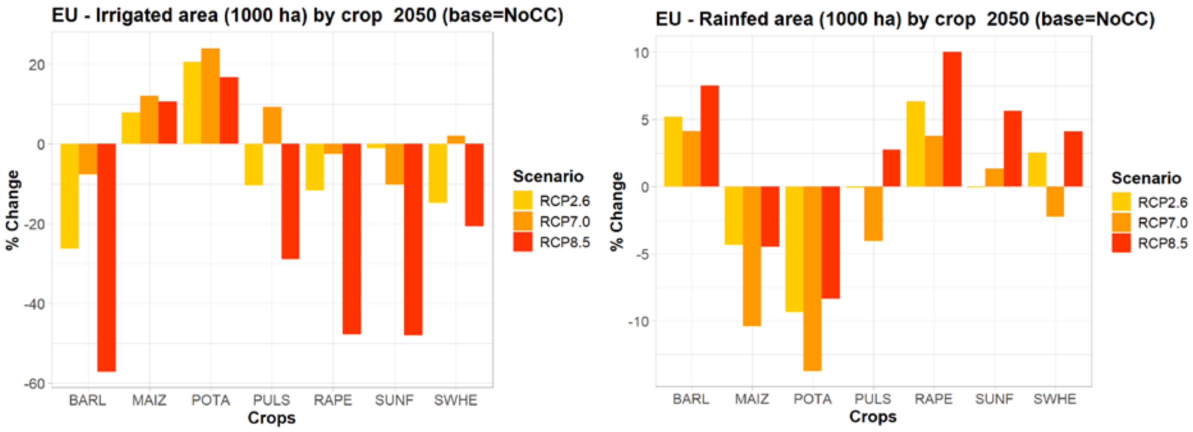


Figure 5. EU changes of agricultural area (irrigated and rainfed) per crop (1000ha) in 2050 (base= NoCC)

From figure 6, looking into country-level and under climate change “SSP5-8.5”, the irrigated area will decrease for almost all EU country. With less water availabilty for irrigation under climate, there is less water use for irrigation and then decrease in irrigated areas. Hence, when the impact of climate change leads to a reduction in freshwater availability, treated water becomes a mitigation option for most of the member states to alleviate the climate change impact especially for countries with high level of water scarcity (Spain, France, Italy…).

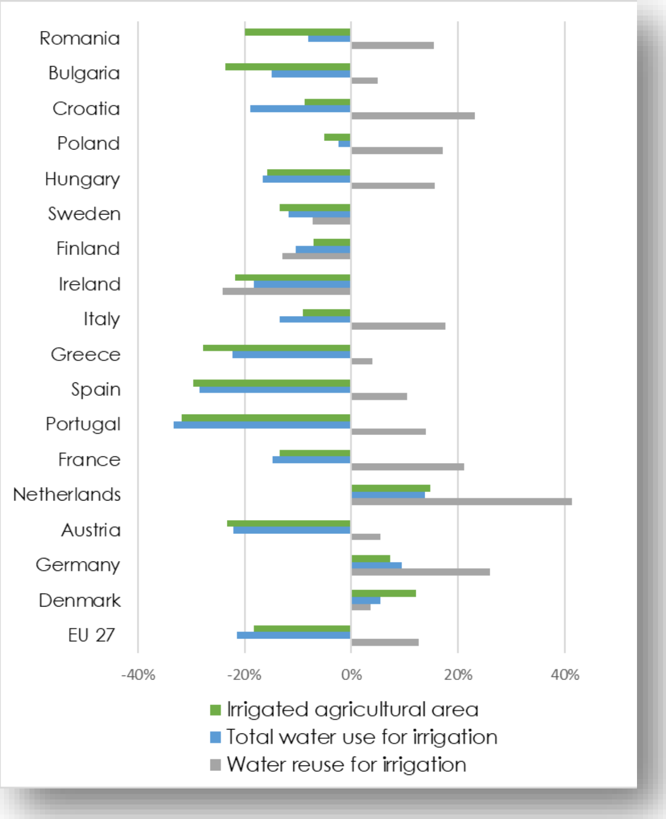


Figure 6. EU changes of water use and reuse for irrigation by EU country under SSP5-8.5 (relative to NoCC in 2050)

5.2 LISFLOOD

An integrated assessment of future water resources, due to climate change, land use change and changes in water consumption is performed using JRC's LISFLOOD water resources model (De Roo et al., 2000; Van der Knijff et al., 2010). For the Tier 1 simulations, LISFLOOD simulations were performed at 5 × 5 km² resolution grid over the extended European domain, which includes all the EU countries, as well as some neighbouring ones such as Albania, Bosnia – Herzegovina, Iceland, Moldova, Montenegro, North Macedonia, Norway, Serbia, and Switzerland at a daily time step.

Table 4. Climate projections used for Tier 1 and Tier 2 simulations.

	Institute	GCM	RCM	Tier 1	Tier 2
1	CLMcom	CNRM-CM5	CCLM4-8-17	X	
2	CLMcom	EC-EARTH	CCLM4-8-17	X	X
3	IPSL	IPSL-CM5A-MR	INERIS-WRF331F	X	X
4	SMHI	HadGEM2-ES	RCA4	X	
5	SMHI	MPI-ESM-LR	RCA4	X	

6	SMHI	IPSL-CM5A-MR	RCA4	X	
7	SMHI	EC-EARTH	RCA4	X	
8	SMHI	CNRM-CM5	RCA4	X	X
9	DMI	EC-EARTH	HIRHAM5	X	X
10	KNMI	EC-EARTH	RACMO22E	X	X
11	CLMcom	MPI-ESM-LR	CCLM4-8-17	X	X

The LISFLOOD water resources model is forced with two Representative Concentration Pathways (RCPs): RCP4.5 and RCP8.5. RCP4.5 may be viewed as a moderate-emissions-mitigation-policy scenario and RCP8.5 as a high-end emissions scenario. For each RCP an ensemble of 11 EURO-CORDEX combinations of Global Climate Models (GCM) and Regional Climate Models (RCM) were used (Jacob et al., 2014) up to 2100 (Table 5). The reference scenario spans the period 1981-2010.

In LISFLOOD, the future projections of land use in Europe are derived from the LUISA modelling platform (Jacobs-Crisioni et al., 2017). LUISA translates socio-economic trends and policy scenarios into processes of territorial development. Among other things, LUISA allocates population, economic activities and land use patterns in space and time, all are constrained by biophysical suitability, policy targets, economic criteria, and many other factors. Apart from the constraints, LUISA incorporates historical trends, current state and future projections in order to capture the complex interactions between human activities and their determinants. Key outputs of the LUISA platform are fine resolution maps (100m) of accessibility, population densities and land-use patterns covering all EU member states and the UK, Serbia, Bosnia Herzegovina and Montenegro until 2050 as described in WP2. For this reason, LISFLOOD is not forced with SSP socio-economic scenarios. Water demand in LISFLOOD, consist of five components from which in Tier 1, the irrigation water demand is estimated dynamically within the model only based on climate conditions. The other four sectorial components are used as input data. These are (manufacturing) industrial water demand, water demand for energy and cooling, livestock water demand and domestic water demand. In general, water use estimated for these four sectors are derived from mainly country-level data (EUROSTAT, AQUASTAT) with different modelling and downscaling and regression techniques for future projections.

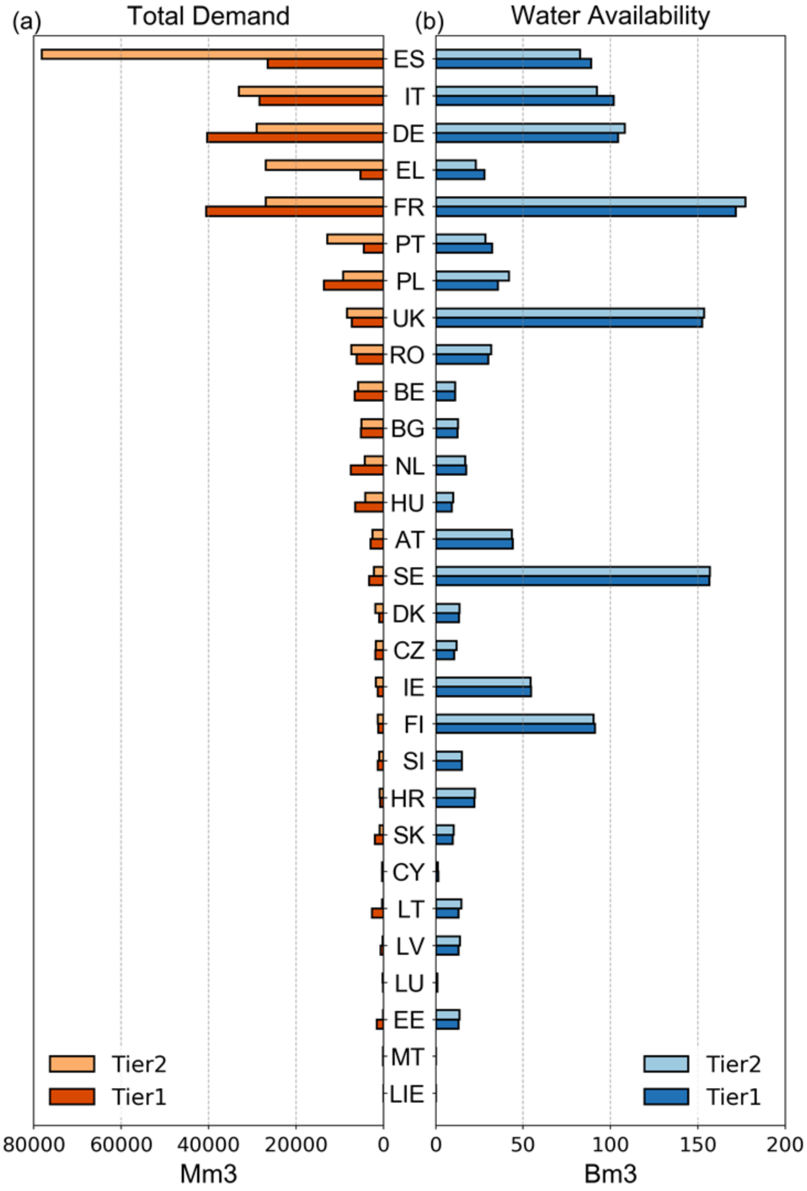


Figure 7. The 30yr ensemble mean (hindcast; 1981-2010) of the (a) total water demand (Mm3) and b) water availability (Bm3) for the Tier 1 and Tier 2 simulations.

For the Tier 2 simulations both the climate forcing and socio-economic data are similar compared to Tier 1, but we modified LISFLOOD by dynamically integrating the EPIC crop growth module (LISFLOOD-EPIC; Task 3.1) to obtain more realistic estimates of irrigation water abstractions. The impact of integrating the CAPRI crops and PRIMES energy scenarios in the Tier 2 simulations is presented in D3.2.

For the interlinkage between the models in Tier 2, we used a scenario of the crop distribution from the CAPRI model, which reflect a business-as-usual scenario with the current CAP and no climate change for 2020, 2030, 2040 and 2050. The irrigated area map from Wriedt et al., 2009 is used to differentiate the CAPRI crop distribution into irrigated and rainfed agriculture.

For the energy scenarios, the annual total water withdrawals and water consumption from solids, gases and nuclear from PRIMES are taken. Given that the PRIMES outputs are at the national level, we used the EC Energy Reference Scenario 2016 (Medarac et al., 2018) disaggregated from country to NUTS2 level as a starting point. The projections are then estimated by the water withdrawals and consumption factors for every 5 years up to 2070 from PRIMES

In figure 7 we show the impact on the water resources between the Tier 1 and Tier 2 results of the ensemble mean of the 6 GCM/RCM combinations used in Tier 2 for the 30yr mean (1981-2010) of the total demand and water availability.

Integrating the CAPRI crops and PRIMES energy scenarios results in more water demand in countries like Spain, Italy, Greece and Portugal where agriculture is the dominated source of water abstraction resulting in less water availability. Applying the modified LISFLOOD-EPIC model for Tier 2 simulates more realistic water abstractions for irrigation. However, the values in Spain might be overestimated or reported values underestimated as discussed in D3.2.

In Tier 2, more water availability and less water demand compared to Tier 1 is observed in countries where industry is an important sector for water withdrawals, like France and Germany. These values in the hindcast of the Tier 2 simulations are the reference or control climate to estimate the impact of future projections on the water resources in Europe.

For now, we present the future projections for the Tier 1 simulations for total demand, water availability and water scarcity months (WEI+ > 0.2) under two Representative Concentration Pathways (RCPs): RCP4.5 and RCP 8.5 emission scenario's. A 30-year window around the years 2030, 2050 and 2080 has been analysed and compared to the 1981-2010 control climate window (hindcast). Each year represents the long-term average over a 30yr period. 2030: 2015-2045, 2050: 2035-2065, 2080: 2065-2095.

Table 5. Estimated average of total water demand (Mm3) per year for the hindcast, RCP4.5 and RCP8.5 emission scenarios for different 30yr periods at country scale based on Tier 1 simulations.

Region	Hindcast	RCP4.5			RCP8.5		
	1981-2010	2030	2050	2080	2030	2050	2080
France	40916	41828	42084	42098	41792	42129	43041
Austria	2884	3103	3168	3177	3102	3163	3182
Belgium	6749	6986	7053	7067	6985	7051	7073
Bulgaria	6118	7206	8209	8487	7211	8222	8574
Switzerland	2909	2960	2944	2939	2959	2943	2944
Cyprus	273	299	316	326	300	319	336
Czech Republic	1845	2440	2895	3018	2439	2893	3019
Germany	40398	45880	49274	50076	45872	49261	50124
Denmark	1041	1576	1749	1797	1563	1744	1808
Estonia	1698	2204	2735	2883	2204	2735	2883
Greece	7277	7760	7855	7998	7819	7961	8582
Spain	26933	29861	30720	30792	30054	31278	33427
Finland	1686	1765	1848	1865	1764	1848	1879
Croatia	1369	1502	1565	1580	1503	1564	1599
Hungary	7255	9211	11077	11576	9209	11055	11594
Ireland	1386	1770	2049	2118	1769	2051	2132
Italy	29318	29249	28963	28660	29189	28751	29915

Liechtenstein	4	4	4	4	4	4	4
Lithuania	2985	4422	6038	6519	4422	6038	6520
Luxembourg	73	91	105	108	91	105	108
Latvia	784	1010	1264	1343	1011	1267	1351
Malta	28	32	36	37	33	37	38
Netherlands	10814	11156	11068	11071	11172	11105	11194
Norway	3182	3124	3063	3050	3122	3066	3066
Poland	14636	19798	24201	25420	19795	24187	25410
Portugal	4794	5082	5145	5111	5111	5237	5480
Romania	7616	9566	11142	11569	9574	11106	11724
Sweden	6945	7625	8248	8412	7640	8290	8617
Slovenia	1246	1417	1564	1598	1416	1559	1606
Slovakia	1941	2422	2826	2922	2420	2814	2933
United Kingdom	8818	10002	10727	10896	10007	10751	10984

Table 5 shows the projected change in total water demand for all economic sectors considered in LISFLOOD at a country scale. Note that the projected change between the RCP4.5 and RCP8.5 emission scenarios are only caused by the irrigation demand as it is driven by climate conditions. The other components are external input data and are changing due to land use, economic, population, and climate changes.

The countries with the total water demand above 20000 Mm3 are France, Germany, Spain, and Italy. From these countries the largest increase in demand is projected in Germany. In general, the total water demand is projected to increase the most in countries where the industrial and domestic water demand is the major source for water abstractions, like Germany, where the demand is following the population and economic growth especially in the cities.

The water availability for current and future climate are presented in Table 6. In general, the climate projections reveal a typically North-South pattern across Europe for water availability. Overall, Southern European countries are projected to face decreasing water availability, particularly Spain, Portugal, Greece and Cyprus. Central and Northern European countries show an increasing annual water availability.

Table 6. Estimated average of water availability (Bm3) per year for the hindcast, RCP4.5 and RCP8.5 emission scenarios for different 30yr periods at country scale based on Tier 1 simulations.

Region	Hindcast	RCP4.5			RCP8.5		
	1981-2010	2030	2050	2080	2030	2050	2080
France	179.67	189.45	188.45	195.81	193.89	197.56	192.87
Austria	44.08	46.69	46.47	49.10	47.04	50.30	50.58
Belgium	11.36	12.70	12.91	13.30	12.81	13.67	14.14

Bulgaria	12.72	13.39	13.49	13.34	13.15	13.28	12.76
Switzerland	33.79	35.80	35.60	36.86	36.45	37.56	37.63
Cyprus	1.91	1.83	1.72	1.53	1.87	1.68	1.26
Czech Republic	10.52	11.96	12.21	12.90	12.28	13.50	13.69
Germany	108.42	120.94	119.48	124.53	122.48	129.21	132.82
Denmark	19.11	20.82	21.05	21.38	20.82	21.92	23.23
Estonia	15.83	17.35	17.86	18.76	17.75	18.40	20.27
Greece	39.09	38.13	37.70	37.61	38.04	38.02	35.64
Spain	94.59	89.76	87.92	92.20	91.81	87.94	79.74
Finland	99.10	108.21	113.14	119.97	113.31	119.05	129.66
Croatia	28.99	29.56	30.40	32.54	30.88	32.90	34.33
Hungary	9.26	10.15	10.91	11.52	10.51	11.82	13.32
Ireland	62.64	64.01	63.30	64.95	64.68	65.85	67.30
Italy	110.02	109.70	108.59	118.95	113.58	117.42	116.81
Liechtenstein	0.14	0.15	0.15	0.16	0.15	0.16	0.16
Lithuania	13.23	15.77	16.33	17.18	16.26	17.23	19.39
Luxembourg	0.90	1.02	1.05	1.11	1.03	1.12	1.12
Latvia	13.81	15.72	16.38	17.19	16.15	17.09	19.20
Malta	0.15	0.15	0.15	0.16	0.15	0.15	0.14
Netherlands	19.35	21.03	21.19	21.48	21.21	22.03	23.50
Norway	316.81	332.92	338.95	346.00	336.59	343.00	367.18
Poland	36.35	42.60	42.99	45.60	43.20	47.04	50.41
Portugal	33.83	30.57	31.10	32.58	32.00	30.90	27.81
Romania	30.30	32.21	32.39	33.05	32.08	33.36	34.94
Sweden	165.45	182.22	186.76	196.54	186.33	197.75	214.13
Slovenia	15.04	15.11	15.35	16.50	15.70	16.81	16.79
Slovakia	9.82	10.79	10.97	11.76	11.15	12.10	12.63
United Kingdom	176.82	183.75	183.38	187.57	186.64	189.97	197.14

To demonstrate the ratio between water consumption versus total water availability, we used the Water Exploitation Index Plus (WEI+) (consumption ratio) as an indicator for water scarcity. The WEI+ is defined as the total water net consumption (water abstraction minus return flow) divided by the available freshwater resources in a region, including upstream inflowing water. WEI+ values have a range between 0 and 1. Different gradations of water scarcity are determined. Values below 0.1 denote "low water scarcity", values between 0.1 and 0.2 denote "moderate water scarcity", "water scarcity" when this ratio is larger than 0.2, and "severe water scarcity" if the ratio exceeds the 0.4 threshold (Faergemann, 2012).

In Table 7, the water scarcity months (WEI+ > 0.2) per year for current and future climate are shown. In present climate, southern European countries, like Cyprus, Greece, Spain, Italy, Malta and Portugal already face water stress conditions for at least 1 month per year. Water scarcity is projected to gradually increase in duration from present climate towards the year 2080 in the Mediterranean regions. Here, the number of water scarcity months can increase up to more than 1 month per year for the RCP8.5 emission scenario compared to the present day climate baseline.

Table 7. Estimated average number of water scarce months (WEI+ > 0.2) per year for the hindcast, RCP4.5 and RCP8.5 emission scenarios for different 30yr periods at country scale based on Tier 1 simulations.

Region	Hindcast	RCP4.5			RCP8.5		
	1981-2010	2030	2050	2080	2030	2050	2080
France	0.24	0.27	0.30	0.29	0.26	0.30	0.43
Austria	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Belgium	0.16	0.18	0.19	0.19	0.18	0.18	0.22
Bulgaria	0.23	0.29	0.33	0.34	0.31	0.33	0.47
Switzerland	0	0	0	0	0	0	0
Cyprus	4.04	4.54	4.57	4.62	4.35	4.62	5.07
Czech Republic	0.02	0.04	0.04	0.03	0.02	0.02	0.02
Germany	0.13	0.14	0.17	0.16	0.14	0.14	0.14
Denmark	0.15	0.19	0.20	0.19	0.13	0.14	0.19
Estonia	0	0	0	0	0	0	0
Greece	2.25	2.33	2.36	2.42	2.36	2.40	2.64
Spain	2.64	2.95	3.10	3.03	2.94	3.18	3.49
Finland	0	0	0	0	0	0	0.01
Croatia	0	0.01	0.01	0.01	0.01	0.01	0.01
Hungary	0.35	0.40	0.43	0.41	0.38	0.37	0.37
Ireland	0	0	0	0	0	0	0.01
Italy	1.41	1.51	1.55	1.50	1.50	1.52	1.66
Liechtenstein	0	0	0	0	0	0	0
Lithuania	0.04	0.05	0.06	0.06	0.04	0.06	0.06
Luxembourg	0	0	0	0	0	0	0
Latvia	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Malta	4.25	4.49	4.57	4.61	4.56	4.82	5.16
Netherlands	0.41	0.37	0.38	0.35	0.38	0.33	0.41

Norway	0	0	0	0	0	0	0
Poland	0.02	0.02	0.02	0.03	0.02	0.02	0.02
Portugal	2.04	2.33	2.48	2.41	2.36	2.58	2.84
Romania	0.20	0.26	0.29	0.26	0.24	0.24	0.30
Sweden	0.04	0.03	0.04	0.03	0.03	0.03	0.03
Slovenia	0.03	0.04	0.15	0.04	0.04	0.04	0.05
Slovakia	0.10	0.12	0.15	0.11	0.12	0.09	0.10
United Kingdom	0.02	0.03	0.03	0.04	0.02	0.04	0.06

If water demand remains at current usage levels and without significant water saving and/or efficiency efforts, the warming climate and reduced precipitation in the Mediterranean causes increases in water scarcity at national level and even more extreme at regional level. This means that people already exposed to water scarcity in the current climate will encounter much more intense water scarcity under a changing climate.

5.3 PRIMES

PRIMES is a large-scale energy system model for the EU, UK as well as 10 non-EU countries including the EFTA countries Norway, Switzerland and Iceland (E3-Modelling 2018). The model is designed to provide with long-term energy system assessments, especially policy impact assessment related to energy markets and climate. It covers all energy sectors and ensures the continuity between the available Eurostat statistics for historic periods and projections.

For Tier 1 scenarios, PRIMES model does not use climate data directly. Most climate parameters provided by the global climate models cannot be directly integrated into our analysis, their impacts are accounted for by using the IAM model outputs, such as changes in energy crop potential due to climate, socioeconomic, and land use changes. PRIMES Net Zero scenario includes recent projections for key global energy commodity prices and the latest EU's climate policies, Fit for-55 legislative package aimed to reduce net greenhouse gas emissions and achieve climate neutrality by 2050 (European Commission 2021f). For the projections on agriculture, forestry, biomass potential PRIMES energy system model relies on the data provided by biophysical models. In the current project, the Tier 2 runs include the following linkages to consider climate change effects by:

- linking with CAPRI model for data on biomass potential. This linkage will allow to include changes in crop productivity and water availability for RCP coming from biophysical model.
- linking the data on water temperatures in RCP scenarios from PCR-GLOBWB.
- linking the data on river discharge in RCP scenarios from LISFLOOD/LISFLOOD-EPIC.

Tier 1 scenarios for the energy sector have been developed with respect to the available statistics and projections at the level of EU and its member states. Projections for the aggregate GDP of EU countries are based on the Ageing Report, European Commission (2021). For the period 2020 to 2050, EU population projections are based on the European Population Projections, base year 2019 (EUROPOP 2019). The population projections and GDP projections are compatible due to their common starting point. At the European level, PRIMES model is interlinked with the GEM-E3 model (for more details and description see D3.1, D3.2 and D3.6), to harmonise the framework conditions as population growth and GDP, as well as sector specific added value and industrial activity levels. Scenarios have been run for 2010 to 2020 reference years calibrated to the available EU statistics, and future projections from 2025 to 2070 with five-year steps.

Scenarios definition for the energy sector

PRIMES TIER 1 scenarios for the EU countries are developed based on the available EU statistics and projections (European Commission 2021, EUROPOP 2019), including the effects of COVID-19 and energy crisis due to Russia's war of aggression against Ukraine. For non-EU regions, GDP and population growth within the SSP2-4.5 scenario was assumed, this is also valid for the framework conditions from the soft-linked GEM-E3 model.

In Tier 1, preliminary modifications to the PRIMES model were introduced to assess the needs for water consumption and withdrawal by thermal power plants. These preliminary results were shared with the project partners and compared with the Tier 1 results from the PCR-GLOBWB model performing sector specific projections for water use.

We modelled two scenarios: Current Policies and Net Zero. Key assumptions and a brief description of each scenario is given below.

Current Policies scenario

We developed a policy baseline scenario for the EU energy sector that will project the no-climate-policy baseline' for EU. The scenario includes policies already in place, without recent 2030 and 2040 targets that are not yet translated into policies. The scenarios were defined in 2022 and the cut-off date for the scope of policies can be associated with EU 2020 Reference scenario. The policy baseline scenario does not include the following policies:

- An updated EU Effort Sharing Regulation (ESR) (European Parliament and the Council, 2023a) targets per Member State for 2030.
- The EU Emission Trading System reform of 2023 (European Commission, 2023a) is not included: the ETS2 system covering buildings and transport systems is not introduced in this scenario.
- The 42.5% EU RES target in 2030, envisaged in RED III (European Parliament and the Council, 2023b).
- -11.7% final energy consumption reduction relative to respective year in the EU Reference Scenario 2020, the target announced in the revised EED (European Commission, 2021d).

Net Zero scenario

The Net Zero scenario includes the EU reaching net zero greenhouse gas emissions by 2050 in compliance with the European Green Deal agreement and Fit-for-55 policy package aiming to contribute to limit scenarios that ensure limit 1.5°C global temperature increase (see European Commission 2020). The scenario includes the target and policies foreseen by the proposals for the changes in the key directives announced within the Fit-for-55 package. As the scenarios were defined before the recent policy developments as discussed above, the following Proposals were included in the design of the scenario:

- 40% EU RES target in 2030 RED (European Commission, 2021e).
- -9% final energy consumption reduction relative to respective year in the EU Reference Scenario 2020, in the proposal for the energy efficiency directive (European Commission, 2021d).
- updated energy performance standards for buildings in EPBD (European Commission, 2021c).
- Proposal for ETS reform 2021.

The socio-economic assumptions used in models should be the same as in Current policies scenario.

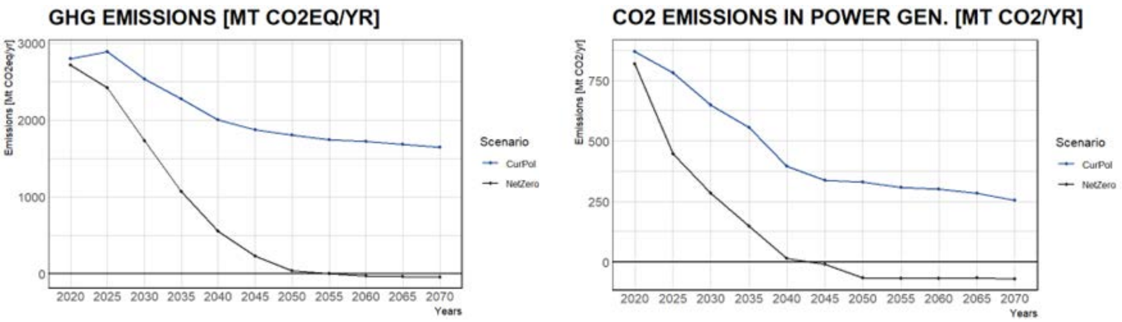
Results

Results for Current Policies and Net Zero scenarios have been uploaded to the YODA repository of Utrecht University (UU). Below, we present some of the key results[1]. Emission reduction pathway for the EU27 is presented on the Figure 8. The Net Zero scenario reaches the net zero emission reduction target for the EU in 2050. The current policies scenario achieves -60% GHG emissions reduction in 2050 and thus misses the EU target. The power sector of the EU reaches the net zero emissions earlier, after 2040, driven by the carbon price: in 3020, carbon price 31 EUR2020/tCO_2 in Current Policies scenario and reaches 260 EUR2020/tCO_2, see Table 5.3.1 and 5.3.2. for the details.

Decarbonisation of the primary energy consumption in Net Zero scenario is accomplished by the increase in the renewable energies – wind and solar, see Figure 9 (left). Final energy consumption in Net Zero scenario rises in the long run, responding to the higher electrification in the end-use sectors, see Figure 9 (right). Decarbonisation of the power generation contributes to the reduction of emissions in the residential, transport and industrial sectors.

Member States with high current water needs for cooling of thermal power plants tend to reduce their needs in the future, when net zero carbon policies and national fossil fuel and nuclear phase-out policies gain momentum.

In the Net Zero scenario, consumption, and withdrawal of water by the thermal power generation is lower than in the Current Policies Scenario in most EU countries. In some Member States, expansion of nuclear and gas capacities contributes to growing water needs in the future. More ambitious Net Zero policies contribute to the reduction of the water needs in the energy sector in the future, compared to Current Policies. This is driven by the larger share of renewable energy generation in the power mix. Lower water consumption and withdrawal needs for cooling thermal capacities contributes to the resilience of the power generation sector to the future climate conditions. However, when intermittent capacities dominate the power mix, flexibility potential of the system gains importance (as long-term battery storages, pumped hydro, etc.). In the Net Zero scenario, hydropower generation (here run of river hydropower, excluding pumping) is higher compared to the Current Policies scenario, see Figure 10)[1].



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[1] The data is also available for the following aggregate regions: EU27 & UK, EU27, Eastern Europe, Scandinavia, South-East Europe, Southern Europe, Iberian Peninsula, Central Europe, United Kingdom & Ireland.

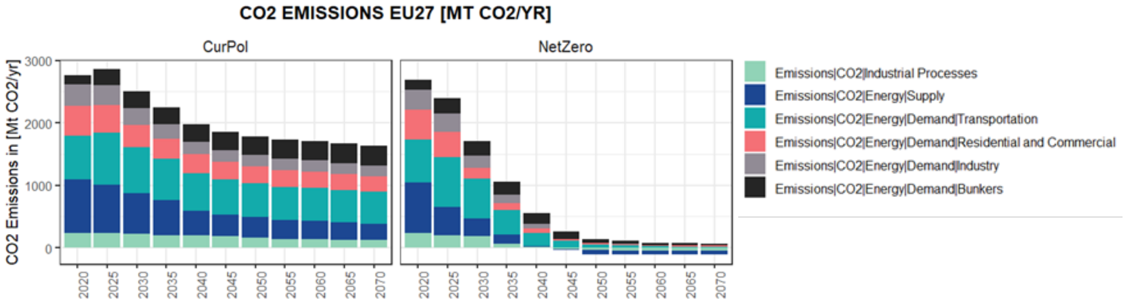


Figure 8. Emissions projections for the EU27 in Current Policies and Net Zero scenarios.

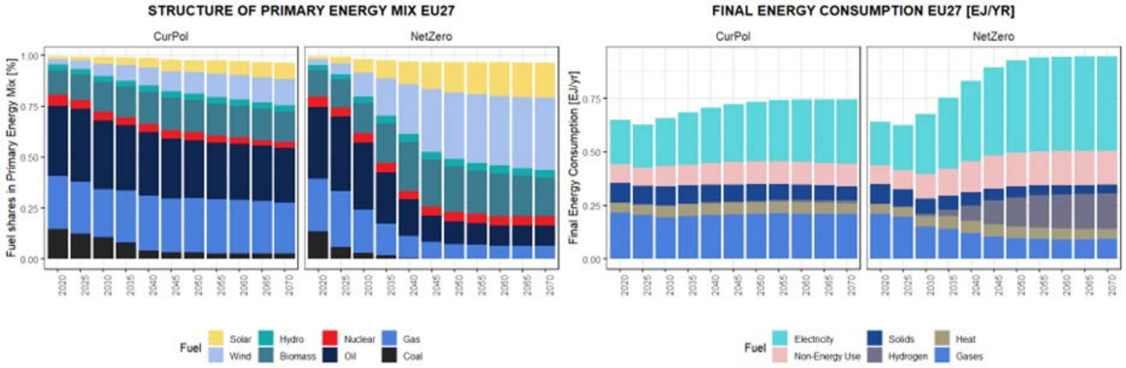
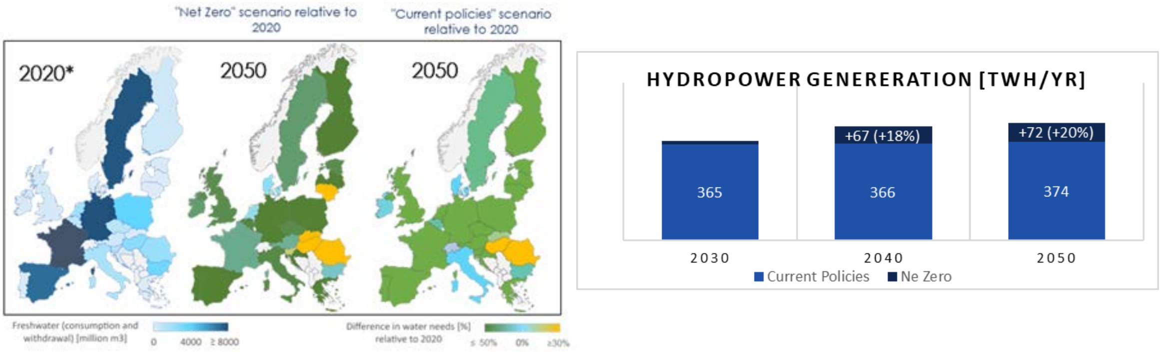


Figure 9. Primary energy mix (left) and final energy consumption in sectors (right).



*semicalibrated data

Figure 10. Freshwater needs for cooling of thermal power plants in 2050 (left) and hydropower generation (right) in the modelled scenarios.

Specific attention is paid to constraints for biomass potential. The Net Zero scenario, compared to Current Policies scenario, requires comparatively higher domestic production of feedstocks, see Figure 11 Understanding the implications of higher ligno-cellulosic crops and water needs from bioenergy demand is crucial. The findings will benefit to the elaboration of mitigation scenarios for the future energy system within the framework of ambitious climate and energy policy targets.

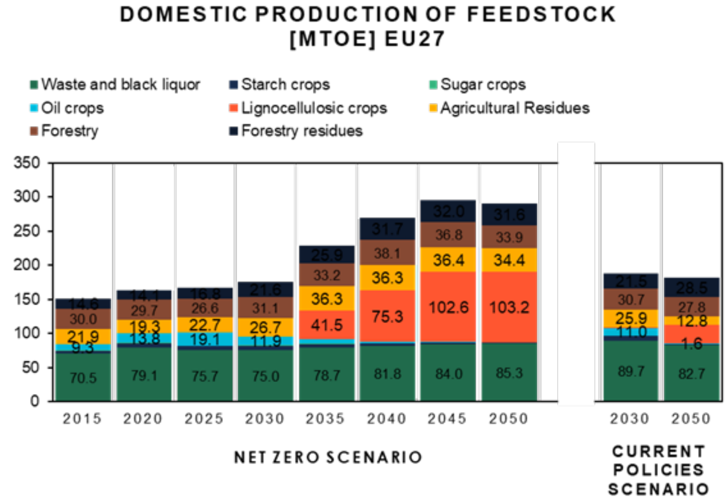


Figure 11. Domestic production of feedstock [Mtoe] in EU27 in the modelled scenarios

5.4 GLOBIO

Our study assessed the effects of variations in streamflow and water temperature—specifically, the weekly minimum and maximum values—on the geographic distribution of 444 riverine fish species across the EU27. We analyzed these impacts under various Representative Concentration Pathways (RCPs: 2.6, 4.5, 6.0, 8.5) using data from five Global Climate Models (GCMs) for the years 2030 and 2050. The selection of these RCPs was based on the availability of corresponding weekly data on streamflow and water temperature (i.e., the required input for the GLOBIO model) in the FutureStreams dataset (Bosmans et al. 2022). While our analysis aligns with the GoNEXUS baseline scenarios for RCP2.6 and RCP8.5, we diverge by incorporating RCP6.0 instead of RCP7.0, thus focusing on a mitigation scenario rather than a baseline. This choice reflects our commitment to exploring potential pathways for reducing climate impact.

We combined the RCPs with three situations for the presence of dams: no dams (for comparison), current dams (from the GRanD and GOODD databases), and current + future dams (adding dams from the FHReD database). We developed two key indicators to measure impact. The first indicator quantifies the proportion of each fish species' geographic range that is at risk due to alterations in streamflow, water temperature, and dam presence, calculated as an average across the Global Climate Models (GCMs) and depicted in Figure 12. These species-level results highlight that impacts are highly variable: for some species, nearly the entire range is threatened by climate change, while for others it is a negligible proportion. In addition, there are clear increases in the proportions of range threatened from 2030 to 2050 and with increasing warming levels, with particularly large proportions of range threatened for the RCP8.5 warming scenario. Further, the presence of dams leads to a clear overall increase in the proportion of threatened range compared to the impact of climate change alone.

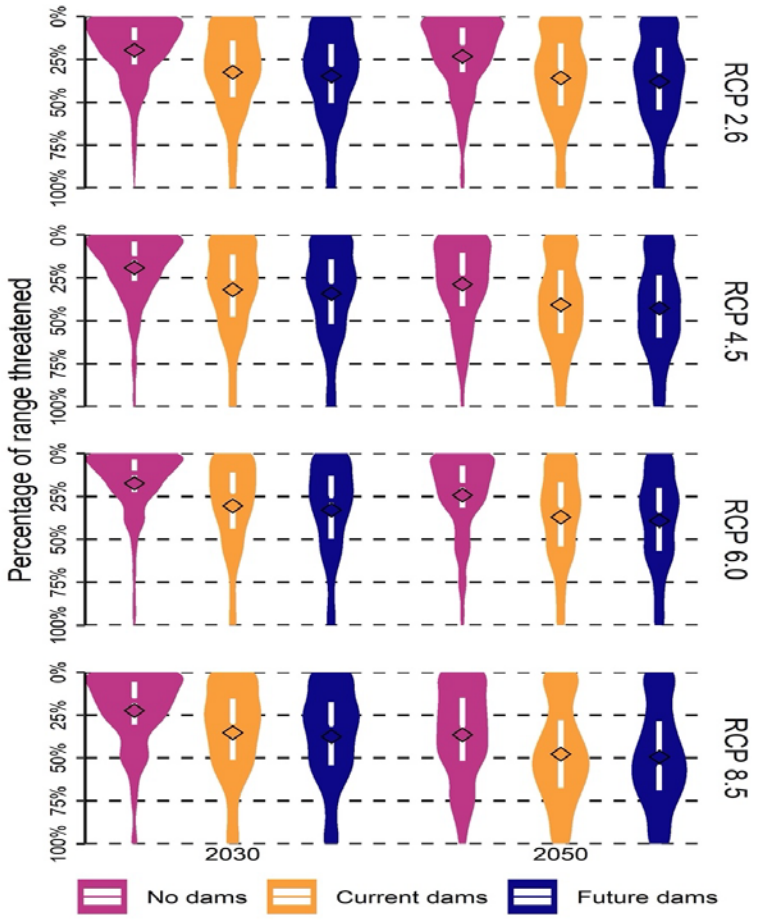


Figure 12. Potentially lost range (%) of riverine fish species in 2030 and 2050. The violin plots show the proportion of geographic range threatened by future climate extremes for 444 riverine fish species in Europe (EU27), different scenario years and three dams situations. For each species and year, the mean across the different GCMs is calculated. Within each violin, the white boxes show the interquartile range as well as the median, while diamonds represent the mean across the species.

Table 8. Median (and 5 – 95 percentiles) of potentially lost range (PLR) across 444 riverine fish species in the EU-27 for different climate change scenarios and years in a future dams situation.

Model	Scenario	Region	Category	Variable	Unit	Year	Value
GLOBIO	RCP2.6	EU27	biodiversity	PLR	%	2030	30.6 (0.0 - 87.1)
GLOBIO	RCP4.5	EU27	biodiversity	PLR	%	2030	29.9 (0.0 - 90.4)
GLOBIO	RCP6.0	EU27	biodiversity	PLR	%	2030	27.2 (0 – 91.6)
GLOBIO	RCP8.5	EU27	biodiversity	PLR	%	2030	33.1 (0.0 - 94.8)
GLOBIO	RCP2.6	EU27	biodiversity	PLR	%	2050	34.5 (0.0 - 93.7)
GLOBIO	RCP4.5	EU27	biodiversity	PLR	%	2050	42.6 (0.7 - 94.2)
GLOBIO	RCP6.0	EU27	biodiversity	PLR	%	2050	35.7 (0.3 - 93.8)
GLOBIO	RCP8.5	EU27	biodiversity	PLR	%	2050	52.2 (1.1 - 98.3)

The second indicator is the potentially affected fraction (PAF) of freshwater fish species per grid cell due to changes in water temperature, streamflow and the presence of dams (Figure 13). These spatially explicit model results reveal that climate change threats are particularly prominent in southern Europe, while threats by dams are more prominent in central Europe and Scandinavia.

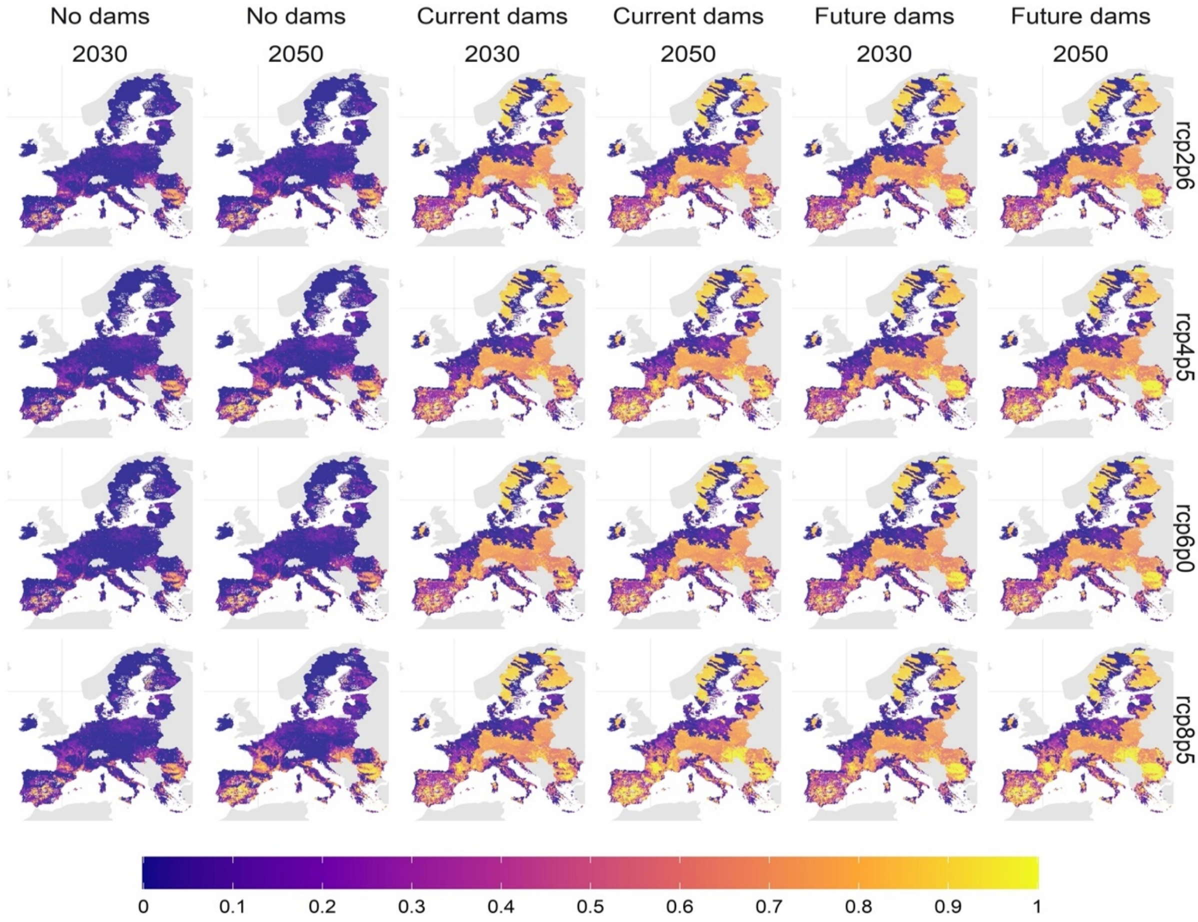


Figure 13. Potentially affected fraction (PAF) of riverine fish species due to exposure to water flow and temperature extremes beyond current levels, for different scenario years and dam situations. Patterns are based on the median PAF across the GCMs at a five arc-minute resolution (~10 km). Gray denotes no data areas (no species occurring or no data available), or areas outside the EU27.

6 Next steps

After tier 1 runs of baselines, the individual models improved will be interconnected. This entails including the interconnections between Water (LISFLOOD-EPIC), Energy (PRIMES), Food (CAPRI) and Ecosystems (GLOBIO). Interlinkages will be established by exchanging information between models for each simulation period. After that, a second scenario run (Tier 2) will then be simulated based on common inputs from WP2 but also using the model linkages. For the Baseline scenario runs (Tier 2 runs), the following scenarios are proposed: Sustainable development (SSP1-2.6) and Weak cooperation (SSP3-7.0) scenarios. The goal is to quantify the impact on the WEFE sectors and policies under the projected climate conditions and model results comparison between Tier 1 and Tier 2 runs.

Furthermore, an update of the evidence obtained and reported in this D5.4, including the outcomes of the simulation of the solutions defined in WP7, will be delivered in D5.5.

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