Deliverable 5.2

Implementation report for Nestos CS

Lead: NTUA
Date: February 2025

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003881

Project Deliverable

Project Number	Project Acronym	Project Title
101003881	NEXOGENESIS	Facilitating the next generation of effective and intelligent water-related policies, utilizing artificial intelligence and reinforcement learning to assess the water-energy-food-ecosystem (WEFE) nexus

Instrument:	Thematic Priority
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Title
Deliverable 5.2: Implementation report for Nestos CS

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Abstract

This Deliverable synthesises the activities implemented in the Nestos/Mesta Case Study between September 2021 and February 2025. It summarises activities related to the different Work Packages (WPs) of the project and outcomes related to: stakeholder engagement, policy analysis and assessment of policy coherence, the design of the Nestos/Mesta conceptual model/map and System Dynamics Model (SDM), the design and testing of the NEXOGENESIS Policy Assessment Tool (NEPAT) for the case of Nestos/Mesta, recommendations and lessons learned.

Nestos/Mesta is a transboundary Case Study (Case Study 1 – CS1) covering the Nestos/Mesta transboundary river basin shared between Greece and Bulgaria. Therefore, in addition to the sustainable management of water, energy, food and ecosystems sectors, transboundary issues regarding the bilateral relationships between Greece and Bulgaria, at both national and local levels, were also analysed as an important first step towards better cooperation and coordination between the two countries, targeting the common management of the river and the available resources. So far, five (5) stakeholder workshops, one (1) round of interviews (field visit) and two (2) Focus Groups have taken place. The final 6th workshop will be conducted in spring 2025.

By implementing a co-creation process, existing problems and pressures on the Water-Energy-Food-Ecosystems (WEFE) nexus were explored, possible solutions and policy options were reported, administrative processes and policy gaps were investigated, data (qualitative/quantitative) to be included in the models was gathered, policies were tested and validated by local stakeholders, and relevant recommendations were formulated. By implementing a trans-disciplinary approach among the several WPs of the project, modes of co-creation were defined (WP5), governance assessment was conducted (WP1), quantitative (physical and socio-economic) data was shared to CS1 (WP2), a fully descriptive conceptual model/map, an advanced hydrological model and an analytical SDM were built (WP3), a beta version of the NEPAT has been designed and is available for testing policies and policy packages (WP4), a roadmap for CS1 implementation along with a CS1 monitoring plan and a plan focusing on the internal communication strategy were prepared (WP5) while, promotion and dissemination material has been shared to CS1 (WP6) supporting impact maximisation and exploitation of project outcomes.

Keywords

Nestos/Mesta Case Study, stakeholder engagement, policies, models, implementation, roadmap, lessons learned, recommendations

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Abbreviations/Acronyms

AVA	*Avellan Cecilia*
BG	*Bulgaria*
CS	*Case study*
D	*Deliverable*
DSS	*Decision Support System*
GD	*Gotse-Delchev municipality*
GR	*Greece*
IPCC	*Intergovernmental Panel on Climate Change*
M	*Month*
MS	*Milestone*
NM	*Nestos Municipality*
NEPAT	*NEXOGENESIS Policy Assessment Tool*
NXG	*NEXOGENESIS project*
PET	*Potential Evapotranspiration*
RB	*River Basin*
RCP	*Representative Concentration Pathway*
RES	*Renewable Energy Sources*
SDM	*System Dynamics Model*
SH	*Stakeholder*
SHE	*Stakeholder Engagement*
SLNAE	*Self-Learning Nexus Assessment Engine*
SSP	*Shared Socioeconomic Pathway*
WEFE	*Water, energy, food, and ecosystems*
WP	*Work package*
WS	*Workshop*

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1. Introduction

Water, energy, food, and ecosystems (WEFE) are interconnected and comprise a coherent system (nexus), which is characterized by complexity and modulated by climatic and socio-economic drivers. In the WEFE nexus content, economic development (including optimal trade, market, and policy solutions) is hampered by resource constraints and their interconnectedness. In addition, the adoption of a sectoral approach in developing and implementing policies may affect nexus characteristics, which in turn can affect decision-making and policy formulation/implementation.

NEXOGENESIS (NXG) project develops and validates:

a) a coherent, cross-sectoral policy-making framework at different scales addressing climate and socio-economic change, as well as stakeholder behaviour and transboundary (diplomacy) issues, developed for and validated by stakeholders, policymakers, and academics;
b) a Self-Learning Nexus Assessment Engine (SLNAE) exploiting reinforcement learning, and supporting streamlining of water-related policies into the WEFE nexus;
c) a WEFE Nexus Footprint, accompanying the SLNAE.

Please note that the Self-Learning Nexus Assessment Engine (SLNAE) is hereafter referred to as the nexus/NEXOGENESIS Policy Assessment Tool (NEPAT). This is because this new term is more intuitive for non-project/non-expert readers.

NXG applies its approach to ***five case studies (CSs): four European and one in Southern Africa*** (Figure 1, Table 1). Through these CSs, strong stakeholder engagement and validation of output, the project will improve policies and policy-making processes to enhance cooperation and help the EU achieve targets related to the Water Framework Directive, the greener CAP, Green Deal ambitions, and ambitions on water diplomacy.

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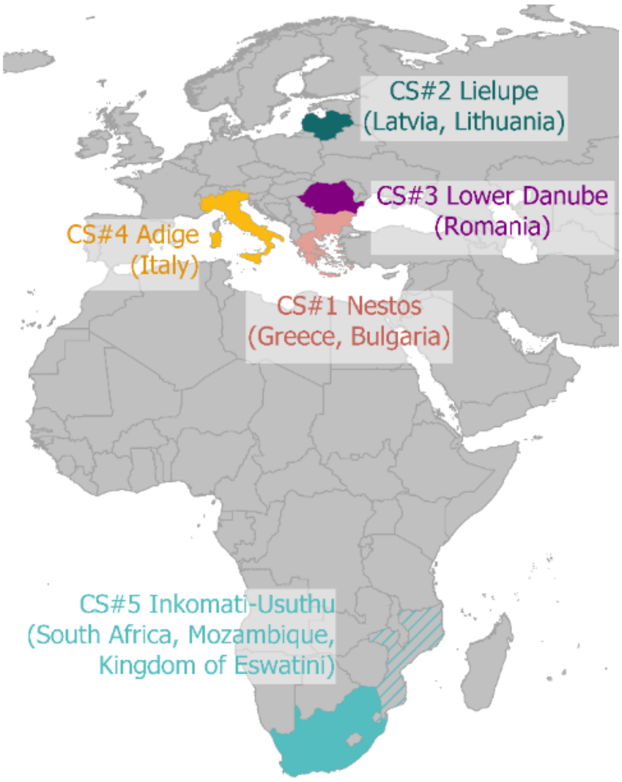
Figure 1: Map of the case studies



The five CSs comprise diverse spatial, social and cultural characteristics, and have a history of development challenges. They also feature strong WEFE nexus relations, with the potential for disruption from policy implementation, allowing for an assessment of how water-related policy can be streamlined into the nexus. They allow for out-scaling to broader regions and, due to the diversity of cases and the coherent framework, wider-scale out-scaling to other regions globally will be possible. Dedicated CS partners offer access to stakeholder consultation at different tiers, ensuring maximum engagement and project impact.

Nestos/Mesta and Lielupe CSs, serve as "frontrunners" (see Table 1), which means that they conduct CS activities slightly earlier (ca. 2 months) than others (so called "followers") to identify potential problems, redundancy or shortcuts in the applied methodology.

Table 1: Overview of the five case studies

Case Study Name	Countries	Project Category
Nestos/Mesta	Greece (GR) Bulgaria (BG)	frontrunner
Lielupe	Lithuania (LT) Latvia (LV)	frontrunner
Jiu, Lower Danube	Romania (RO)	follower
Adige	Italy (IT)	follower
Inkomati-Usuthu	South Africa (RSA)	follower

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1.1 Goals of the report

This deliverable (D5.2) focuses on the Nestos/Mesta CS (CS1) development, implementation and validation processes between September 2021 and February 2025. Nestos/Mesta is a transboundary CS covering the Nestos/Mesta river basin shared between Greece (GR) and Bulgaria (BG). Technical information, including the modelling of the physical system (e.g. hydrological model and SDM) and the analysis of the WEFE nexus policy framework in the two countries as well as details related to stakeholder engagement and co-creation activities are analytically delineated. Relevant activities include the detailed description of the state-of-the-art as to the physical environment and the available resources, the exploration of pressures put on the WEFE nexus, the analysis of policies governing the relevant sectors (water, energy, food/agriculture, ecosystems/biodiversity), the organisation/coordination of participatory activities (stakeholder workshops, interviews, focus groups), the establishment of a roadmap based on local priorities and the systematisation of stakeholder (SH) input (Papadopoulou et al., 2025, (under review)) in order to be incorporated into solutions / policy packages quantified and inserted into models and the NEPAT. The deliverable concludes with emerging CS-specific lessons learned, experiences and recommendations as to the future development of the study area under climate change conditions. CS activities outlined in the *NXG Roadmap* (MS2), the communication activities relevant for CSs presented in the *NXG Internal Communication Plan* (MS5), the SH identification process to generate the stakeholder register for each CS described in the *NXG Stakeholder Register* (MS6), and the monitoring activities outlined in the *NXG monitoring plan* (MS8) are also summarised.

In this context:

- existing problems and pressures were explored based on literature review (scientific findings reported for Nestos/Mesta RB), previous experience (the partner's involvement in previous projects) and SHs' input (bilateral interaction with local actors) (WP5/NTUA, Nestos Municipality (NM), Gotse-Delchev Municipality (GD));
- a detailed conceptual model/map was prepared by modellers (WP3/UTH) and CS leaders (NTUA), and validated by local SHs (WP5/NM,GD), describing in qualitative terms the prevailing interlinkages, interdependencies and trade-offs among the WEFE nexus sectors;
- an advanced hydrological model describing the hydrological behaviour of the Nestos/Mesta river basin was designed and validated (WP3/NTUA);
- a complex System Dynamics Model (SDM) – "translation" of conceptual model/map into quantitative terms – was designed (WP3/UTH) including quantitative data referred to the water, energy, food and ecosystems sectors and incorporating trends described in four IPCC scenarios: (i) RCP2.6 scenario (Low emissions scenario), (ii) RCP8.5 (High emissions scenario), (iii) SSP2 (Middle of the road) and (iv) SSP4 (Inequality – A road divided);
- a policy inventory, including policies governing the WEFE sectors, was created and assessment of coherence among policies was conducted (WP1/NTUA);
- solutions/responses to current problems were sought along with local SHs and a list of policy interventions, co-created with and validated by local SHs, was prepared (WP5/NTUA,NM,GD);
- policy quantification ("translation" of policies into model terms) followed in order for policies to be inserted in the SDM and the NEPAT (WP3/UTH,NTUA);

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- a first (beta) version of the NEPAT was designed (WP4/EURECAT) and was available to CS leaders for testing;
- NEPAT was demonstrated to local SHs (5th SHs' workshop) and policy packages were validated, based on local priorities (WP5/NTUA, NM, GD);
- in total, five (5) SHs' Workshops, one (1) round of interviews (field visit) and two (2) focus groups have already taken place in Greece and Bulgaria where Greek and Bulgarian SHs were given the chance to express their opinions, preferences, aspirations and future expectations (WP1 and WP5/NTUA, NM, GD);
- a 6th SHs' Workshop (WS), the final one, will be organised in spring 2025 where the governance roadmap for CS1 will be presented (already in progress) and the final agreement for the sustainable management of the river basin, based on priorities expressed by local SHs, will take place;
- lessons learned and recommendations are formulated, integrating local needs, SHs' views, CS leaders experience and trans-disciplinary interaction between CS and project WPs.

Note that KPIs and risks are being reported by the co-ordinator of NXG (WP7). A full description of the case study co-ordination process in WP5 is provided in Annex 1. In the following sections, a detailed analysis of all the above mentioned issues takes place. The progress of the Nestos/Mesta CS and the stages of its "maturing" process throughout these 42 months of NXG project are presented along with relevant technological and social achievements.

1.2 Methodology to build the report

A trans-disciplinary co-creation approach has been used to integrate knowledge and experiences at different levels within the several WPs of the project by applying an iterative process for building and refining this deliverable. The document has been developed during months 1-42 of the project to summarise all CS related activities. The outline for this deliverable was developed internally and discussed within WP5. It was based on the outline and information included in MS15 "Intermediate report on case study implementation and co-creation activities for the Nestos/Mesta CS" and MS23 "Second intermediate report on case study implementation and co-creation activities for the Nestos/Mesta CS" (Papadopoulou et al., 2024).

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2 Description of the Nestos/Mesta Case Study

2.1 Basic characteristics

Nestos/Mesta is a transboundary river situated in the Balkan area. It springs from the Rila Mountains in Bulgaria and discharges in the Thracian Sea, Northern Greece (Figure 2). Its basin covers an area of 5,479 km^2 (approximately 2,000 km^2 in Greek territory), and its length is about 243 km. The greater part of Nestos/Mesta river basin is (semi-) mountainous; the only exception is the delta area (estuaries). The river forms a significant ecosystem throughout its course and its delta is a unique ecosystem protected by the Ramsar Convention. It is also considered as a first priority site under EU Natura 2000. In the early 1990s, two dams were constructed mainly for electricity production purposes, in the Greek part of the river (downstream), Thissavros and Platanovrisi (170 m and 95 m height, respectively), by the Greek Public Power Corporation S.A. (PPC) at a distance of 30 km and 45 km respectively from the Greek-Bulgarian border. The dams, besides energy production, cover the irrigation needs of highly economic value cultivated areas downstream and regulate the ecological flow throughout the year. Moreover, a dam to regulate the river flow downstream to the irrigation network of the delta plain is operated near Toxotes village.

Figure 2: Location of the Nestos/Mesta CS

Small towns and villages are located within the Nestos/Mesta river basin and the main activities supporting local income are agriculture and livestock. Aquaculture and mussel farming activities are also taking place within the Nestos Delta region. High value crops (e.g. kiwis) are intensively cultivated and seasonal water resources management is therefore a major issue

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that needs to be resolved to overcome the conflicting water uses between electricity production and irrigation needs. As a result, groundwater is pumped, leading to problems related to seawater intrusion. Water is also needed to maintain the sensitive and protected Nestos Delta ecosystem. Finally, it should be mentioned that the region consists an important transit hub as the airport of Kavala and the port of Keramoti serve nationally and internationally significant tourist flows, especially during the summer.

2.2 Description of the nexus components

The main nexus issues addressed during the project include water use, energy production, ecosystem health and food production. The Nestos/Mesta river basin is among the low-income regions in both Greece and Bulgaria. The prevalent economic sectors supporting local income are agriculture and livestock, and there is limited industrial activity which is more pronounced in the Bulgarian part. The basin has a significantly valuable ecosystem, the health of which may conflict with hydropower generation. Agricultural and livestock activities, in the Greek part, demand significant irrigation water, particularly during the Mediterranean summer, something that entails conflicts between the water and energy sectors as both energy producers and farmers use water from the two dams in order to cover energy and irrigation needs. Over-pumping groundwater has emerged as a problem, threatening groundwater coastal aquifer from seawater intrusion, impacting wetland ecosystems and affecting groundwater quality. Thus, water use conflicts and sustainable management of the available surface and groundwater resources constitute important issues taken into consideration.

2.2.1 Water

Regarding the water sector, flood risk is of utmost importance and emphasis should be placed on the construction of relevant infrastructures that will optimize flood management. Water-diplomacy issues between Greece and Bulgaria are also important and require the adoption of efficient policies targeting at the mitigation of flood events and the reduction of pollution. Water pollution is affected by surface runoff in the cultivated area and plastic waste discarded in the river from several activities taking place in the region. Main water uses include water supply, irrigation, hydro-power production and ecological flow. Water use conflicts between agricultural and energy sectors are critical, especially during the dry summer season. Preservation of the minimum ecological flow is also a significant factor that should be taken into consideration as it directly affects the quality and conservation of ecosystems.

2.2.2 Energy

Electricity production in the region is via the two hydropower dams (Thissavros and Platanovrisi) located along the Greek side that also regulate the water flow downstream. As already mentioned, an important conflict between the energy and the water sectors is limited water volumes for irrigation due to the restrictions of the dam operator in the operation of the hydro-power facilities. Emphasis has not paid yet in the rich geothermal potential of the area that may be exploited while, cultivation of energy crops, exploitation of agricultural and forest

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biomass, and expansion of photovoltaics in buildings and "low-productivity" land should also be prioritized.

2.2.3 Food

Food production is strongly tied to the agricultural sector and thus affected by the new conditions imposed by climate change (e.g. increase in irrigation water requirements). High-value crops such as kiwis, grapes, asparagus, almond trees, walnuts, hazelnuts, floriculture, corns and maize, aromatic herbs, cotton, apple trees, forest crops, olives, energy crops, citrus trees, tobacco, horticultural products (vegetables and fruits), forage plants, cereals and legumes cover significant amount of agricultural land. Livestock is a dynamic sector that also contributes to the food supply chain locally (e.g. meat, milk and honey). Aquaculture activity is also important, including fish and mussels breeding.

2.2.4 Ecosystems

The Nestos/Mesta river basin consists of one of the most vital ecosystems of the Southern Balkan Peninsula. Its delta is of utmost ecological importance and is protected by the Ramsar Convention as a first priority NATURA 2000 site. The natural beauty of the landscape attracts a significant number of visitors, especially during the summer. The main pressures that the ecosystem faces are: a) the fluctuating ecological flow (a minimum threshold should be maintained during the whole year), b) the coastal erosion (especially in the estuaries), c) the impacts of climate change on the aquatic ecosystem (i.e. threats on flora and fauna) and d) flood risks and drought.

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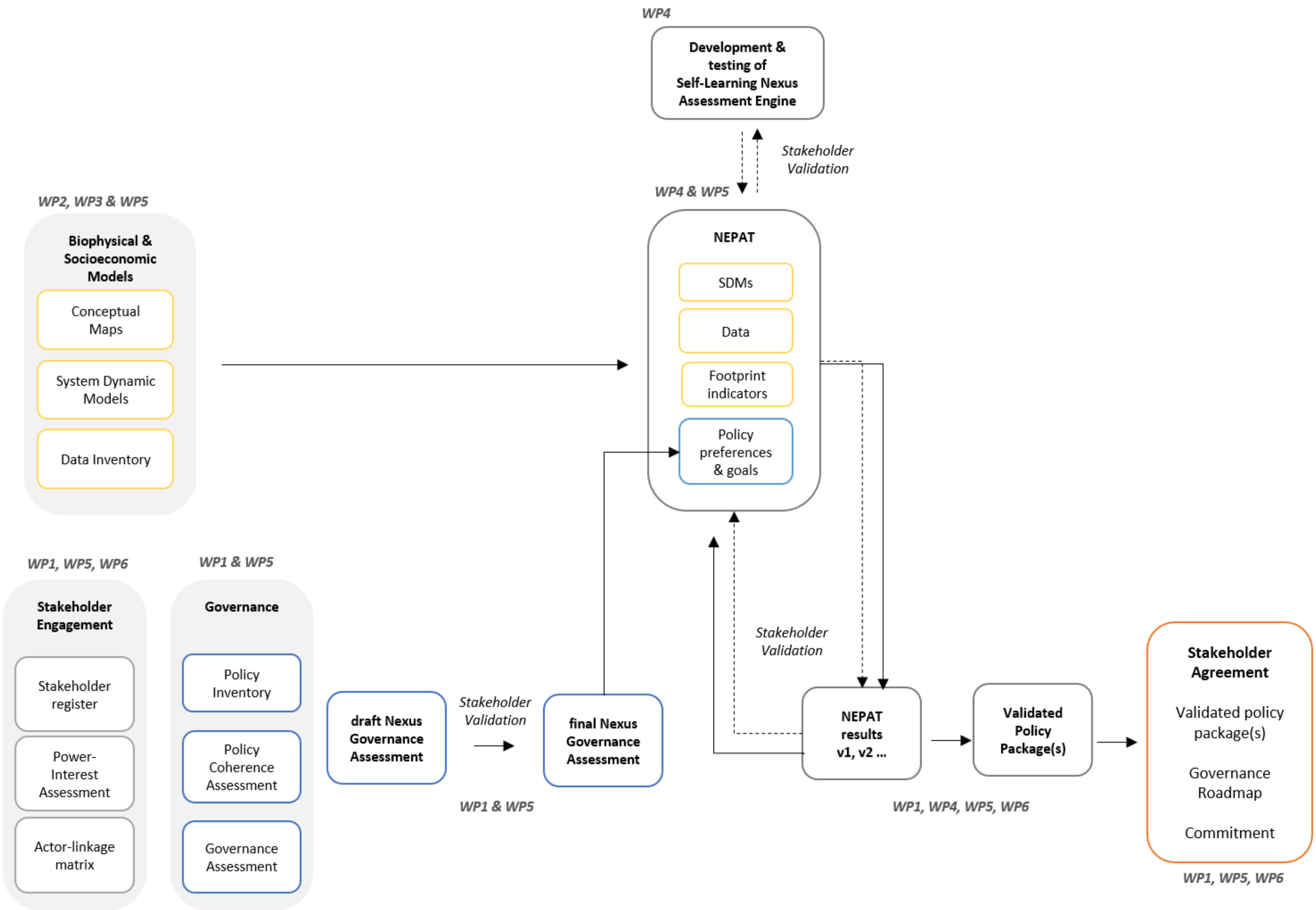
3 Implementation of the case study work in WPs 1-6

This section describes the activities conducted in the Nestos/Mesta CS within each WP of NEXOGENESIS. Figure 3 provides an overview of the NXG approach, showing the outputs from each WP and how the WPs are connected. A full list of all individual activities performed during the project can be found in Annex 2.

Figure 3: Overview of the NXG approach, showing the main activities in WP1-6 and the connections between WPs (figure produced by Sabina Khan, UFZ)



3.1 From stakeholder perception to nexus governance assessment (WP1)

The NXG project builds on a coherent, cross-sectoral policy-making framework at different scales addressing climate and socio-economic change, as well as stakeholder behaviour and transboundary (diplomacy) issues. WP1 specifically focuses on the co-creation of WEFE nexus governance and water policy streamlining. Thus, WP1 creates a water-energy-food-ecosystem

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(WEFE) nexus governance assessment tool (NXGAT) that is used in the course of the project to measure the quality of existing and potentially future WEFE nexus governance regimes.

4.1.1 Governance assessment in the CS

Governance assessment in the Nestos/Mesta CS refers to policy analysis of several WEFE nexus-related policies (Greek and Bulgarian policy framework), assessment of policy coherence, a series of interviews between WP1 and local stakeholders as well as the organisation of two focus groups (March 2023: with Bulgarian SHs and May 2023: with Greek SHs) aiming at the validation of policy coherence analysis by a targeted group of stakeholders (policy experts and practitioners).

Regarding policy analysis and assessment of policy coherence, a policy inventory including WEFE nexus-related policies (16 Greek policy papers, 9 Bulgarian policy papers) has been created (Table 2). When examining their content, policy goals and instruments were extracted and ties between one nexus sector and the rest, from a policy level perspective, were explored. The assessment of policy coherence and the level of integration of sectoral policies was conducted by searching references that a sectoral policy paper makes to other sectoral policy papers (e.g. a reference to agricultural or energy policies that is included in a water policy document). Based on the outcomes of the policy analysis process, a strong level of integration exists between energy and water policies, agricultural/food and water policies, and energy and biodiversity/ecosystems policies. The results have been further elaborated by WP1 and a deeper insight into the level of integration and existing policy gaps can be found in D1.2 *"Governance and Policy Assessment in Case Studies"*.

Table 2: Overview of the policy inventory (GR/BG)

No	Country	WEFE sector	Type of document	Title of document
1	GR	Water	Law (Law 3199/2003)	Law 3199/2003 on the protection and management of water resources - Reconciliation with the WFD 2000/60/EC
2	GR	Water	Decree (Decree 51/2007)	Legislative Decree 51/2007 on the determination of measures and procedures for the integrated protection and management of water resources in compliance with the WFD 2000/60/EC
3	GR	Water	Decision [Decision 39626/2208/E130 (2009)]	Measures for the protection of groundwater from pollution and deterioration in compliance with the European Directive 2006/118/EC
4	GR	Water	Common Ministerial Decision [Decision 31822/1542/E130 (2010)]	Assessment and management of flood risk in compliance with the provisions of the European Directive 2007/60/EC

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No	Country	WEFE sector	Type of document	Title of document
5	GR	Water	Common Ministerial Decision [Decision 135275 (2017)]	General rules regulating the costs and pricing system of water services – Method and processes for recovering costs for water services and relevant water uses
6	GR	Energy	Decision (Decision 49828/2008)	Special legislative framework of spatial planning and sustainable development of the renewable energy sector; strategic environmental impact assessment
7	GR	Energy	Law (Law 3468/2006)	Electricity production from RES and cogeneration of high performance electricity and heat
8	GR	Energy	Law (Law 3734/2009)	Promotion of energy cogeneration - Issues concerning the Mesochora hydroelectric power project
9	GR	Energy	Law (Law 4001/2011)	Operation of electricity and natural gas markets - Research, production and transmission networks for hydrocarbons
10	GR	Energy	Law (Law 4414/2016)	Support electricity production from RES, high performance electricity and heat production from cogeneration - Natural gas supply and distribution
11	GR	Energy/Climate	Decision (Decision 4/31-12-2019)	Ratification of the national energy plan for energy and climate
12	GR	Food/Agriculture	Law (Law 4036/2012)	Pesticides market in Greece - Rational use of pesticides
13	GR	Food/Agriculture	Law (Law 4282/2014)	Development of the aquaculture sector
14	GR	Food	Law (law 4235/2014)	Administrative measures, processes and penalties for the implementation of EU and national legislation in the sectors of food, feed, health and protection of animals
15	GR	Biodiversity/Ecosystems	Law (Law 3937/2011)	Preservation of biodiversity
16	GR	Biodiversity/Ecosystems	Decision (Decision 40332/2014)	National strategy for biodiversity between 2014-2029 and 5-years action plan
17	BG	Water	Law	Water law
18	BG	Water	Ordinance No.1/10-10-2007	Ordinance No.1 from 10.10.2007 on the exploration, use, and protection of groundwater
19	BG	Water	Law	Law on regulation of water supply and sewerage services
20	BG	Ecosystems	Law	Environmental protection act
21	BG	Cross sector	Law	Disaster protection act
22	BG	Energy	Law	Energy act

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No	Country	WEFE sector	Type of document	Title of document
23	BG	Energy	Law	Energy from renewables act
24	BG	Climate	Law	Climate change mitigation act
25	BG	Water	Regulation	Regulation No. 2 on the protection of waters against nitrate pollution from agricultural sources

In July 2022, Nestos/Mesta CS leaders and partners (NTUA, Nestos Municipality, Gotse-Delchev Municipality), along with WP1, organised a field visit in the Nestos/Mesta river basin. A total of 25 stakeholders (14 from the Greek side and 11 from the Bulgarian side) took part in the interviews conducted by WP1. The main issues discussed related to:

- flood security and prevention;
- preservation of ecosystems;
- level of cooperation among the several decision-making bodies (national, regional, local);
- responsibilities as to water management and energy issues in the Nestos river basin (Greek side);
- agriculture and water management;
- protection of species/fish in the region;
- the role of dams for water management and irrigation water needs;
- relationships among different levels and scales of sectoral governance (water, agriculture, energy and ecosystems);
- the role of the actors in such different levels and scales of governance and their relationships (cooperative or competitive);
- strategies and tools applied to change the governance of the WEFE sectors; and
- responsibilities and resources allocation.

Deliverable 1.2 analyses the outcomes of the field visit, and elaborates on current needs, problems and inconsistencies. Briefly, in Bulgaria, the current governance system is described as *"highly restrictive"*, due to the centralised and hierarchical administrative context, the long amount of time needed for administrative tasks, fragmentations of responsibilities across administrative organisations, the sectoral economic vision of the WEFE domains, and the need for cross-sector collaboration in issues related to environmental protection and renewable energy conflicts. In Greece, the current governance system is slightly less challenging, although still described as "*restrictive*" due to the centralised and hierarchical administrative context, the lack of structured communication between governance levels, and the lack of trust between actors in different WEFE domains.

In March and May 2023, two separate online focus groups were organised in Greece and Bulgaria where a core group of stakeholders (experts-practitioners) participated so that they could validate the results of policy coherence analysis. Participants were representatives of the WEFE nexus sectors (one representative per nexus sector) that have a strong knowledge background on policy design and policy implementation. The focus groups started with a general discussion regarding the results of policy coherence analysis and the relevant scores (SH impressions); a discussion on specific policy instruments and how do they work in practice followed. Issues regarding policy gaps and trade-offs that need to be managed were also raised. Some indicative findings for specific policies that need to be improved include:

- policy papers concerning the preservation of ecosystems/biodiversity should be more integrated with policy papers addressing the food/agricultural sector (Governance assessment results: *no integration*),
- policy papers dealing with the management of hydroelectric power plants should be more integrated with policy papers addressing the ecosystems/biodiversity sector (Governance assessment results*: no integration*),
- policy papers addressing water management issues (e.g. the one that adopts WFD2000/60) need to be more integrated with policy papers addressing the energy sector (Governance assessment results: *weak integration*).

More details can be found in D1.2 *"Governance and Policy Assessment in Case Studies".*

Finally, it should be noted that an additional analysis, concerning the assessment of policy coherence among WEFE nexus-related policies, was conducted in the Nestos/Mesta CS. The methodology introduced by Nilsson et al. (2012), Nilsson et al. (2017) and Weitz et al. (2018), originally applied for assessing environmental policies and the coherence among SDGs, was tested. This methodology was adopted for assessing the level of policy coherence among policies governing the WEFE nexus in the Greek part of the Nestos/Mesta river basin. Two impact matrices were built (policy goals vs. policy goals impact matrix and policy instruments vs. policy goals impact matrix) and pairwise evaluations between pairs of policy goals and pairs of policy goals-policy instruments took place on the basis of a seven-point scale indicating if the implementation of a policy cancels, counteracts, constrains, enables, reinforces, is indivisible from, or is coherent with the implementation of another policy (Papadopoulou et al. 2023). Results are analytically presented in a paper that has been submitted for publication (Mooren et al., 2025 (under review)).

4.1.2 Integrating nexus governance and policy knowledge into modelling and the NEPAT

Nexus governance and policy knowledge was incorporated in the NEPAT through policies, the performance of which are assessed by the tool. For that purpose, policies were quantified - translated into model terms, and indicators calculating their performance were designed. To achieve this, policy packages were structured including policy goals and policy instruments/interventions; policies were translated into the SDM (variables, parameters, equations and indicators) and integrated with the available quantitative data (climatic, demographic, energy data, etc.).

Nestos/Mesta CS was developed based on all the above-mentioned issues in close cooperation with WP1, WP2, WP3, WP4 and the engaged SHs. Some preliminary policy packages were presented and discussed with the stakeholders during the 2nd SHs' workshop in November 2022. The final draft of policy goals and policy instruments was presented to and validated by SHs at the 3rd workshop in March 2023. The final, validated set of policy packages is presented in D1.3 *"Policies for the Self-Learning Nexus Assessment Engine"* and includes policies related to:

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- *Water re-use for irrigation* (wastewater treatment);
- *Agricultural development of new (dynamic) crop types* that could be cultivated in the region (e.g. crops and agricultural products with export capabilities);
- *Increase energy generation from RES* (e.g. exploitation of geothermy, energy crops and photovoltaics for energy production);
- *Preservation of ecosystems* (e.g. reforestation);
- *Protection of water quality*;
- *Modernisation of irrigation infrastructures and saving of irrigation water*;
- *Cultivation of less water demanding crops;*
- *Flood risk management and monitoring water volumes coming from upstream / construction of infrastructures supporting flood prevention;* and
- *Policies targeted at "cleaning" the river and removing transported sediments.*

Such policies were further refined and a final list was determined, including policies that could be quantified and included in the NEPAT based on the available data inserted in the SDM. During February and March 2024, Nestos/Mesta CS leaders worked in close collaboration with WP3 – UTH and explored the possibilities for policy quantification. Based on the available data and the structure of the SDM, **10 policy goals and 12 policy instruments were translated into model terms and integrated in the SDM**. Policy goals and policy instruments reflect local priorities and local needs, and are expected to contribute to the mitigation of climate change impacts and pressures as well as to the confrontation of existing problems; these policies concern:

- **Water sector**: Change of irrigation systems/practices (furrow, drip, sprinkler) – Water saving by the agricultural sector / Limitation of water losses.
- **Water sector**: Replacement of open irrigation canals transferring water from the river to crops by closed pipelines – Water saving by the agricultural sector / Limitation of water losses.
- **Water sector**: Reduction of nitrogen quantity discharged into the river – Reduction of agricultural waste / Decrease of nitrogen concentration in the river.
- **Water sector**: Cultivation of less water-demanding crops – Water saving by the agricultural sector.
- **Water sector**: Extensive use of water saving infrastructures by the sector of livestock – Water saving by the sector of livestock.
- **Ecosystems sector**: Reinforcement of reforestation activities – Protection of forest land / Support CO_2 sequestration.
- **Food sector**: Cultivation of dynamic crops (edible pulse, olives, vegetables) instead of cereals, cotton and sugar-beets – Agricultural development and export capabilities / Diversification of crops.
- **Energy sector**: Decrease of electricity generated by conventional energy sources and increase of electricity produced from RES – Increase RES share in the final gross energy generation / Exploitation of the available renewable energy sources.

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4.1.3 Co-creation of policy packages, governance roadmap and SH agreement

As already mentioned, the Nestos/Mesta CS leaders (NTUA) in collaboration with NM and GD partners prepared policy packages to be incorporated into the NEPAT. This process was carried out with all the involved WPs (WP1, WP2, WP3, WP5) as well as with the SHs involved in the project.

At the beginning of the project, a detailed policy inventory was created and included WEFE nexus-related policies, policy goals and policy instruments dealing with the management of the WEFE nexus sectors. In addition, the main pressures faced in the Nestos/Mesta river basin were explored by CS leaders and the involved SHs during the first workshop. Stakeholders reported on existing problems, shortcomings and pressures that should be taken into consideration during the analysis of relevant policy packages and the design of integrated solutions. Based on this input, CS leaders explored the most suitable policies to be inserted and tested in the NEPAT.

The main issues that suggested to be incorporated in the relevant policy packages concerned:

- “cleaning” the river from transported sediments, flood prevention and protection;
- water use balance (especially when it comes to dams and water availability for energy and irrigation);
- sustainable management of the available water resources / water saving and reduction of water losses;
- protection of water quality;
- wastewater treatment;
- energy production from RES (solar, water, geothermy, agricultural and forest biomass, energy crops);
- sustainable development of agriculture and livestock;
- elimination of land use conflicts (pastures and protected areas);
- official registration of drills/wells;
- preservation of ecosystems (e.g. securing of minimum environmental flow, reduction of waste disposal, management of illegal landfills, protection of forest land);
- monitoring volumes of water coming from upstream (Bulgaria);
- protection of biodiversity from intensive agriculture / expansion of agricultural land;
- creation of an inventory including biodiversity threats;
- reinforcement of aquaculture activities; and
- energy production from composting.

A detailed Excel file, including all requirements for the development of policy packages, was prepared and sent to the Nestos/Mesta CS leaders by WP1. CS leaders worked on all the required data in close cooperation with WP2 and WP3.

A critical factor for designing proper and effective policy packages is data availability as the quantification of policies is a prerequisite in order to be able to incorporate such policies in the SDM and the NEPAT. Thus, data provided by WP2 and also data gathered by national and European databases were fully exploited because a rich data repository would

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allow the quantification of significant policies. Unfortunately, not all of the suggested/validated policy packages were quantified due to data availability limitations but quantified policies reflect critical hot-spots/priorities reported by local SHs such as: a) water saving and reduction of water losses, b) sustainable and rational use of the available water resources, c) further development of the agricultural sector by considering export capabilities of the produced agricultural products, d) reduction of agricultural waste discharged in the river, and e) production of energy by exploiting RES.

In brief, preliminary policy packages were designed (based on regional priorities and pressures reported by the stakeholders during the 1st SHs' workshop) and presented to stakeholders during the 2nd SHs' workshop. A fruitful discussion took place and participants contributed strongly to the validation of suggested policies and the enrichment of this list with additional policies, important for them. The "co-exploration" and "co-creation" participatory approach of the project enabled SHs' opinions and aspirations to be embodied in the final policy packages, which were validated at the 3rd SHs' workshop. WP1 received the list of policies (analytically described in the previous section) that had been quantified for this CS. Unfortunately, there were some policies that could not be quantified (e.g., exploitation of geothermy for energy production, construction of infrastructures to prevent flooding, re-use of water – treated/reclaimed water) due to lack of reliable data.

Regarding the governance roadmap, detailed discussions took place during the face-to-face WP1-WP5 meetings in January 2024 (in Berlin) and in January 2025 (in Athens) in order to start organising the next steps and to decide on the type of stakeholder agreement for the Nestos/Mesta CS. The plan is to select policies included in SH validated policy packages (recommended by the NEPAT), e.g. policies related to the modernisation of irrigation systems, the replacement of open irrigation canals that transfer water from the river to the crops by closed pipelines, the extensive use of water saving infrastructures by the sector of livestock or the cultivation of less water-demanding crops, and to suggest a timeline for their implementation. This plan will be validated during the 6th SHs' Workshop that is going to take place in spring 2025. The timeline will consider the stakeholders to be involved in the implementation of the specific policies, the required resources, the time-horizon for policy implementation, and specific actions/tasks to be undertaken.

In August 2024, CS leaders received relevant material from WP1 (governance roadmap guidance and presentation template) and started working on it. Before conducting the 5th SHs' workshop, they prepared an example of a governance roadmap, based on theory of change and results chains, i.e. explicit steps towards policy adoption and policy implementation by involving local communities and high-level decision makers in the whole process (more details in section 4.5.4 "Summary of the effects of the engagement activities"), to be presented to the SHs. Two indicative examples of policies representing the water and energy sectors were prepared. During the 5th WS such examples were demonstrated to the SHs and a discussion followed. Further work includes the finalisation of the governance roadmap, based on SH validated policy packages, in order a detailed timeline to be presented to and validated by the stakeholders during the sixth SHs' workshop, and a SH agreement to be achieved.

Overall, collaboration with WP1 is excellent. CS leaders are in frequent communication with WP1 team to support all activities related to WEFE nexus governance in the Nestos/Mesta CS.

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3.2 From bio-geophysical modelling to baseline scenarios (WP2)

WP2 focuses on identifying and bringing together relevant nexus data, creating a coherent scientific portfolio of data across case studies to characterize physical, environmental and socio-economic components under current and future climate change conditions through the coming century. The portfolio is developed in line with a set of selected IPCC scenarios, as a combination of shared socioeconomic pathway (SSP) and representative concentration pathway (RCP) scenarios.

The goal is to provide data support for each case study (WP5) concerning appropriate nexus data combinations, and modelling design for WP3 and WP4 purposes. This also supports SHs' acceptance and co-development in WP1 and WP5, in order to characterize relevant case-specific biophysical-human interactions between nexus components.

3.2.1 Quantitative data sharing – Co-creation of trans-disciplinary knowledge

Technical knowledge refers to the quantification of qualitative data into quantitative data, the design of the CS conceptual model/map and SDM, and the incorporation of CS data (policies, SDM and indicators) into the NEPAT. The conceptual model revealed critical interlinkages between the WEFE nexus components and provided significant guidance for the design of the SDM and the required data. Trans-disciplinary knowledge refers to knowledge sharing among CSs, WPs and involved stakeholders, and it also concerns the integration of sectoral knowledge under a common WEFE nexus framework.

Based on the experience and knowledge gained after the 1st and 2nd SHs' WSs, CS leaders along with WP2 and WP3 focused on fulfilling data requirements in order for qualitative information to be modelled and inserted in the SDM and the NEPAT. Quantitative data was delivered by WP2 to WP3 and was further processed and calibrated so that they inserted in the hydrological model and the SDM. Future climate/biophysical and socio-economic data trends were shared, characterising climatic, hydrological, environmental and socio-economic variables in line with RCP2.6, RCP8.5, SSP2 and SSP4 IPCC scenarios. Such data referred to precipitation, temperature, humidity, radiation, surface wind speed, atmospheric pressure, demographic projections, water consumption and withdrawal, nitrogen and phosphorus runoff, imports and exports, food demand, energy generation and emissions. Further details on data sources and models can be retrieved in: D2.1 *"Document information and consolidated data available according to specific Nexus dimensions from Modelling, Repository and Inter-Comparison projects"*, D2.2 *"Nexus data vector of biophysical data for each case study"*, D2.3 *"Nexus data vector of socio-economic data for each case study"* and D2.4 *"Grid-level socio-economic data set"*.

Additional data sources for the Nestos/Mesta CS include: Corine Land Cover / Copernicus Land Monitoring Service (land use – land cover data, digital elevation model), Hellenic National Meteorological Service (data: rainfall, wind speed and direction, temperature, relative humidity,

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barometric pressure), Hellenic Public Power Corporation (data: inflow in dams, ecological flow, irrigation discharge, hydroelectric discharge), Hellenic Statistical Authority, EUROSTAT, etc.

3.3 From conceptual model to complexity science modelling and WEFE nexus footprint (WP3)

WP3 links the biophysical modelling (WP2) and stakeholder input (WP1/WP5), and integrates the outcomes of these WPs through novel complexity science approaches to assess the impacts of water-related policies in a nexus context. For the Nestos/Mesta CS this was performed under different scenarios, according to the requests of WP5 and the stakeholder input and recommendations from WP1/WP5.

3.3.1 Overview of interrelationships among WEFE Nexus components

Complex interlinkages between the nexus sectors have been investigated by WP3 (UTH) and CS leaders, discussed with the stakeholders during the workshops, and taken into consideration during the design of the CSs conceptual model and SDM.

The main interlinkages between WEFE nexus components in the Nestos/Mesta river basin are:

- **Water → Energy**: Energy is needed for: (a) wastewater treatment, (b) pumping for covering irrigation needs.
- **Water → Food**: Water is needed for: (a) irrigation, (b) food processing.
- **Water → Ecosystems**: Continuous water provision is necessary for the preservation and maintenance of ecosystems/wetlands (minimal environmental flow) as water supports ecosystem and wetland sustainability.
- **Energy → Water**: The energy sector uses large volumes of water from dams in order to produce electricity.
- **Energy → Food**: Energy is required for: (a) using agricultural equipment, (b) pumping, (c) food processing. Also, energy crops and photovoltaics limit the area of agricultural land.
- **Energy → Ecosystems**: Energy production infrastructures (e.g. photovoltaics) and energy crops may unsettle the balance of ecosystems and limit the land currently occupied by ecosystems (land use conflicts as the energy sector may eliminate land occupied by ecosystems). In addition, when it comes to hydro-electric power production, the energy sector decreases the amounts of water that are available for the preservation of ecosystems and causes fluctuations in ecological/environmental flow.
- **Food → Water**: The agricultural sector contributes to water pollution (pesticides, fertilizers and other agricultural waste), while food production/processing requires water

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(irrigation infrastructures e.g. irrigation channels, water pumping). The food/ agricultural sector is an important water consumer in the Nestos/Mesta river basin area.
- **Food → Energy**: Food production and processing need significant amounts of energy (agricultural equipment, pumping). On the other hand, agricultural/food waste can be exploited for energy production (biomass).
- **Food → Ecosystems**: The expansion of agricultural land threatens ecosystem maintenance (via wetlands drainage and reduction of grassland), affects ecosystems' quality (via pollution and agricultural waste), and unsettles ecosystem balance.
- **Ecosystems → Water**: The groundwater aquifer is strongly dependent on the proper functioning of ecosystems as ecosystems provide water to the groundwater aquifer. Moreover, ecosystems contribute to the maintenance of water balance.
- **Ecosystems → Energy**: The maintenance of ecosystems requires energy input.
- **Ecosystems → Food**: The preservation of ecosystems puts constraints on the expansion of agricultural land, while securing the minimum environmental flow may affect water used for irrigation purposes.

3.3.2 Main WEFE Nexus challenges

The Nestos/Mesta river is the main water supplier to the physical ecosystem and the economic sectors and activities taking place within its basin. Moreover, it is a transboundary river basin and its sustainable management requires common actions and cooperative efforts by SHs in both Greece (GR) and Bulgaria (BG). WEFE nexus challenges have been explored and also discussed during the SHs workshops organised by both Greek and Bulgarian partners.

The main challenges identified by SHs concern issues related to:
- Preservation of the Nestos ecologically-significant delta (GR).
- Mitigation of flood risk (GR).
- Mitigation of coastal erosion (GR).
- Compromise on water-diplomacy issues between the upstream and downstream countries (GR and BG).
- Monitoring water quality and mitigation of pollution (GR).
- Sustainable management of the available water resources (GR and BG).
- Removal of transported sediments (GR).
- Elimination of land use conflicts (GR and BG).
- Management of conflicts between water uses (irrigation, hydro-electricity power production, minimal environmental flow) (GR).
- Climate change impacts on the aquatic ecosystem (food production, threats on flora and fauna) (GR).
- Exploitation of geothermy for energy production (GR).
- Wastewater treatment (BG).
- Waste disposal and landfills (BG).
- Assessment and sustainable management of eco-system services (GR).
- Strengthen cooperation between municipalities and other interested stakeholders (GR).
- Establishment of a transnational managerial authority – Agreement on a common action plan (GR and BG).

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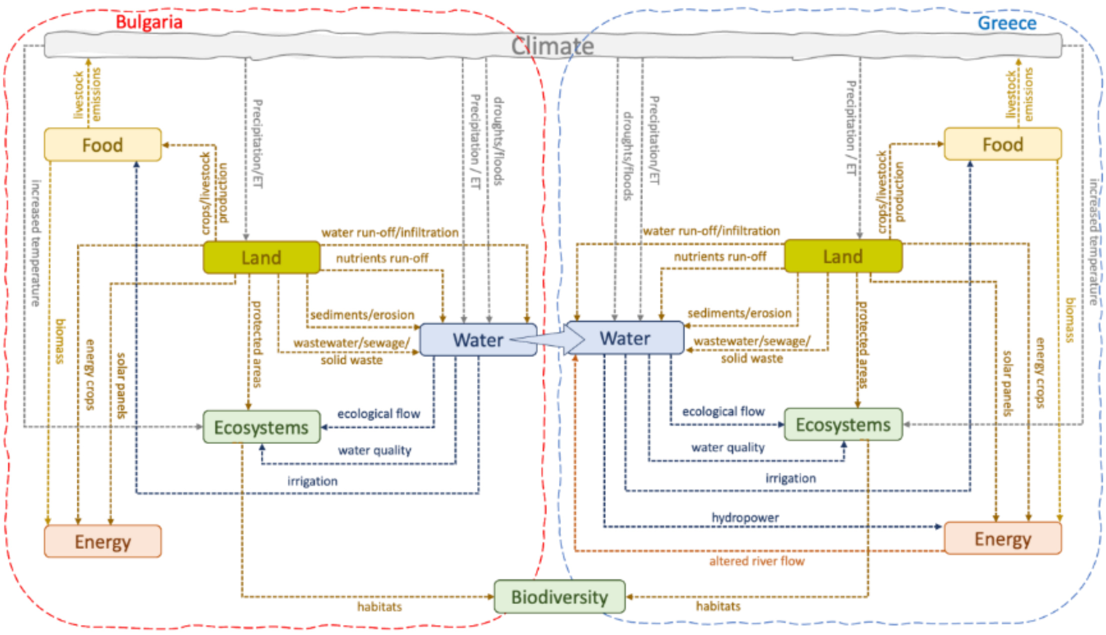
- Design of a common hydrological model for the river basin (GR and BG).
- Organised timber management (BG).
- Assessment of water losses by the agricultural sector (GR).
- Ecological flow: regime definition (GR).
- Combustion of agricultural waste (GR).
- Reinforcing composting activities (BG).
- Regulations/controls regarding grazing land (pastures) (BG).
- Further development of aquaculture (GR).

Such challenges have been taken into consideration to be included into the final policy packages in the NEPAT. Relevant quantitative data were also collected however, not all of the aforementioned challenges are included in the SDM due to lack of available data.

3.3.3 Conceptual Model

The conceptual model/map of the Nestos/Mesta river basin was developed by UTH with the support of CS leaders (NTUA). A preliminary draft was presented to the SHs during the 1st SHs workshop and the final version was validated by the SHs during the 2nd SHs workshop (Figure 4). The adopted methodological approach and stages of its development are analytically described in [Deliverable 3.1: *Conceptual models completed for all case studies*] (pp.17-23).

Figure 4: High-level conceptual map depicting the Nexus interlinkages for the Nestos/Mesta River Basin, source: Laspidou et al. (2022)



In brief, the conceptual model of the Nestos/Mesta CS represents a simple diagram depicting the interlinkages among the WEFE nexus components. It is divided into two sub-systems, the *upstream* (Bulgarian part - Mesta River) and the *downstream* (Greek part - Nestos River), where the water flows across the borders of the two countries (Laspidou et al., 2022).

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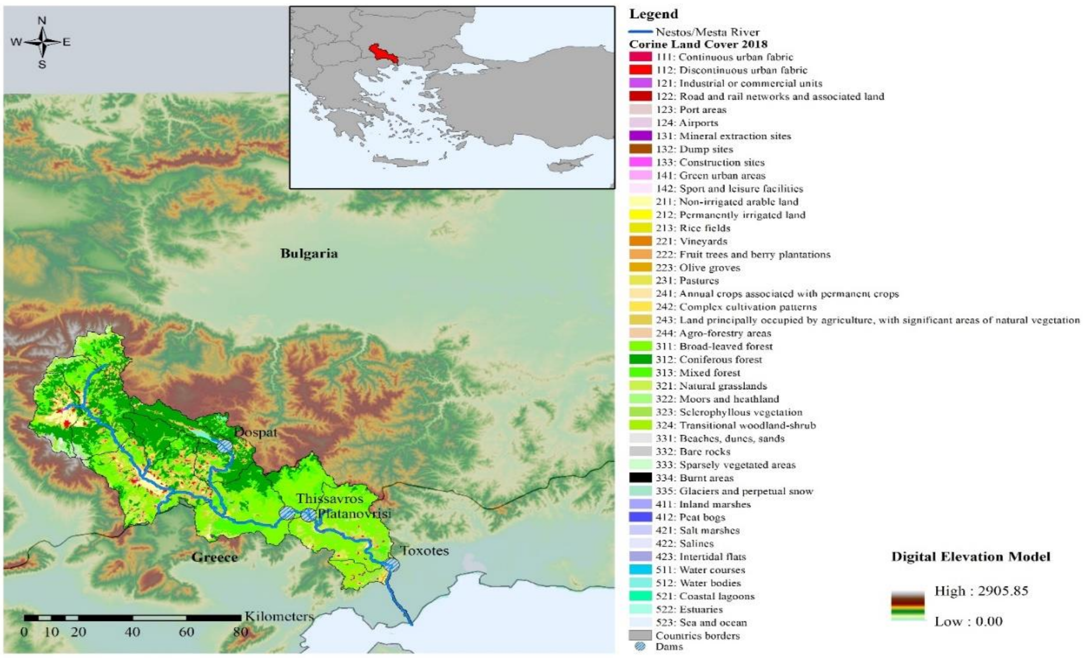
Water is the "common component" shared by the two countries. Precipitation and evapotranspiration rates are strongly dependent on climatic conditions directly affecting the water balance in the river basin. The availability of water also affects the ecosystems, the endemic species (flora and fauna) and the environmental flow. Water is used for irrigation, water supply, electricity production and food processing. Its quality is an important factor for securing the functioning of ecosystems and the production of high-quality agricultural products. The energy sector concerns mainly electricity production from hydropower plants and thus requires significant volumes of water. According to Corine Land Cover 2018, the main land uses in the area are: forest land, agricultural land, grasslands and transitional woodland-shrubs. Agriculture affects water quality (run-off), while human settlements and industrial activities are also "responsible" for waste disposal into the river. Sector-specific conceptual maps can be found in *D3.1: Conceptual models completed for all case studies* (pp.17-23).

3.3.4 Hydrological model and System Dynamic Modelling approach

Hydrological Model

Nestos/Mesta (GR-BG) river basin is one of the 71 transboundary river basins of Europe situated in the Balkan area (Figure 5). The basin is located in eco-region 7 (Eastern Balkans; Directive 2000/60/EC-Annex XIA) and its total catchment area is about 5,479 km^2. A minimum environmental flow of 6 m^3/s is required to be maintained for the conservation of the deltaic ecosystems and for supporting the high value agricultural (e.g., kiwi), livestock and aquacultural (e.g., mussel farms) activities taking place in the area.

Figure 5: Nestos/Mesta river basin, sub-basins, land uses and elevations



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Within the framework of the Nestos/Mesta CS, an advanced hydrological model was designed (Kourtis et al., 2023; Kourtis et al., 2025 (under review)), including 11 sub-basins of the Nestos/Mesta transboundary river basin (7 sub-basins for the Bulgarian side and 4 sub-basins for the Greek side of the basin). Figure 5 presents the study area with the sub-basins, the elevations, the dams and the land uses. The predominant land use–land cover types in the basin are: forests and semi-natural areas (81.0%); agricultural areas (16.4%); artificial surfaces (1.4%); water bodies (1.0%); and wetlands (0.2%).

The hydrological model of the Nestos/Mesta basin was developed by employing the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) software developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers. HEC-HMS software has been widely used around the globe for the simulation of both continuous and event-based rainfall-runoff processes of dendritic watersheds. The main methods used for the replication of the physical processes were: (i) the simple canopy method to model the rainfall retained by plants, (ii) the SCS Curve Number method to represent the infiltration processes within the basin, (iii) the SCS Unit Hydrograph to model the surface runoff processes, and (iv) the constant monthly to model the base-flow in the basin. Time of concentration for each sub-basin was estimated using the Giandotti method while, evapotranspiration was estimated by employing the Thornthwaite method. Data from various sources were exploited for estimating the different parameters of the developed model (e.g., digital elevation model, observed and future precipitation and temperature, land use-land cover data, soil data, dam characteristics and operation rules, observed discharge).

For the Greek part of the Nestos/Mesta basin, rainfall observations from eight (8) stations were available from 1980–1981 to 2018–2019 (according to hydrological year October-September), while for the Bulgarian part of the basin rainfall observations from sixteen (16) stations were available from 01/01/2000 to 01/01/2006. In addition, temperature measurements were available in four (4) stations, one (1) in the Greek part and three (3) in the Bulgarian part of the Nestos/Mesta basin respectively. Average rainfall was estimated for the catchment area using the Thiessen Polygon method.

Calibration of the hydrological model, employing the Nash-Sutcliffe coefficient as the objective function, took place for the period spanning from 12/2018 to 12/2010 while the validation period spanned from 04/2017 to 04/2018; only for the Greek part of the basin with observed data, discharge, available in the two dams (Thissavros and Platanovrisi). For both the calibration and the validation periods, results suggested a very good agreement between the observed and the simulated monthly runoff. Future climate projection data from WP2, i.e., rainfall, and temperature were exploited as an input to the hydrological model. Climate change projections from three climate models (i.e., GFDL, IPSL and MPI) and two Shared Socioeconomic Pathways (SSP; i.e., SSP1-2.6 and SSP5-8.5) scenarios were used as drivers to the calibrated-validated hydrological model. In Figure 6 indicative results, i.e. discharge in m^3, are presented for one of the Greek sub-basins, of the hydrological model.

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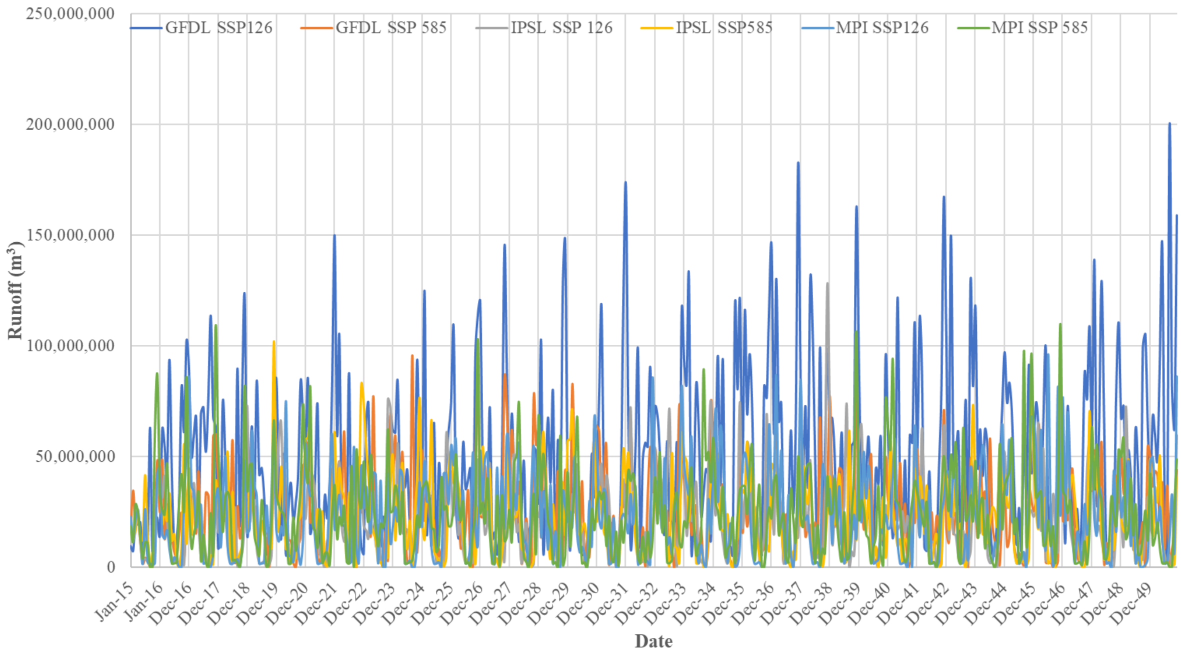
Figure 6: Indicative results in one sub-basin (GR) for different climate models and scenarios



The results of the hydrological model, under all climate scenarios and for all the sub-basins, along with a plethora of other data concerning water, energy, food/agriculture, ecosystems, land uses and climate, was incorporated in the Nestos/Mesta SDM. Four versions of the SDM were provided to WP4 to be integrated into the NEPAT, including relevant outputs of the following RCPs and SSPs scenarios combinations:

(i) RCP2.6/SSP2, where: 'RCP2.6: Low emissions scenario, SSP2: Middle of the road;
(ii) RCP2.6/SSP4, where: 'RCP2.6: Low emissions scenario, SSP4: Inequality (A road divided)';
(iii) RCP8.5/SSP2, where: 'RCP8.5: High emissions scenario, SSP2: Middle of the road'; and,
(iv) RCP8.5/SSP4, where: 'RCP8.5: High emissions scenario, SSP4: Inequality (A road divided)'.

For each version of the SDM, users are provided the flexibility to evaluate outcomes with or without the application of specific case study-oriented policies. Furthermore, the model offers the capability to extract results across multiple spatial scales, including individual sub-basins, the aggregated sub-basins within the Greek and Bulgarian territories, or the entire Nestos/Mesta River basin. The reference scale for the model's calculations is the sub-basin level, ensuring detailed and region-specific insights.

System Dynamics Model

A System Dynamics Model (SDM) (Figure 7) was designed specifically for the Nestos/Mesta river basin, capturing the interactions between water, energy, food, ecosystems (WEFE) and climate variables across its sub-basins. The SDM mirrors the physical structure of the basin, where sub-basins function as independent units that both contribute to and withdraw water from the river through various human activities. This model effectively tracks water flows

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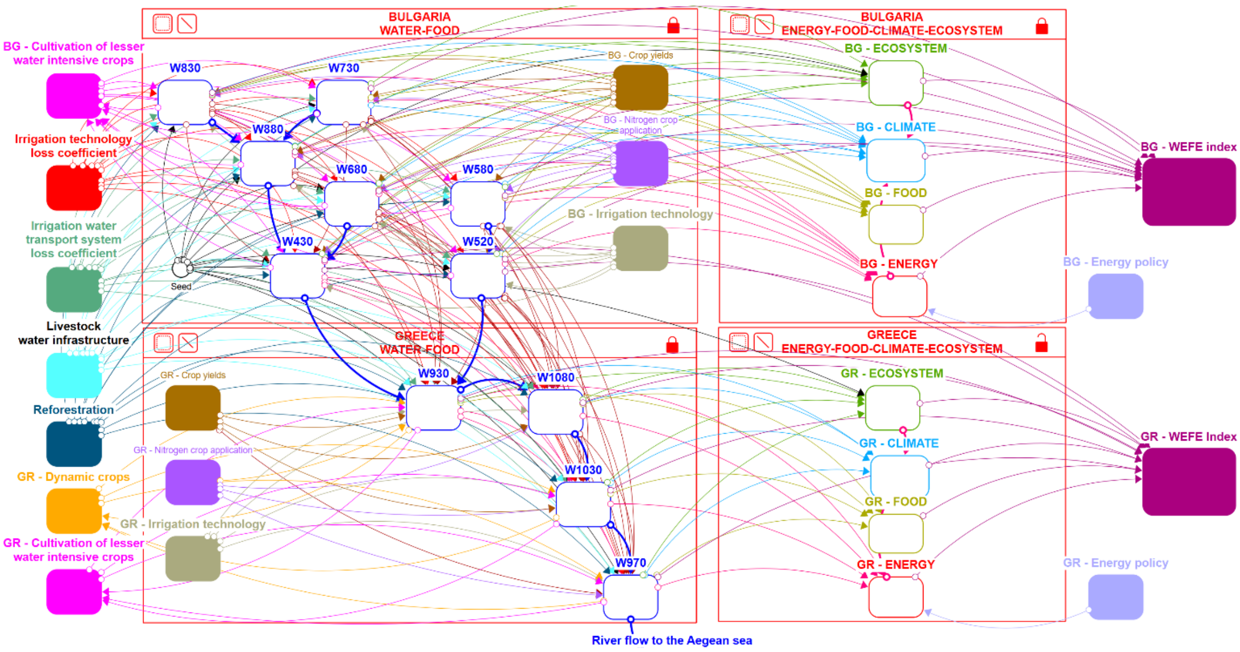
through the system, starting from the sub-basins and ending with the river's discharge into the Aegean Sea.

The blue-outlined modules in Figure 7 represent the sub-basins of the river, with blue arrows illustrating the water flows between them. The final arrow at the bottom of the figure signifies the river's flow into the Aegean Sea, marking the completion of the water's journey. The model also incorporates policy modules, represented by the filled-coloured elements, allowing users to evaluate the effects of implementing different policy options. Examples of such policies include cultivation of less water-intensive crops, improvements in irrigation technology, enhancements to irrigation water transport systems, livestock water infrastructure, reforestation, and the adoption of dynamic crops. The rightmost, purple-filled modules represent the WEFE indices for the Bulgarian and Greek regions, providing a summary of the overall performance of water, energy, food, and ecosystem interactions for each country.

Figure 7: The first level overview of the Nestos/Mesta SDM



The upper left red frame, titled "BULGARIA WATER-FOOD," includes all seven sub-basins located in the Bulgarian part of the river basin. Similarly, the lower left red frame, titled "GREECE WATER-FOOD," includes the four sub-basins in the Greek part of the river basin. At the sub-basin level, the SDM allows users to calculate both current and future values of variables, primarily focusing on water and food-related parameters. The upper and lower right frames of the figure represent regional analyses, where users can calculate variables related to food, energy, climate, and ecosystem interactions for both the Bulgarian and Greek parts of the river basin. Lastly, the modules on the rightmost side of the figure display the WEFE indices for both regions, providing an aggregated measure of the interactions and performance of these sectors.

This SDM is highly versatile, giving users the ability to simulate different scenarios by applying various policies either independently or in combination. For instance, users can implement the policy of cultivating less water-intensive crops in both Greek and Bulgarian parts

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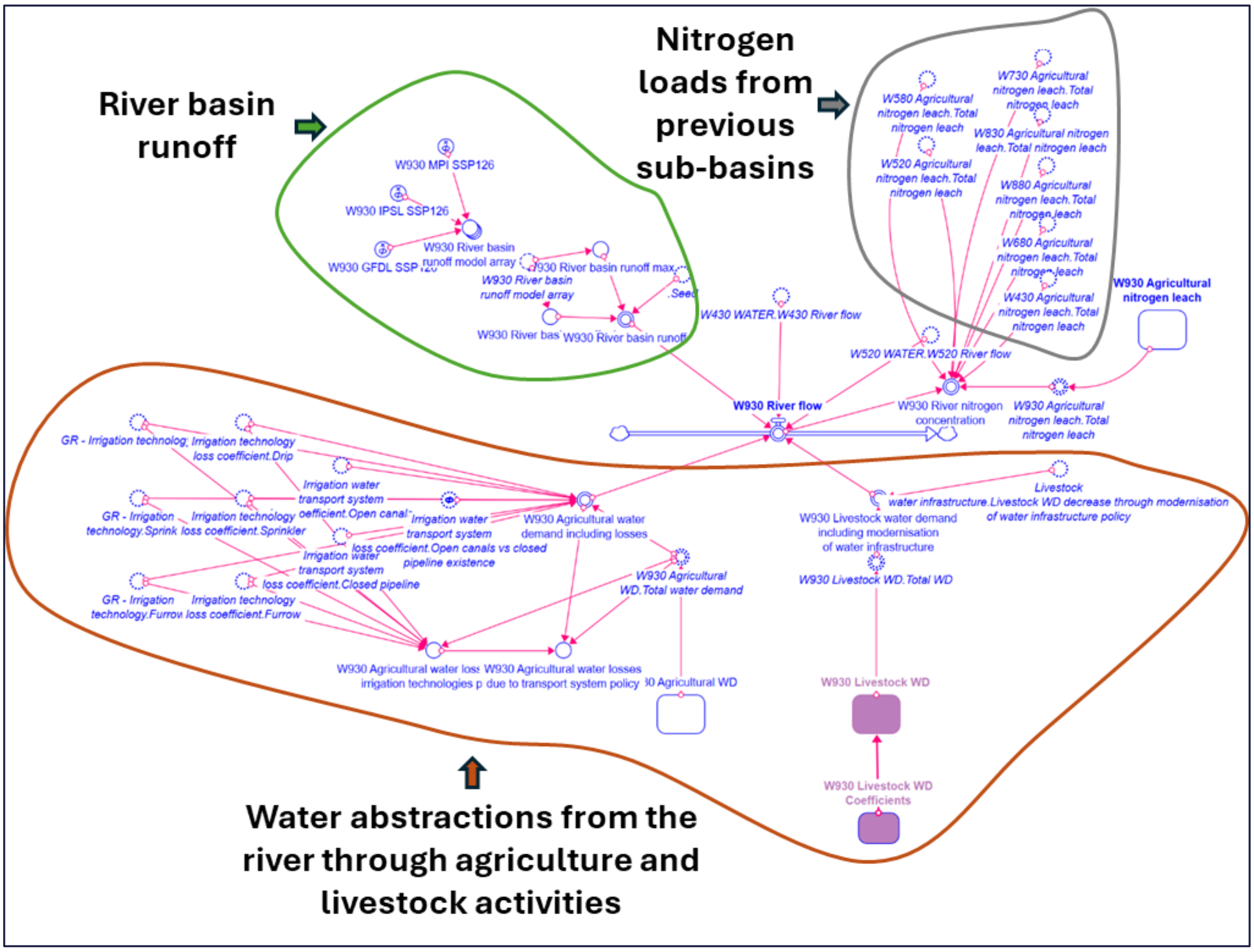
simultaneously or apply a combination of policies to explore synergies and trade-offs. This flexibility ensures detailed, scenario-based planning and robust decision-making at both the sub-basin level, focusing on water and food variables, and the regional level, addressing broader WEFE interactions.

In summary, the SDM offers a comprehensive framework for analyzing and optimizing water, food, energy, and ecosystem interactions at multiple spatial scales while allowing the incorporation of user-defined policy interventions. This ensures a robust approach for sustainable management of the Nestos/Mesta river basin's resources. The following paragraphs provide a brief overview of all the WEFE sectors modelled within the SDM.

Water: In Figure 8, the W830 sub-basin water module is illustrated as designed within the Stella Architect interface. This visual representation demonstrates the interconnected processes of hydrology and water management in the sub-basin. The model is built around three key components: river flow, water demand, and river quality, all of which dynamically interact to simulate the system's behavior. A critical input to this system is the river basin runoff, which initiates the flow of water through the sub-basin and links it to upstream and downstream regions.

Figure 8: The W830 sub-basin water module,



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River Basin Runoff

The river basin runoff is the primary source of water entering the W830 sub-basin, as indicated in the top-left section of Figure 8. This runoff represents the natural flow of water generated by precipitation, surface flow, and upstream contributions from previous sub-basins. The figure highlights how this runoff is affected by climatic factors (e.g., rainfall and temperature) under different RCP & SSP scenarios, creating variability in water availability. Additionally, runoff serves as a carrier of nitrogen loads and other pollutants originating from upstream sub-basins. These nutrient loads directly influence water quality in the W830 sub-basin and are visually represented in the diagram, where they flow into the river flow subsection. This underscores the cascading impact of upstream processes on downstream ecosystems.

River Flow

The model calculates river flow in the W830 sub-basin by accounting for the balance between the water entering the system (runoff and upstream inflow) and the water extracted for various demands (agriculture and livestock). Below is the formula that can be used to represent this process mathematically:

$$Q_{river\_flow} = Q_{runoff} + Q_{inflow\_upstream} - \left(WD_{agriculture} + WD_{livestock}\right) \quad (1)$$

Where:

- Q_{river_flow}: The river flow for the W830 sub-basin (m³/month)
- Q_{runoff} : The local river basin runoff generated in the sub-basin (m³/month)
- $Q_{inflow\_upstream}$: The inflow of water from the upstream sub-basin (m³/month)
- $WD_{agriculture}$: Water demand for agricultural activities (m³/month)
- $Q_{livestock}$: Water demand for livestock activities (m³/month)

The model's modular structure ensures that each sub-basin maintains consistency in how river flow is computed and transferred, providing a seamless representation of water movement across the entire river basin.

Water Demand

Agricultural Water Demand depends on the cultivated area of each crop type and their specific monthly water requirements. The model integrates irrigation inefficiencies, as depicted by various technologies (e.g., furrow, sprinkler, and drip systems), and accounts for water transportation losses (e.g., open canals vs. closed pipelines). This component highlights the role of infrastructure and irrigation technology in determining overall water use efficiency. The following formula represents the mechanism mathematically:

$$WD_{agriculture} = \sum_{i=1}^{n} (A_i * WR_i * (1 + L_{irrigation})) \quad (2)$$

Where:

- A_i: Cultivated area of crop i (m²)
- WR_i: Monthly water requirement per unit area of crop i (m³/m²)
- $L_{irrigation}$: Loss coefficient due to irrigation inefficiencies (e.g., furrow, sprinkler, drip systems, transportation systems, etc.)

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Livestock Water Demand is calculated based on the population of animals and their per capita water consumption. As shown in the bottom-right section of the figure, modernisation of water infrastructure policies helps reduce livestock water losses and subsequently demand, demonstrating the model's ability to simulate the impacts of policy interventions. The following formula represents the mechanism mathematically:

$$WD_{livestock} = \sum_{j=1}^{m} (P_j * WC_j) \quad (3)$$

Where:

- P_j: Population of livestock type j in the sub-basin
- WC_j: Water consumption per animal of livestock type j (m^3/month)

River Quality

The river quality subsection models the concentration of Total Nitrogen (TN), which result from fertilizer applications in agricultural areas. These nutrients leach into the river system depending on soil characteristics, crop absorption capacity, and proximity to the river. Figure 8 demonstrates how these pollutants are transported downstream, compounding the nutrient loads in subsequent sub-basins. By capturing this dynamic, the model provides insights into the environmental impact of agricultural practices on water quality.

Figure 8 emphasizes the modular structure of the sub-basin, where **river basin runoff** serves as the starting point for all hydrological processes. The diagram showcases the interconnected nature of water flow, demand, and quality while visually representing feedback loops and interdependencies. This design ensures consistency across all sub-basins while enabling detailed tracking of water dynamics throughout the Nestos/Mesta river basin.

Energy: The energy module included in the SDM captures the dynamics of energy production, consumption, and balance within the sub-basin W830 (Figure 9). It integrates multiple energy sources, consumption drivers, and policy scenarios to simulate the interaction between supply and demand, ensuring a holistic representation of energy flows. While the module compares local energy production with consumption within the sub-basin, it is important to note that energy production in this region, although locally generated, feeds into the national energy network. As such, the comparison between local production and consumption represents a modeling assumption rather than a strict localized energy accounting.

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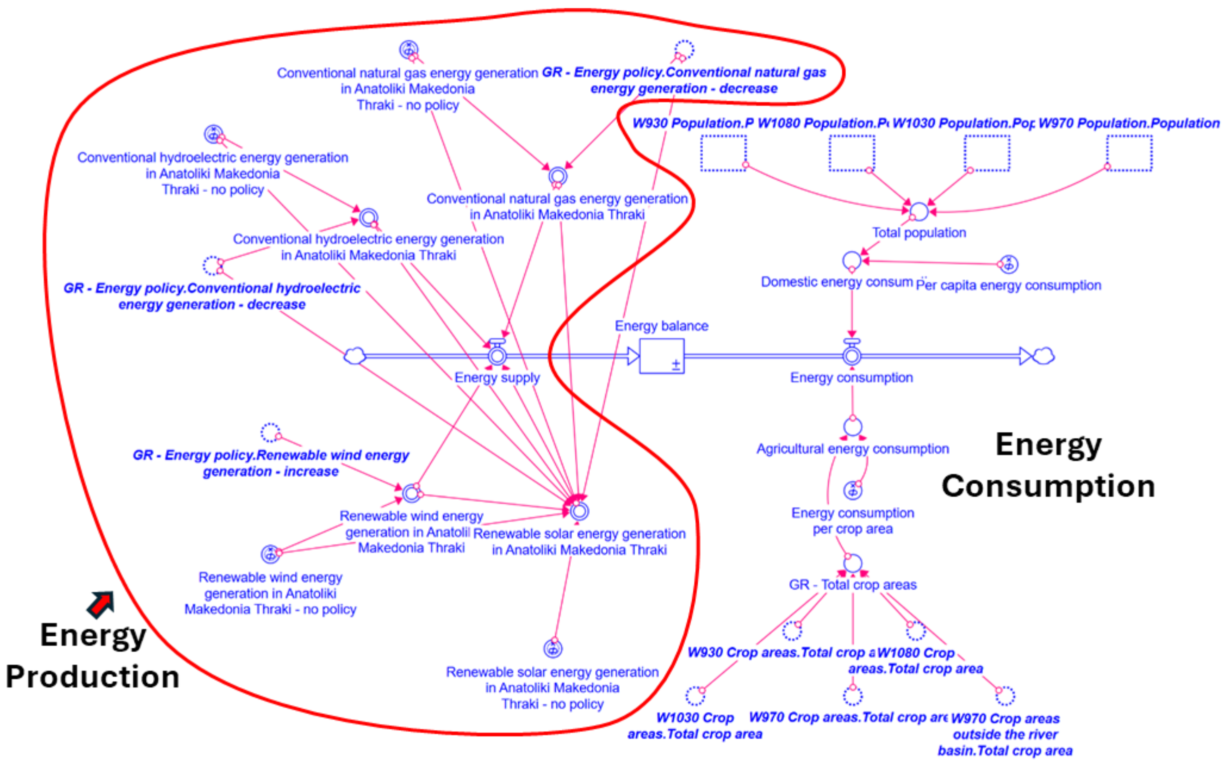
Figure 9: The Greek territory energy module



Energy Production

The energy supply lies in the combination of conventional and renewable energy sources. Conventional energy production includes natural gas and hydroelectric power generation within the Region of Eastern Macedonia and Thrace. These traditional sources represent the baseline supply for the sub-basin. The model explicitly incorporates policy scenarios, such as an increase in natural gas generation to explore how policy interventions might impact the availability of conventional energy.

In parallel, renewable energy sources play a critical role in diversifying the energy supply. The model accounts for wind and solar energy generation, which are also concentrated in the Region of Eastern Macedonia and Thrace. Policies promoting renewable energy, such as increasing wind energy generation, are simulated to evaluate their impact on overall energy production. Additionally, the model distinguishes between scenarios with and without policy interventions, enabling detailed comparisons of energy generation under various conditions. Together, conventional and renewable sources contribute to the total energy supply, which forms a key input to the overall energy balance. Despite being modeled as localized, the energy production from these sources integrates into the national energy grid, making the comparison with local consumption an assumption for analytical purposes.

Energy Consumption

Energy demand within the sub-basin is driven by two primary sectors: domestic energy consumption and agricultural energy consumption.

Domestic energy use is closely linked to the population of the sub-basin, which is distributed across all the sub-basins. The model calculates total domestic energy consumption by multiplying the per capita energy use by the total population. This approach highlights how

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demographic changes, such as population growth or decline, directly influence energy demand. The formula for **domestic energy consumption** in the model can be expressed as:

$$E_{domestic} = P_{total} * E_{per_{capita}} \quad (4)$$

Where:

- $E_{domestic}$: Total domestic energy consumption (e.g., in kWh/month)
- P_{total}: Total population within the sub-basin (e.g., sum of populations in W930, W1080, etc.)
- E_{per_capita}: Per capita energy consumption (e.g., kWh/person/month)

Agricultural energy consumption, on the other hand, is determined by the extent of farming activities within the sub-basin. The model calculates energy use in agriculture by considering the total crop area, which includes fields inside the river basin. The formula for **agricultural energy consumption** in the model can be expressed as:

$$E_{agriculture} = \sum_{i=1}^{n} (A_i * E_{per_{area},i}) \quad (5)$$

Where:

- $E_{agriculture}$: Total agricultural energy consumption (kWh/month)
- A_i: Cultivated area of crop i (square meters)
- $E_{per\_area,i}$: Energy consumption per unit area for crop I ($kWh/m^2/month$)
- n: Number of different crop types cultivated in the region

The total energy consumption is the sum of domestic and agricultural energy use, providing a comprehensive view of the energy demands within the sub-basin. By integrating population dynamics and agricultural activities, the model effectively captures the key drivers of energy consumption.

Energy Balance

Energy balance represents the difference between energy supply and energy consumption. The energy balance is calculated as the total energy supply minus the total energy consumption. This measure determines whether the sub-basin has an energy surplus or deficit. A positive energy balance indicates a surplus that could theoretically support local energy needs, while a negative balance highlights a deficit that may require additional energy imports or policy adjustments. However, it is important to emphasize that the energy production modeled here, while originating in the sub-basin, is integrated into the national energy grid. As such, the direct comparison between local energy production and consumption does not reflect actual energy distribution but rather provides a framework for assessing the potential contribution of the sub-basin to regional energy sustainability.

Food: The food module is designed to simulate the dynamics of food production, food demand, and the resulting food balance within the Greek and/or Bulgarian territory (Figure 10). It integrates agricultural and livestock production with population-driven food consumption to evaluate whether local food production can meet demand. The module combines both crop and livestock food production, calculates total food demand, and assesses the balance between supply and demand.

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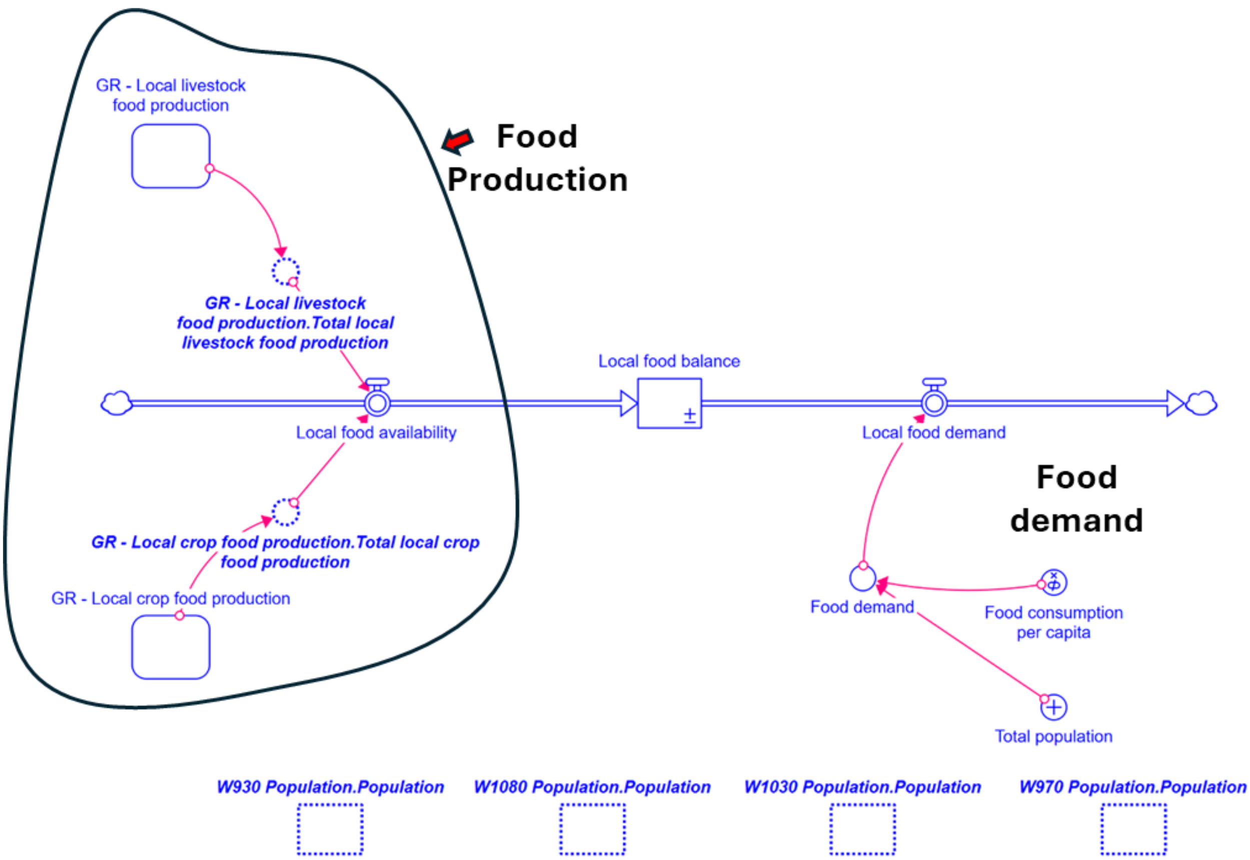
Figure 10: The Greek territory food module



Total food production is the sum of crop-based and livestock-based food production:

$$FP_{total} = FP_{crop} + FP_{livestock} \quad (6)$$

Where:

- FP_{total}: Total food production (kg)

The formula for **crop-based food production** is:

$$FP_{crop} = \sum_{i=1}^{n}(A_i * Y_i) \quad (7)$$

Where:

- FP_{crop}: Total crop-based food production (kg)
- A_i: Cultivated area of crop i (square meters)
- Y_i: Yield per unit area for crop i (e.g., kg/m^2)
- n: Number of crop types grown in the Greek and/or Bulgarian territory

This calculation sums up the food production from all cultivated crops, considering their specific yields and cultivated areas.

The formula for **livestock-based food production** is:

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$$FP_{livestock} = \sum_{j=1}^{m} (P_j * Y_j) \quad (8)$$

Where:

- $FP_{livestock}$: Total livestock-based food production (kg)
- P_j: Population of livestock type j (heads)
- Y_j: Food yield per animal of type j (kg/head)
- m: Number of livestock types in the sub-basin

Food demand represents the amount of food required by the sub-basin's population. It is driven by the **total population** and the **average food consumption per capita**.

The formula for food demand is:

$$FD_{local} = P_{total} * FC_{per\_capita} \quad (9)$$

Where:

- FD_{local}: Local food demand (kg)
- P_{total}: Total population of the sub-basin
- FC_{per_capita}: Food consumption per capita (kg/person)

This formula estimates the total food needed to meet the dietary requirements of all individuals in the selected territory.

Food balance assesses the relationship between local food production and demand. It is calculated as:

$$FB_{local} = FP_{total} - FD_{local} \quad (10)$$

Where:

- FB_{local}: Local food balance (cumulative kg)

A positive food balance indicates surplus food production that can be exported or stored. A negative balance suggests a food deficit, requiring imports or other measures to meet demand. The food module captures the dynamics of local food production, local food demand, and the resulting local food balance. This module integrates the supply (food production) and demand (population-driven food needs) components to assess whether the sub-basin can meet its food requirements locally.

Ecosystem: The ecosystem module in the System Dynamics Model (SDM) captures the critical interplay between land use, biodiversity, and climate-related carbon storage, offering a

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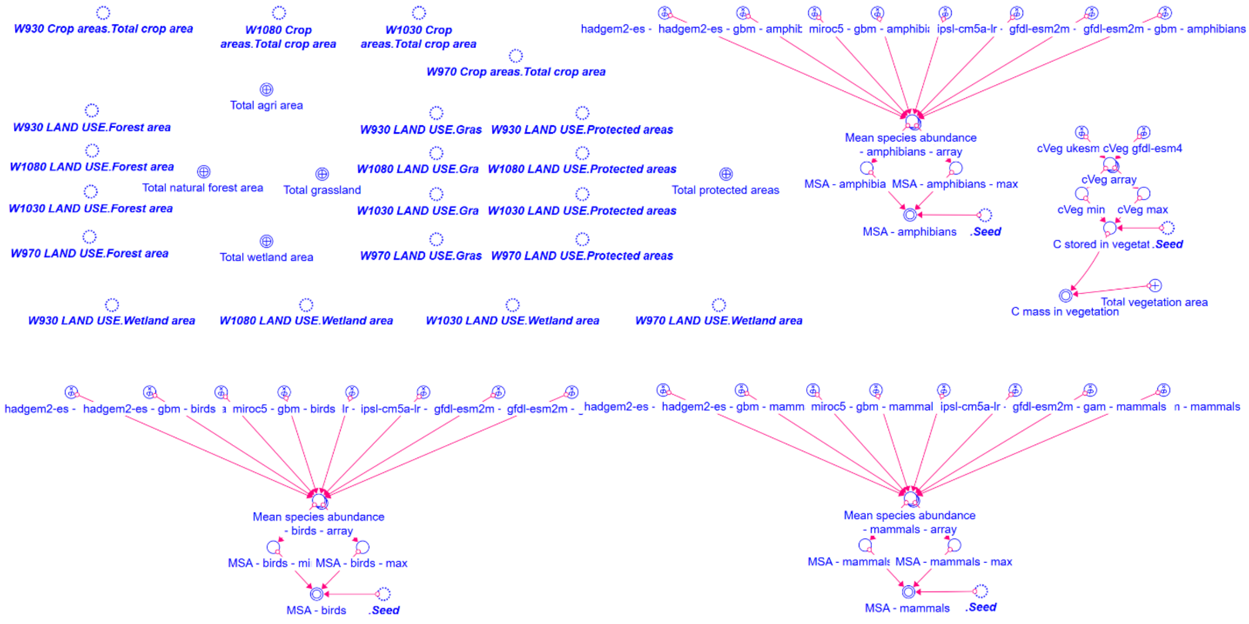
comprehensive perspective on ecosystem dynamics (Figure 11). This module integrates several key land categories and biodiversity indicators, allowing for a nuanced assessment of ecosystem health and functionality.

Figure 11: The Greek territory ecosystem module



Land Use Categories

The module accounts for different land use categories, each contributing to the overall ecosystem status and climate dynamics:

(i) **Agricultural Areas**: Represent the total cultivated area across the sub-basins, emphasising the interplay between food production and ecosystem conservation.
(ii) **Natural Forest Areas**: Capture the extent of forested land, which serves as a crucial carbon sink and supports diverse species.
(iii) **Wetland Areas**: Include the total wetland regions, which are vital for maintaining hydrological cycles, supporting biodiversity, and acting as natural carbon reservoirs.
(iv) **Grassland Areas**: Represent open landscapes that provide habitats for various species and contribute to carbon storage.
(v) **Protected Areas**: Highlight regions designated for biodiversity conservation, safeguarding critical habitats from anthropogenic impacts.

Biodiversity Indicators

The module incorporates **Mean Species Abundance (MSA)** as a key biodiversity metric, which assesses the diversity and abundance of specific species groups:

(i) **Amphibians**: Sensitive to environmental changes, amphibians serve as indicators of ecosystem health.
(ii) **Birds**: Reflect the state of terrestrial and aquatic habitats and their capacity to support avian populations.
(iii) **Mammals**: Represent terrestrial biodiversity and are integral to ecosystem stability.

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The MSA for each group is calculated based on land use, habitat conditions, and climate scenarios, providing insights into species diversity under various environmental conditions.

Carbon Storage in Vegetation

The module also quantifies **carbon mass in vegetation**, a key component of the global carbon cycle. This includes:

- **Carbon Stored in Forest Vegetation**: Reflecting the role of forests as carbon sinks.
- **Carbon Stored in Grasslands and Wetlands**: Highlighting the capacity of these ecosystems to sequester carbon and mitigate greenhouse gas (GHG) emissions.

Carbon storage dynamics are influenced by land use changes, vegetation growth, and climate scenarios, emphasizing the interdependence between ecosystems and climate change mitigation.

Integrated Ecosystem Analysis

By combining land use categories, biodiversity indicators, and carbon storage metrics, the ecosystem module enables a holistic assessment of ecosystem functionality and resilience. It provides insights into: (i) the impact of land use changes on biodiversity and carbon sequestration, (ii) the trade-offs between agricultural expansion and ecosystem conservation, (iii) the role of protected areas in preserving biodiversity and maintaining ecosystem services (ii) the impact of RCPs and SSPs on future conditions affecting ecosystems.

Climate: The climate module in the System Dynamics Model (SDM) quantifies **CO_2 equivalent (CO_2e) emissions** and **CO_2 sequestration**, providing a net balance of greenhouse gases for the region (Figure 12). Emissions originate from the agricultural sector (managed soil emissions, rice cultivation, urea application, field burning), wetland areas, livestock (e.g., cattle, sheep, goats), and the energy sector (conventional and renewable energy generation). These are offset by CO_2 sequestration from grasslands, agricultural areas, and forests, which act as natural carbon sinks.

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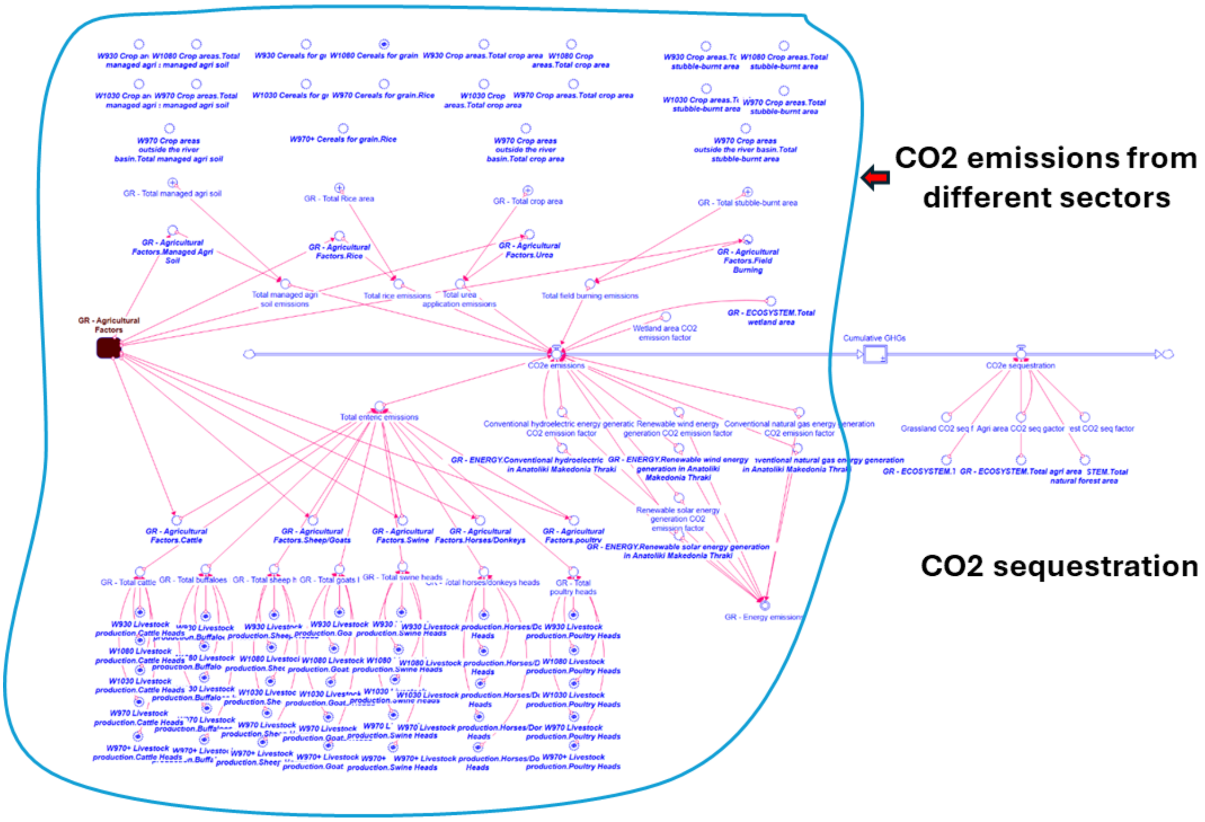
Figure 12: The Greek territory climate module



The net CO_2 balance is calculated as:

$$NET\ CO_2 Balance = Total\ \ CO_2e\ Emissions - Total\ \ CO_2\ Sequestration \quad (11)$$

A **positive balance** indicates net emissions, contributing to atmospheric CO_2, while a **negative balance** signifies a net carbon sink, supporting climate mitigation. By integrating emissions and sequestration flows, the module evaluates the interplay between land use, energy generation, and ecosystem dynamics, providing insights into the region's climate impact. It enables scenario-based analysis of policies such as transitioning to renewable energy, enhancing forest and grassland conservation, and improving agricultural practices. The climate module is an essential tool for designing sustainable strategies and achieving carbon neutrality.

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3.4 From nexus governance and complexity science modelling to NEXOGENESIS policy assessment tool NEPAT (WP4)

The objective of WP4 is to develop the NEXOGENESIS Policy Assessment Tool (NEPAT) to distil integrative policies that maximize the overall nexus benefits while dealing with conflicting nexus decisions and objectives.

3.4.1 NEPAT development

At the outset of the project, preliminary policy packages were designed and discussed with the involved stakeholders during the 2nd SHs' workshop. An analytical Excel file, including all the relevant information and required data, was provided by WP1. The most important challenge in this process was the translation of policies into model terms, an extremely demanding task depending on the availability of all necessary quantitative data. The development of relevant indicators, measuring the performance of the respective policies, was launched by CS leaders (NTUA) and WP3 (UTH) and then, it was validated by the other partners involved in the CS in order to achieve representative measurable outcomes for the proposed solutions.

After the 2nd SHs' workshop, an extensive list of policies was created, including the feedback provided by the stakeholders. Such policies, incorporated all the issues identified as "WEFE nexus challenges" as well as suggestions proposed, and presented to stakeholders during the 3rd SHs' workshop (March 2023) in order to be validated by the participants. At this stage, the process of quantifying the validated policies into the SDM and inserting them into the NEPAT was initiated.

Thus, the final list of policies (before quantification) included:

- **Water saving** by the **agricultural** and **livestock sectors** (e.g. modernisation of irrigation systems/equipment, cultivation of less water-demanding crops, use of water saving infrastructures by the sector of livestock).
- **Protection of water quality** – Reduction of agricultural waste (e.g. reduction of nitrogen discharged in the river).
- **Protection of ecosystems and biodiversity**.
- **Assessment of ecosystem services**.
- **Removal of transported sediments**.
- **Flood prevention and protection**.
- **Secure water use balance** (especially in relation to dams and water availability for energy and irrigation).
- **Wastewater treatment and use of treated water for irrigation**.
- **Exploitation of geothermy for energy production**.
- **Energy production from multiple renewable energy sources** (photovoltaics, energy crops, wind parks, biomass/agricultural waste) / Exploitation of hybrid technologies.

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- **Sustainable development of agriculture and preservation of ecosystems** (e.g. securing the minimum environmental flow, limiting the expansion of agricultural land).
- **Agricultural development** and new crop types that could be cultivated in the region (e.g. crops and agricultural products with export capabilities).
- **Reinforcement of livestock activities**.
- **Further development of the aquaculture sector**.

Such policies were further refined and specified into achievable policy goals and interventions. Thereafter, they were connected to quantitative data included into the SDM and matched with specific indicators measuring their performance. Based on the available data, 10 policy goals were set (Table 3) and 12 policy instruments (Table 4) were finally translated into model terms and quantified for use into the SDM and the NEPAT.

Table 3: Policy goals inserted in the NEPAT

No	Policy Goal	Description
1	Decrease of water demand in Greek sub-basins by 2030, 2040, 2050	The policy goal to decrease water demand in Greek sub-basins focuses on implementing strategic measures to ensure sustainable water use in the face of growing scarcity and climate change impacts. This involves enhancing water efficiency across various sectors, including agriculture and livestock, through the adoption of advanced irrigation technologies, replacement of open irrigation canals with closed pipelines, cultivation of less water-demanding crops, and extensive use of water saving infrastructures by the livestock sector.
2	Decrease of water demand in Bulgarian sub-basins by 2030, 2040, 2050	The policy goal to decrease water demand in Bulgarian sub-basins focuses on implementing strategic measures to ensure sustainable water use in the face of growing scarcity and climate change impacts. This involves enhancing water efficiency across various sectors, including agriculture and livestock, through the adoption of advanced irrigation technologies, replacement of open irrigation canals with closed pipelines, cultivation of less water-demanding crops, and extensive use of water saving infrastructures by the livestock sector.
3	Decrease of emissions originating from energy production in Greek sub-basins by 2030, 2040, 2050	The policy goal to decrease emissions originating from energy production in Greek sub-basins aims to significantly reduce the carbon footprint and environmental impact of the energy sector. This involves transitioning from reliance on fossil fuels to renewable energy sources, such as wind, solar, and hydropower, combined with enhancing energy efficiency across all production processes.
4	Decrease of emissions originating from energy production in Bulgarian sub-basins by 2030, 2040, 2050	The policy goal to decrease emissions originating from energy production in Bulgarian sub-basins aims to significantly reduce the carbon footprint and environmental impact of the energy sector. This involves transitioning from reliance on fossil fuels to renewable energy sources, such as wind, solar, and hydropower, combined with enhancing energy efficiency across all production processes.
5	Decrease of emissions originating from all sectors	The policy goal to decrease emissions originating from all sectors in Greek sub-basins aims at transforming the regional landscape into a model of environmental sustainability. This comprehensive

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No	Policy Goal	Description
	in Greek sub-basins by 2030, 2040, 2050	approach involves reducing emissions across key sectors such as agriculture and livestock, by implementing cleaner technologies, enhancing energy efficiency, and promoting sustainable practices.
6	Decrease of emissions originating from all sectors in Bulgarian sub-basins by 2030, 2040, 2050	The policy goal to decrease emissions originating from all sectors in Bulgarian sub-basins aims at transforming the regional landscape into a model of environmental sustainability. This comprehensive approach involves reducing emissions across key sectors such as agriculture and livestock, by implementing cleaner technologies, enhancing energy efficiency, and promoting sustainable practices.
7	Decrease of Nestos (GR) nitrogen concentration by 2030, 2040, 2050	The policy goal to decrease nitrogen concentration in the Nestos (GR) river focuses on improving water quality to support ecological health and sustainability in the region. This initiative involves implementing best practices in agriculture to reduce fertilizer runoff.
8	Decrease of Mesta (BG) nitrogen concentration by 2030, 2040, 2050	The policy goal to decrease nitrogen concentration in the Mesta (BG) river focuses on improving water quality to support ecological health and sustainability in the region. This initiative involves implementing best practices in agriculture to reduce fertilizer runoff.
9	Crop per drop increase in Greek sub-basins by 2030, 2040, 2050	The policy goal to increase "Crop per Drop" in Greek sub-basins aims to enhance agricultural water-use efficiency, ensuring higher yields with less water. This involves adopting advanced irrigation technologies such as drip and precision irrigation systems, alongside implementing best practices in soil and water management. Achieving this goal will help safeguard water resources, boost agricultural productivity and support sustainable food security in the face of climate change and growing resource constraints.
10	Crop per drop increase in Bulgarian sub-basins by 2030, 2040, 2050	The policy goal to increase "Crop per Drop" in Bulgarian sub-basins aims to enhance agricultural water-use efficiency, ensuring higher yields with less water. This involves adopting advanced irrigation technologies such as drip and precision irrigation systems, alongside implementing best practices in soil and water management. Achieving this goal will help safeguard water resources, boost agricultural productivity and support sustainable food security in the face of climate change and growing resource constraints.

Table 4: Policy instruments inserted in the NEPAT

No	Policy Instrument	Description
1	Change of irrigation systems in Bulgarian sub-basins	This policy instrument focuses on changing the irrigation systems in Bulgarian sub-basins from furrow to drip, addressing water inefficiencies in agriculture and ensuring sustainable water resource management. Furrow irrigation, which involves flooding channels between crop rows, often results in significant water loss due to evaporation, deep percolation, and runoff. The transition to drip irrigation aims to conserve water by delivering it directly to the plant roots

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No	Policy Instrument	Description
		through a network of tubes, minimizing these losses and enhancing water use efficiency.
2	Change of irrigation systems in Greek sub-basins	This policy instrument focuses on changing the irrigation systems in Greek sub-basins from furrow to drip, addressing water inefficiencies in agriculture and ensuring sustainable water resource management. Furrow irrigation, which involves flooding channels between crop rows, often results in significant water loss due to evaporation, deep percolation, and runoff. The transition to drip irrigation aims to conserve water by delivering it directly to the plant roots through a network of tubes, minimizing these losses and enhancing water use efficiency.
3	Replacement of open irrigation canals that transfer water from the river to crops by closed pipelines (GR)	This policy instrument aims to replace open irrigation canals with closed pipelines. It is designed to enhance the efficiency and sustainability of water transportation in the agricultural sector. Open canals, which have traditionally been used to transfer water from rivers to crops, suffer from high water losses due to evaporation, seepage, and contamination. This inefficiency leads to excessive water usage and diminished availability for agricultural needs. By transitioning to closed pipeline systems, water conservation is significantly improved as these pipelines reduce or eliminate losses associated with open canals.
4	Reducing the quantity of nitrogen discharged in Bulgarian sub-basins	This policy instrument aims at reducing the quantity of nitrogen discharged in Bulgarian sub-basins by decreasing the amount of nitrogen applied to crops. It seeks to address the critical issue of nitrogen pollution in water bodies. Excessive use of nitrogen fertilizers in agriculture can lead to nutrient runoff, which contaminates rivers, lakes, and groundwater, causing eutrophication, harmful algal blooms, and damage to aquatic ecosystems. This policy focuses on optimizing nitrogen usage to balance agricultural productivity with environmental health.
5	Reducing the quantity of nitrogen discharged in Greek sub-basins	This policy instrument aims at reducing the quantity of nitrogen discharged in Greek sub-basins by decreasing the amount of nitrogen applied to crops. It seeks to address the critical issue of nitrogen pollution in water bodies. Excessive use of nitrogen fertilizers in agriculture can lead to nutrient runoff, which contaminates rivers, lakes, and groundwater, causing eutrophication, harmful algal blooms, and damage to aquatic ecosystems. This policy focuses on optimizing nitrogen usage to balance agricultural productivity with environmental health.
6	Cultivation of less water-demanding crops in Greek sub-basins	This policy instrument encourages the cultivation of less water-demanding crops in Greek sub-basins to address the critical issue of water scarcity in the region. By reducing the areas dedicated to water-intensive crops such as maize, rice, cotton, and clovers, and increasing the cultivation of crops that require less water, like rapeseed, olive trees, soybeans, and sweet potatoes, this policy aims to promote more

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No	Policy Instrument	Description
		sustainable water use and ensure the long-term viability of agriculture in these sub-basins.
7	Cultivation of less water-demanding crops in Bulgarian sub-basins	This policy instrument encourages the cultivation of less water-demanding crops in Bulgarian sub-basins to address the critical issue of water scarcity in the region. By reducing the areas dedicated to water-intensive crops such as maize, rice, cotton, and clovers, and increasing the cultivation of crops that require less water, like rapeseed, olive trees, soybeans, and sweet potatoes, this policy aims to promote more sustainable water use and ensure the long-term viability of agriculture in these sub-basins.
8	Extensive use of water saving infrastructures by the sector of livestock	The policy instrument to promote extensive use of water-saving infrastructures in the sector of livestock aims to address water scarcity by enhancing efficiency and sustainability in farming practices. Key strategies include the adoption of technologies such as automated watering systems and water recycling units to significantly reduce water consumption in livestock operations. By doing so, the policy not only conserves vital water resources but also strengthens the long-term viability and resilience of the livestock industry.
9	Reforestation activities	The policy instrument promoting reforestation activities is a comprehensive effort aimed at restoring degraded landscapes, enhancing biodiversity and combating climate change. By planting trees in areas that have been deforested or degraded, the policy seeks to replenish forest cover, which plays a crucial role in carbon sequestration by absorbing CO_2, thereby mitigating warming. These reforestation activities contribute to restoring natural habitats, increasing biodiversity and improving ecosystem services such as water regulation and soil stabilization.
10	Cultivation of dynamic crops (edible pulse, olives, vegetables) instead of cereals, cotton and sugar beets – based also on RIS3 strategy (GR)	This policy instrument encourages the cultivation of dynamic crops such as edible pulses, olives, and vegetables, in place of traditional cereals, cotton and sugar beets, and seeks to address various agricultural challenges by promoting more sustainable and economically viable farming practices. These dynamic crops are chosen for their adaptability to climate variability, lower water requirements, and higher market demand, which can enhance farm profitability and reduce environmental impact.
11	Decrease of electricity generated by conventional energy sources and increase of electricity produced from RES in the Greek part	This policy instrument aims at decreasing electricity generated from conventional energy sources and increasing electricity production from RES in Greece as a strategic initiative to transform the national energy landscape towards sustainability and reduce carbon emissions. This policy addresses the urgent need to mitigate climate change impacts by transitioning from fossil fuels, such as coal and oil, to cleaner, renewable alternatives like wind, solar, and hydroelectric power.
12	Decrease of electricity generated by conventional	This policy instrument aims at decreasing electricity generated from conventional energy sources and increasing

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No	Policy Instrument	Description
	energy sources and increase of electricity produced from RES in the Bulgarian part	electricity production from RES in Bulgaria as a strategic initiative to transform the national energy landscape towards sustainability and reduce carbon emissions. This policy addresses the urgent need to mitigate climate change impacts by transitioning from fossil fuels, such as coal and oil, to cleaner, renewable alternatives like wind, solar, and hydroelectric power.

WP4 worked on the incorporation of policies into the NEPAT. Different achievement levels have been defined for each of the goals per each year (milestone) while, policy impacts are calculated based on a set of indicators such as: cumulative GHGs, forest area, total nitrogen load, nitrogen concentration, water withdrawals, etc.

The first (beta) version of the Nestos/Mesta NEPAT was available in August 2024 and CS leaders tested the tool in order to explore its functionalities and assess its outcomes. The main functionalities of the tool concern policy impact assessment, i.e. assessment of the impacts of policy implementation on the achievement of policy goals, and formulation of policy packages/policy recommendations towards the achievement of specific policy goals (DSS). The Nestos/Mesta version of NEPAT was demonstrated to stakeholders during the 5th SHs' workshop (November 2024). Stakeholders attended a session, fully dedicated to various NEPAT simulation runs, interpreting results and applying the DSS in order to get policy recommendations for achieving specific policy goals.

Regarding policy impact assessment, indicative examples were presented including simulations:

(i) without implementing policy instruments,
(ii) with implementing policy instruments / different policy packages.

Indicative results of different simulations are presented in Figures 13-15.

NEXOGENESIS STREAMLINING WATER RELATED POLICIES

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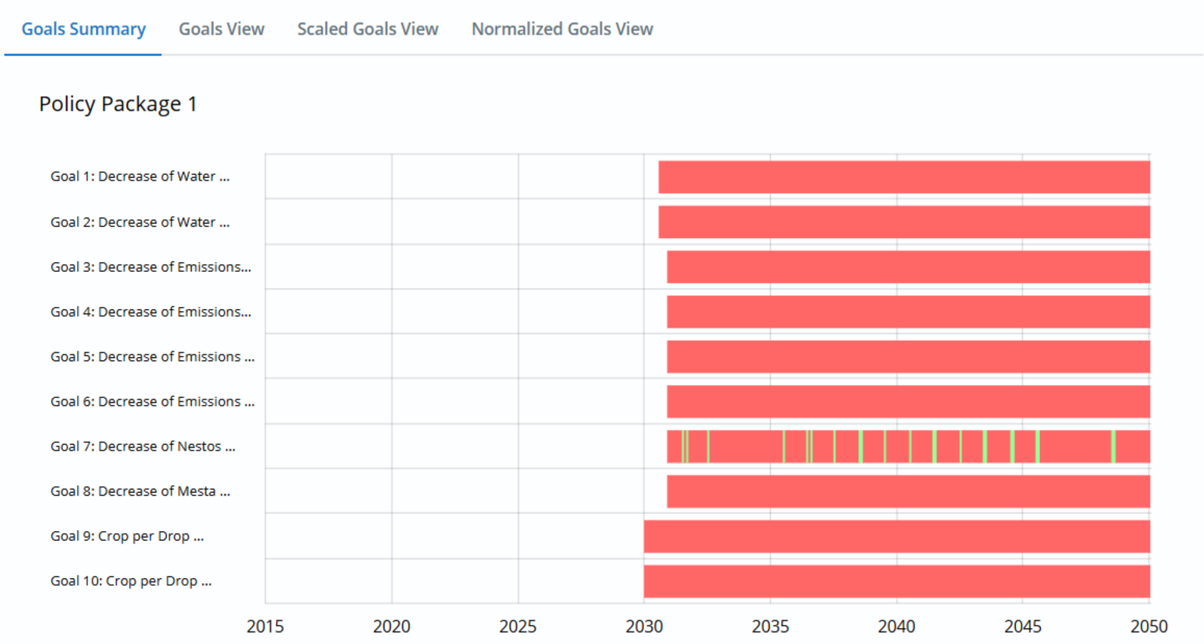
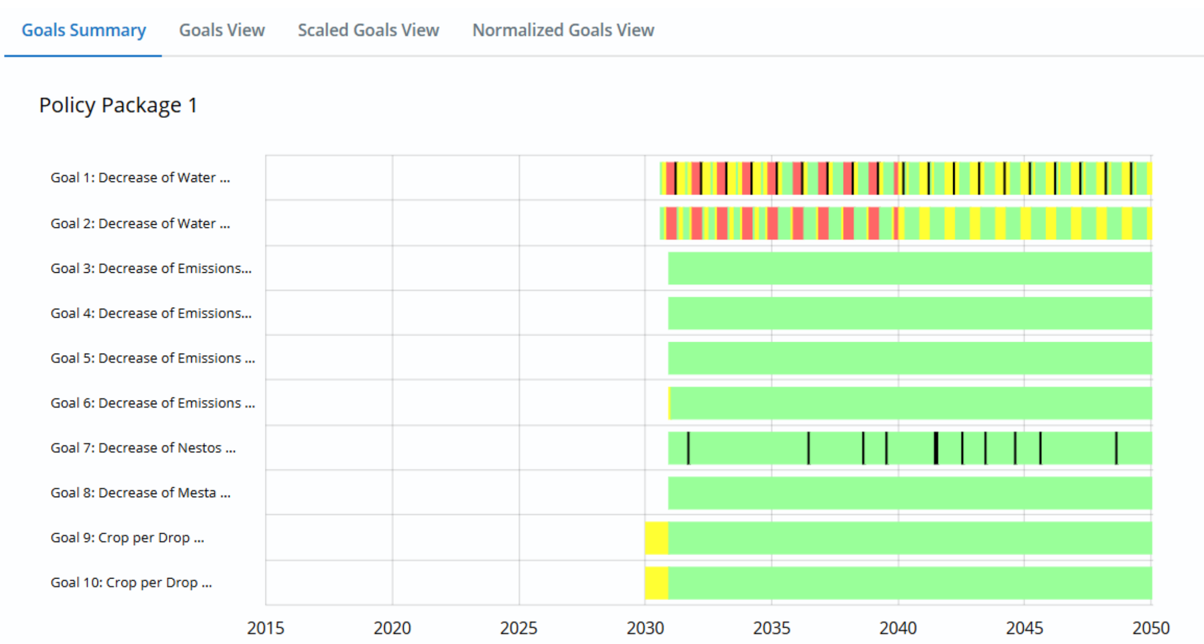
Figure 13: Level of goals' achievement without implementing policies



Results presented in Figure 13, are based on current trends; no policy instruments have been applied. Red bars indicate that goals are achieved at a level between 0%-50% with respect to the reference scenario (current trends). This entails the need for interventions so that a satisfying level of goals' accomplishment, i.e. above 50%, is attained. Goal 7 "Decrease of Nestos nitrogen concentration" is improved periodically (green colour) but this is due to the fluctuation of water volume in the river.

Figure 14: Level of goals' achievement when implementing all policies inserted in the NEPAT



The outcomes of the simulation presented in Figure 14 include the level of goals' achievement by implementing all policy instruments inserted in the NEPAT. Obviously, there are important

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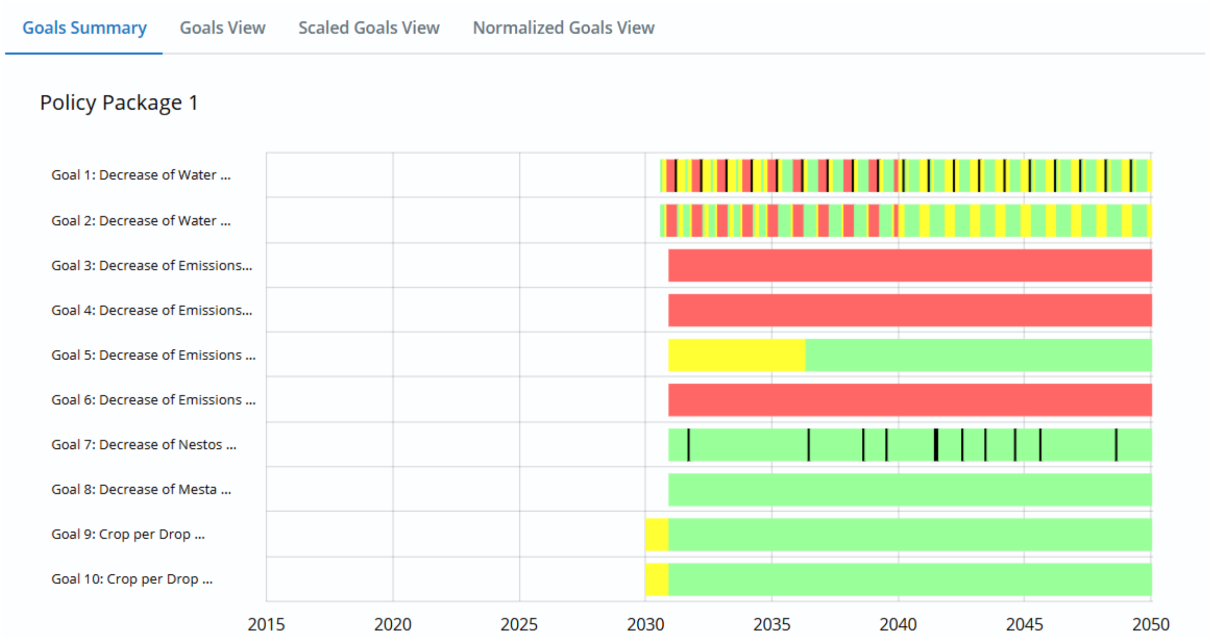
differentiations compared to the first simulation (without applying any policy). More analytically, green bars indicate that the respective goals have been achieved; yellow bars indicate a 50%-100% level of achievement while, black bars indicate that goals have not been achieved at all and the progress of the system is worse compared to the reference scenario (current trends). According to the results, goals are reached at a satisfactory level, and thus the “nexus” is rather achieved, while fluctuations observed in some goals are due to trade-offs that need to be further analysed and managed. It should be mentioned that these results were obtained by applying policies only once until 2030.

Figure 15: Level of goals’ achievement when implementing only water-related policies



This third simulation includes the application of policy instruments regulating the water sector until 2030. Apart from the improvement of goals having to do with the water sector, Goal 5, related to the energy sector and the reduction of emissions in the Greek part of the basin, is also improved. However, this simulation indicates that the improvement of the “nexus” as an integrated system needs further interventions that will also boost the development of the other WEFE nexus sectors.

Regarding the DSS, two indicative simulations were presented to stakeholders in order policy packages for achieving specific goals to be recommended by the NEPAT. Two goals capturing the interest of stakeholders and having already been set as priorities from scratch were selected. Relevant policy packages were recommended by the NEPAT DSS and validated by SHs. These simulations are presented in Figures 16 and 17.

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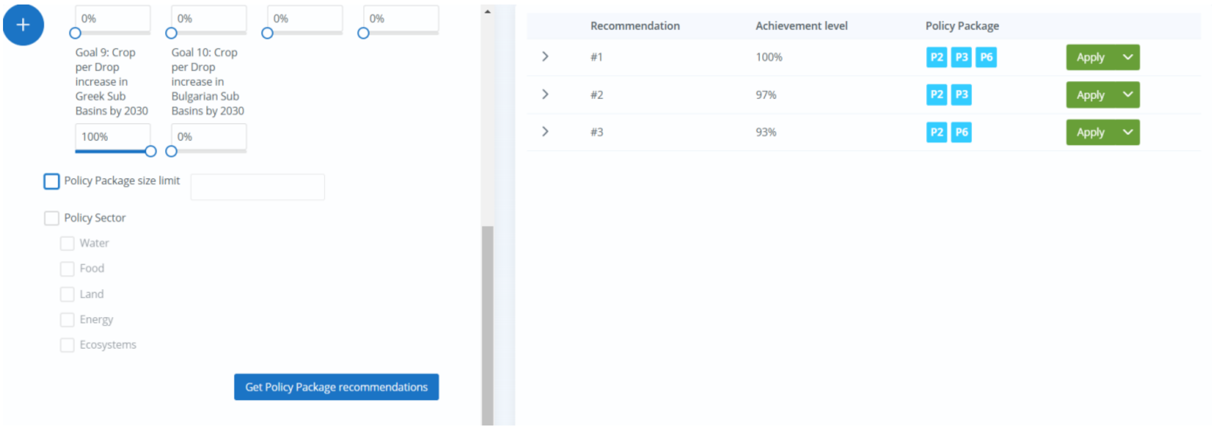
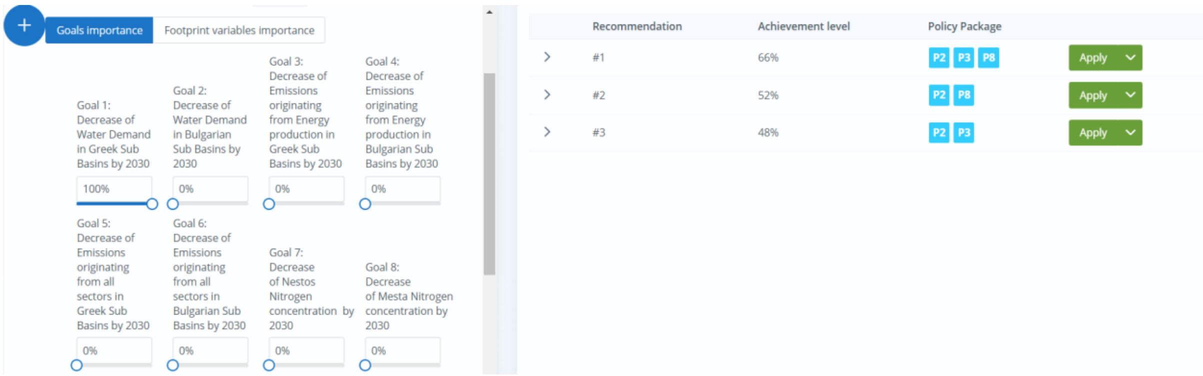
Figure 16: 1st DSS Simulation – Policy recommendations for achieving Goal 9: Crop per Drop increase in Greek sub-basins by 2030



The first simulation concerns the achievement of Goal 9 *“Crop per Drop increase in Greek sub-basins by 2030*”. The DSS recommends the most suitable policy instruments – policy packages (combinations of policy instruments) in order the specific goal to be achieved. The goal’s achievement level depends on the number and combinations of policy instruments. Goal 9 is achieved by 100% in case policy instruments P2 *“Change of irrigation systems in Greek sub-basins”*, P3 *“Replacement of open irrigation canals that transfer water from the river to the crops by closed pipelines”* and P6 *“Cultivation of less water-demanding crops in Greek sub-basins”* are implemented. Different combinations of policy instruments, e.g. P2 and P3 or P2 and P6 result in 97% and 93% of Goal 9 achievement respectively.

Stakeholders prioritised policy instruments P2 and P3, and mentioned that the suggested infrastructures are completely necessary for the development and modernisation of the agricultural sector (food production) while at the same time, they will decisively contribute to the reduction of water losses. Moreover, compared to policy instrument P6, their implementation is much easier and needs less time and economic resources. Changing crop types entails much more time to be applied; the required costs are higher while farmers will need economic support until the new crops will be mature enough in order the initial costs disposed for their cultivation to be paid off.

Figure 17: 2nd DSS Simulation – Policy recommendations for achieving Goal 1: Decrease of water demand in Greek sub-basins by 2030



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The second simulation concerns the achievement of Goal 1 "*Decrease of water demand in Greek sub-basins by 2030"*. In this case, the DSS recommends as the most suitable policy instruments – policy packages to reach the specific goal by 66%, policy instrument P2 *"Change of irrigation systems in Greek sub-basins"*, policy instrument P3 *"Replacement of open irrigation canals that transfer water from the river to the crops by closed pipelines"* and policy instrument P8 *"Extensive use of water saving infrastructures by the sector of livestock"*. Different combinations of policy instruments, e.g. P2 and P8 or P2 and P3 result in 52% and 48% of Goal 1 achievement respectively.

Similarly to the first simulation results, stakeholders subscribed the implementation of policy instruments P2 and P3. Regarding policy instrument P8, they strongly agree with the modernisation of infrastructures in the sector of livestock as smarter use of water means reduction of water losses and reduction of relevant costs for stockmen. However, funding is required so that the proposed changes to be initiated.

Similar examples for the Bulgarian basin were demonstrated to Bulgarian SHs, i.e. recommendation of policy packages for achieving Goal 10 *"Crop per Drop increase in Bulgarian sub-basins by 2030*" and recommendation of policy packages for achieving Goal 2 *"Decrease of water demand in Bulgarian sub-basins by 2030*". In the first case, the recommended policy packages included policy instrument P1 *"Change of irrigation systems in Bulgarian sub-basins"*, policy instrument P3 *"Replacement of open irrigation canals that transfer water from the river to the crops by closed pipelines"* and policy instrument P7 *"Cultivation of less water-demanding crops in Bulgarian sub-basins"*. The achievement level of Goal 10 according to different combinations of policies is:

- 100%, implementation of policies P1, P3
- 92%, implementation of policies P1, P7
- 90%, implementation of policy P1

In the second case, the recommended policy packages included policy instrument *P1 "Change of irrigation systems in Bulgarian sub-basins"*, policy instrument P3 *"Replacement of open irrigation canals that transfer water from the river to the crops by closed pipelines"* and policy instrument P8 *"Extensive use of water saving infrastructures by the sector of livestock"*. The achievement level of Goal 2 according to different combinations of policies is:

- 83%, implementation of policy instruments P1, P3, P8
- 76%, implementation of policy instruments P1, P8
- 58%, implementation of policy instruments P1, P3

Reactions of Bulgarian SHs were more or less the same as Gotse-Delchev is a low income agricultural area and residents are dependent on water availability for food production. Reinforcement of agricultural income is critical and thus, further development and modernisation of the agricultural sector represents an important local priority.

Further technical details on the NEPAT are presented in Deliverables: D4.1 "Self-learning nexus engine specifications and technical design" (M10), D4.3 "Simulation policy framework" (M34), D4.4 "Core module of the self-learning nexus engine" and D4.5 "Final version of the self-assessment nexus engine with the corresponding validation" (M42).

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3.5 Stakeholder engagement and stakeholder workshops (WP5)

NEXOGENESIS follows a 5-step stakeholder engagement (SHE) process:

- **Step 1** is the definition of the SHE aim to ensure a clear process and allow defining expectations and communicating to the SHs their role in the co-creation process.
- **Step 2**, stakeholder analysis, starts with the identification of who should be involved where and how (e.g., SH 1 should be informed, whereas there should be close collaboration to empower SH 2) by classifying stakeholders and analysing their relationship to the project, as well as to each other.
- **Step 3**, the stakeholder engagement plan, assesses the SHs' interest to identify incentives and benefits that can drive their engagement in the project.
- **Step 4**, stakeholder management and sustainment, determines how to maintain this interest and engagement of the SHs throughout the duration of the project and how to sustain the SHs' engagement beyond the lifetime of the project.
- **Step 5** aims at evaluating the participatory process and its effects on the project, as well as on the CS's objectives. MS6 describes methods for Steps 1 and 2, whereas D5.1 (due M45) will describe the methods for all remaining steps.

3.5.1 Overview of current stakeholder landscape

Table 5 shows the number of SHs identified in the CS and Table 6 provides more detail about how SHs were categorised.

*Table 5: Overview of identified stakeholders (SHs) in the case study (*consortium members are excluded)*

	Preliminary	Without consent	With consent (PPCF)
No. of total identified SHs	126	79 (62.10%)	47 (37.30%)

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Table 6: Categorisation of stakeholders (SHs) in the case study

Categories	Number
By Tier[1]	
Tier 1	45, with consent: 5
Tier 2	52, with consent: 26
Tier 3	26, with consent: 16
***No tier indicated**	3, with consent: 0
By occupation[2]	
1. Civil society	3, with consent: 2
2. Public initiatives	0
3. Policy makers at local level/municipalities	48, with consent: 12
4. Policy makers at national level	1, with consent: 0
5. Agricultural authorities and representatives	11, with consent: 3
6. Energy authorities and representatives	1, with consent: 1
7. Water management authorities and representatives	13, with consent: 3
8. River basin authorities and representatives	0, with consent: 3
9. Environmental protection authorities and representatives	9, with consent: 6
10. Business/private or public enterprises	15, with consent: 6
11. Media/science communicators	7, with consent: 0
12. Other (Academic/Research Institutes, public servants)	15, with consent: 11
13. Other consortium members (a.k.a. internal stakeholders)	7
***Not indicated occupation**	3, with consent: 0
By interest and power (only 1 option) ***only SHs having signed the PPCF and based on how they themselves assessed their levels of interest and power**	
High Interest - High Power (HI-HP)	14
High Interest - Low Power (HI-LP)	21
Low Interest - High Power (LI-HP)	0
Low Interest - Low Power (LI-LP)	12
Female	17
Male	30
Other	-
By WEFE sector (multiple options – some SHs indicated more than one sector based also on their interests) ***only SHs having signed the PPCF**	
Water	27
Energy	8
Food	7
Ecosystems	29
By actor-links (multiple options)	

[1] Tier 1: This tier includes stakeholders who will be directly engaged in project implementation and/or outcomes and are strongly case-specific (e.g., representatives of the local municipality, civil society organisations -CSOs-). SHs will potentially collaborate (they might be informed or consulted only) in the processes of development of the models and self-learning nexus assessment engine, and analysis and validation of policy suggestions. Tier 2: This tier includes stakeholders with an interest in the application of project results and products. A wider constellation of interested SHs (e.g., local government, European policy departments -EC DGs-, stakeholders in different basins) who wish to utilise the NXG engine may be engaged. Tier 3: This tier includes stakeholders with a general interest in the project. This is a wide group of stakeholders for the dissemination of outcomes which could include neighbouring basin or country authorities, business or private enterprises, and national planning agencies.
[2] Description of stakeholder categories can be found in MS6.

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*only SHs having signed the PPCF	
Conflict	17
Complementary	138
Cooperation	149
Non-existent	470
Blanks	0

3.5.2 Summary of engagement approach

SHE activities carried out in this CS were based on:

a) co-exploration of existing pressures, future challenges and hot-spots;
b) co-design of possible policies and solutions/responses to current problems; and
c) co-development of policy packages as well as a governance roadmap including specific steps towards policy adoption and implementation.

In Table 7 an overview of the engagement approach is presented.

Table 7: Overview of the engagement approach

	Co-exploration	Co-design		Co-development	
	Information	**Consultation**	**Involvement**	**Collaboration**	**Empowerment**
Stakeholder category (expected - given NXG aim)	All categories	All categories	All categories	All categories	Local decision makers (municipality, regional directorate), farmers
Power and Interest (PI)	All categories	All categories	All categories	Academic sector, local decision makers, farmers	Local decision makers, farmers
CS focus and activity	Co-exploration of existing problems and pressures (workshop), Informing about results on held meetings and workshops (e.g., email, newsletter, "thank you" emails).	Co-design possible solutions to the reported problems (workshops), Consult about perception of trust context (e.g., survey).	Stakeholders' involvement in co-designing possible solutions/ policy packages (workshops), Involve in framing trust issues (e.g., survey, focus group, interview).	Engage in framing the issue and developing solution pathways (e.g., focus groups, interviews, workshops).	Engage in framing and finding solution pathways by themselves (e.g., focus groups, workshops, training/capacity building).

Annex 2 includes a list of all engagement activities conducted to date.

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3.5.3 Summary of workshops

WP5 supports the application of the NXG approach in the five case studies. NXG builds on co-creation, both within the consortium and with the stakeholders at CS level. Thus, CS workshops with stakeholders are an important building block of the stakeholder engagement strategy. Table 8 provides a summary of the workshops and Table 9 summarises the gender distribution of participants.

Table 8: Summary of workshops, including main goals, structure, outcomes, experiences and lessons learned

WS	Goals	Structure, activities	Main outcomes	Experiences (positive/ negative)	Lessons learned
1	– Introduction of the NXG project (goals, expected results, work carried out by WPs, stakeholder engagement approach) – Identification of problems and pressures in the Nestos/Mesta river basin – Initial version of conceptual model	– Introduction to the aims of the meeting – Presentation of the NXG project – Presentation of the initial version of the conceptual model – Open discussion on pressures and problems – Meeting minutes	– Main existing pressures reported – Input to the conceptual model acquired	Positive aspects: – Open discussion session was successful and NXG partners gained significant input as to existing problems and pressures – SHs indicated their interest in the project Negative aspects: – Limited representation of the energy and food sectors – Limited responses to questionnaires	Open discussion is a very effective mode of communication as SHs feel that they can express their views without any constraint
2	– Validation of the conceptual model – Discussion of preliminary policy packages	– Presentation of the conceptual model and validation by SHs – Presentation of proposed policies and suggestions by SHs – Open discussion – Meeting minutes	– Conceptual model: validated – Input on possible policies to be added and tested in the NEPAT	Positive aspects: Open discussion session was successful and NXG partners gained significant input as to policy priorities and issues to be added in the final version of the conceptual model/map and the SDM Negative aspects: – Limited representation of the energy sector (dam operator) due to conflicts with farmers	NXG partners should re-think the administration of questionnaires (length, complexity, timing and frequency)

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WS	Goals	Structure, activities	Main outcomes	Experiences (positive/ negative)	Lessons learned
				– Limited responses to questionnaires – Lower participation compared to the first workshop	
3	– Nexus governance assessment / Presentation of results – Validation of policy packages – Questionnaires on the SHE process assessment – Data used and modelling techniques	– Presentation of the results of the nexus governance assessment (WP1/WP5) – Validation of the final policy packages (to be quantified in the SDM) by the SHs (WP5) – Assessment of the SHE process / Questionnaire (WP5) – Poster presentations on: 1. the biophysical and socio-economic data used by the project and 2. The modelling techniques used for analysing and modelling WEFE nexus interlinkages (SDM)	– SHs elaborated on issues concerning nexus governance and possible future activities that could be undertaken in transboundary level – SHs validated the final policy packages and a list of policies to be quantified was created – SHs answered the questionnaire prepared by AVA, targeting at the assessment of the SHE process	<u>Positive aspects:</u> – International workshop between Greece and Bulgaria / High response to participate/High number of participants – A bi-national dialogue between Greek and Bulgarian SHs was initiated for the first time – Strengthening relationships between local Greek and Bulgarian SHs – Agreement on policies to be quantified in the SDM and tested by the NEPAT <u>Negative aspects:</u> – Limited number of responses to the questionnaires – Limited participation of the energy sector (dam operator)	– SHs are willing to exploit the scientific outcomes of the project – SHs are positive towards the establishment of local partnerships and the undertaking of local-scale activities – SHs feel that their 'voice' is not heard by high-level decision makers – International mode of workshop has been proven to be more effective however the language barrier is crucial for the establishment of a trustful relationship among SHs – Communication between administrative levels/organisations should be improved and bureaucracy should be limited
4	Presentation of the NEPAT and collection of feedback from SHs on NEPAT's GUI and functionalities	– WP4 (EURECAT) presented the GUI and the main functionalities of the NEPAT – SHs provided their feedback as to further improvements	– SHs took a first 'taste' of the functionalities of the NEPAT and the results that this tool will provide – WP4 gained useful feedback from SHs that will	<u>Positive aspects:</u> – Presentation of the tool and its contribution to the decision-making process – Implementation of policies and incorporation of SHs' expectations in the NEPAT	The critical role that a DSS can play in the design of improved policies

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WS	Goals	Structure, activities	Main outcomes	Experiences (positive/ negative)	Lessons learned
		(Menti questionnaire)	allow them to further elaborate on the functionalities of the tool based on SHs' expectations	– Representation of the energy sector at expert/practitioner level <u>Negative aspects:</u> The workshop was mainly targeted to experts who have a knowledge background on technical aspects	
5	– Demonstration of the Nestos/Mesta NEPAT version – Introduction to the governance roadmap and results chains – Assessment of the SHE process	– Presentation on the progress of the CS – Brief presentation of the final version of the SDM (basis for the quantification of policies in the NEPAT) – Demonstration of the NEPAT, simulations concerning policy impacts on the goals set and DSS simulations for exploring policy recommendations – Policy validation by stakeholders, i.e. validation of policies included and tested in the NEPAT – Presentation of an indicative governance roadmap based on "theory of change" and results chains in order stakeholders to understand the next steps towards policy adoption and	– SHs understood how the NEPAT works in the case of the Nestos/Mesta CS, its functionalities and the types of results it produces – Policies included in the NEPAT, and going to be further processed during the design of the governance roadmap, were validated by SHs – SHs understood how the results chains are designed in order to explicitly describe specific steps towards policy adoption and policy implementation – SHs answered the questionnaires	<u>Positive aspects:</u> – Presentation of the Nestos/Mesta version of the NEPAT – SHs are satisfied by the new possibilities offered by the tool and are willing to further test it – SHs are convinced that scientific data are credible, they 'trust' numerical data and they want to further exploit the outcomes of the project – Validated policies reflect local priorities <u>Negative aspects:</u> – Absence of high-level decision makers, absence of the dam operator – Results chains constitute a useful tool for designing the process of policy adoption and policy implementation (through the	– SHs are willing to test and use the NEPAT, they trust the reliability of its results and they think that it is an important tool supporting policy impact assessment based on numerical data – They are positive towards designing a complete and robust results chain that will be further exploited towards policy implementation (*it should be mentioned that this policy is included in one of the validated policy packages of the NEPAT)

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WS	Goals	Structure, activities	Main outcomes	Experiences (positive/ negative)	Lessons learned
		policy implementation (final agreement that will take place during the 6th WS) – Brief presentation on the SHE process approach and re-assessment of the SHE process by SHs via a questionnaire (same questionnaire as the one used after the 3rd WS in order results to be compared)	prepared by AVA and targeting at the re-assessment of the SHE process	description of explicit steps) but approaching high-level decision makers and receiving the necessary funding (economic resources) is still the difficult part of the whole process	

Table 9: Gender distribution of participants

Workshop No.	Males	Females	Total
Workshop 1	26	12	38
Workshop 2	21	6	27
Workshop 3	27	10	37
Workshop 4	18	8	26
Workshop 5	35	18	53

3.5.4 Summary of the engagement activities

So far, five SHs' workshops have been conducted. The first two workshops took place separately (March-April 2022 and November 2022 respectively) in the Municipality of Nestos (GR) and in the Municipality of Gotse-Delchev (BG), and were co-organized by NTUA, UTH, Municipality of Nestos and Municipality of Gotse-Delchev. The third workshop (March 2023) was an international one where stakeholders from both countries participated in a joint WS that took place in the Municipality of Nestos (GR), and co-organised by NTUA, UTH, Municipality of Nestos, Municipality of Gotse-Delchev, WP1, WP2, WP3 and AVA. The fourth workshop was held online (February 2024) and conducted with the assistance of WP4 (EURECAT). The fifth workshop took place in November 2024, in the Municipality of Nestos (GR) (November 21) and in the Municipality of Gotse-Delchev (BG) (November 22); it was co-organised by NTUA, UTH, Municipality of Nestos, Municipality of Gotse-Delchev and AVA.

During the first workshops (Municipality of Nestos – on 4 March 2022, Municipality of Gotse-Delchev – on 7 April 2022) a general presentation of the NXG project and its objectives was given by CS leaders. The presentation focused on the general and specific goals of the project,

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the work that would be carried out by the different WPs, and the participatory / stakeholder engagement approach that the consortium adopts in order to co-create, with the engaged stakeholders, the future development of the CSs through the establishment of a river contract / stakeholder agreement. In addition, existing problems and pressures were discussed using a reciprocal mode of co-exploration between project partners and the involved stakeholders. Project partners presented some problems that were identified before the first workshop. In response, stakeholders gave their feedback and also reported additional pressures in the area. An introductory discussion on the conceptual model/map (qualitative schematic representation of WEFE nexus sectors and interactions) was also carried out and a first draft of the conceptual model/map was presented to stakeholders who were asked to elaborate more on possible interactions and trade-offs.

The main issues of discussion concerned:

- flood risk, management of water volumes coming from upstream;
- problems created in the river by carried material/sediments;
- conflicts between antagonistic water uses (especially between the energy and agricultural sectors);
- river pollution;
- wastewater treatment;
- sustainable development of agriculture;
- energy production from RES;
- sustainable water use;
- ageing irrigation infrastructures and water losses;
- cultivation of water-intensive crops with increased water needs;
- erosion in the estuaries;
- endangered species; and
- ecosystems preservation with special emphasis on securing minimal environmental flow.

The main achievements of the 1st WSs are briefly the following:

- pressures on the river basin were elicited;
- existing problems were discussed;
- input to the conceptual model/map was gained by SHs; and
- an adequate number of SHs corresponded to the WS invitation and “trust building” between CS leaders and SHs started to be fostered.

SHs’ input was incorporated into the preliminary version of the conceptual model/map, and CS leaders started to explore policies and possible solutions linked to the problems reported by stakeholders.

In total, 38 SHs (19 GR and 19 BG) participated in these two 1st WSs. Their distribution according to the institution/sector they represent is presented in Table 10.

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Table 10: SHs distribution according to the institution/sector they represent (WS 1)

Institution / sector (according to the categories for the SH register)	No. of participants (registrations)			
	In total	Male	Female	Non-binary
External stakeholders (outside of the project partners):				
1. Civil society	-	-	-	-
2. Public initiatives	-	-	-	-
3. Policy makers at local level/municipalities	18	12	6	-
4. Policy makers at national level	-	-	-	-
5. Agricultural authorities and representatives	2	2	-	-
6. Energy authorities and representatives	-	-	-	-
7. Water management authorities and representatives	5	5	-	-
8. River basin authorities and representatives	1	-	1	-
9. Environmental protection authorities & representatives	7	3	4	-
10. Business/private or public enterprises	1	1	-	-
11. Media/science communicators	2	1	1	-
12. Other (Academic/Research Institutes)	2	2	-	-

The second workshops (Municipality of Nestos – on 18 November 2022, Municipality of Gotse-Delchev – on 24 November 2022) focused on the validation of the conceptual model/map and on discussing possible policy packages (goals and interventions) to be embodied (quantified) in the SDM and tested in the NEPAT. The conceptual model/map was validated by the stakeholders and its final version was prepared by WP3 (UTH). In addition, CS leaders had prepared a list of possible policy packages (by taking into consideration pressures reported by stakeholders during the first workshop) and a discussion took place regarding the suggested policies. Stakeholders noted that the main issues that should be considered during policy- and decision- making are:

- co-operation between Greece and Bulgaria, compromising water-diplomacy issues;
- flood protection and prevention;
- removal of carried material/sediments;
- support of agricultural income;
- modernisation of irrigation infrastructures;
- monitoring water quality and confrontation of pollution;
- confrontation of coastal erosion;
- exploitation of geothermy for energy production;
- preservation of ecosystems;
- wastewater treatment;
- elimination of land use conflicts (e.g. pastures and protected areas);
- elimination of water use conflicts;
- official registration of drills/wells;
- preservation of ecosystems (e.g. securing of environmental flow, waste disposal, management of illegal landfills, etc.); and
- protection of local flora and fauna.

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CS leaders also suggested cultivation of crops with export capabilities (based on the priorities set by the Research and Innovation Smart Specialisation Strategy for the Region of Eastern Macedonia and Thrace), exploitation of energy crops / photovoltaics / wind parks / biomass (agricultural waste) for energy production, and re-use of treated wastewater for irrigation purposes.

The main achievements of the 2nd WSs include:

- validation of the conceptual model/map by SHs;
- elicitation of suggestions as to possible policy packages by SHs;
- identification of conflicts (farmers vs. dam operator) and synergies (municipal authorities and farmers) between SHs; and
- raising awareness among local SHs.

In total, 27 SHs (13 GR and 14 BG) participated in these two 2nd WSs. Their distribution according to the institution/sector they represent is presented in Table 11.

Table 11: SHs distribution according to the institution/sector they represent (WS 2)

Institution / sector (according to the categories for the SH register)	No. of participants (registrations)			
	In total	Male	Female	Non-binary
External stakeholders (outside of the project partners):				
1. Civil society	-	-	-	-
2. Public initiatives	-	-	-	-
3. Policy makers at local level/municipalities	12	9	3	-
4. Policy makers at national level	-	-	-	-
5. Agricultural authorities and representatives	1	1	-	-
6. Energy authorities and representatives	1	1	-	-
7. Water management authorities and representatives	2	2	-	-
8. River basin authorities and representatives	2	1	1	-
9. Environmental protection authorities & representatives	3	2	1	-
10. Business/private or public enterprises	1	1	-	-
11. Media/science communicators	3	2	1	-
12. Other (Academic/Research Institutes)	2	2	-	-

The outcomes of the second SHs' workshops were analysed in detail. Special emphasis was placed on integrating SHs' reported needs into the "under-construction" policy packages.

The third workshop took place on 28 March 2023 in the premises of the Municipality of Nestos (GR) in collaboration with the Municipality of Gotse-Delchev. This workshop was devoted to policy validation (policies to be quantified in the SDM and included in the NEPAT), WP1 (Task 1.4 and round 2 of nexus governance and policy assessment Task 1.2), WP2 and WP3 needs. First, the results of policy coherence / WEFE nexus governance assessment (WP1) and draft policy packages were discussed, refined, and validated by SHs (WP1/WP5). The final validated list of policies included (also referred in section 3.1 "From stakeholder perception to nexus governance assessment (WP1)"):

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- “cleaning” the river from transported sediments;
- flood prevention and protection / flood risk management;
- water use balance (especially when it comes to dams and water availability for energy and irrigation);
- sustainable management of the available water resources / water saving and reduction of water losses;
- cultivation of less water demanding crops;
- protection of water quality;
- wastewater treatment – water re-use for irrigation;
- energy production from RES (solar, water, geothermy, agricultural biomass, energy crops, composting);
- sustainable development of agriculture and livestock – new (dynamic) crop types that could be cultivated in the region (e.g. crops and agricultural products with export capabilities);
- elimination of land use conflicts (pastures and protected areas);
- official registration of drills/wells;
- preservation of ecosystems (e.g. securing of minimum environmental flow, waste disposal, management of illegal landfills, protection of forest land);
- monitoring volumes of water coming from upstream (Bulgaria);
- protection of biodiversity from intensive agriculture / expansion of agricultural land;
- creation of an inventory including biodiversity threats; and
- reinforcement of aquaculture activities.

Second, biophysical and socioeconomic modelling results were presented to stakeholders (poster presentation). Third, an extended presentation concerning the SHE approach and the expected results, prepared by AVA, took place and afterwards, SHs responded a questionnaire in order to assess the SHE process. The third workshop went very well. It was an international workshop, at which both Greek and Bulgarian SHs met in person and exchanged opinions and ideas. There was simultaneous translation between Bulgarian and Greek languages, which helped to ensure effective communication between the participants. The three main sessions of the workshop focused on: (i) WEFE nexus governance assessment; (ii) Validation of policy packages; and (iii) Assessment of the SHE process. There was a lot of interest by the involved SHs who provided useful feedback. Some SHs seemed to be very committed as they participated in all of the first three workshops and gave their feedback. The third workshop was successful due to the high number of involved SHs and also the joint international nature of the event. It should be mentioned that it was the first time that local SHs from Greece and Bulgaria participated in a common workshop and had the chance to exchange views as to the integrated management of the river basin.

The main achievements of the 3rd WS are:

- willingness of SHs to increase the level of cooperation between the two countries and to create broader synergies at local scale;
- valuable input gained as to the suggested policies – additional interventions proposed by SHs;
- SHs indicated satisfaction for their involvement in the project; and

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- Greek and Bulgarian SHs met and exchanged views.

In total, 37 SHs (30 GR and 7 BG) participated in the 3rd WS. Their distribution according to the institution/sector they represent is presented in Table 12.

Table 12: SHs distribution according to the institution/sector they represent (WS 3)

Institution / sector (according to the categories for the SH register)	No. of participants (registrations)			
	In total	Male	Female	Non-binary
External stakeholders (outside of the project partners):				
1. Civil society	1	1	-	-
2. Public initiatives	-	-	-	-
3. Policy makers at local level/municipalities	18	13	5	-
4. Policy makers at national level	-	-	-	-
5. Agricultural authorities and representatives	8	7	1	-
6. Energy authorities and representatives	-	-	-	-
7. Water management authorities and representatives	2	2	-	-
8. River basin authorities and representatives	-	-	-	-
9. Environmental protection authorities & representatives	2	-	2	-
10. Business/private or public enterprises	2	2	-	-
11. Media/science communicators	2	1	1	-
12. Other (Academic/Research Institutes)	2	1	1	-

The fourth workshop was held online on 21 February 2024. WP4 (EURECAT) presented the NEPAT and collected feedback from SHs on the NEPAT's GUI and functionalities to enable further improvements to be made, based on the expectations of SHs. This was also a successful international workshop, at which stakeholders from Greece, Bulgaria, Romania and South Africa participated and got a first impression of the functionalities of the NEPAT. SHs gave their feedback in order to support further improvements. However, this workshop was mostly oriented to experts - stakeholders with a rather strong background on technicalities - because the emphasis was placed on the technical benefits of the tool. Thus, stakeholders from Greece were mainly representatives of academic/research institutes. However, representatives of the business sector and local governmental authorities were also present. In contrast to the first three workshops, the participation of non-technical stakeholders was rather limited. Holding the fourth workshop in English also limited who could attend. Only the Lielupe version of NEPAT was presented to the participants (the Nestos/Mesta version of the tool was not ready yet). However, it was a practical way to hold the workshop online and with other CSs attending. WP4 (EURECAT) used a Menti survey to receive feedback about the workshop, which was analysed in detail, although indications are that the SHs found the workshop useful.

The main achievements of the 4th WS refer to:

- SHs' satisfaction by the whole concept of policy assessment by using a tool like NEPAT, also supporting decision-making by "producing" policy recommendations (DSS);

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- SHs were happy to see that input provided by their side (in previous WSs) was integrated in the NEPAT; and
- SHs took a “first taste” on how the tool works and what type of outcomes it produces through the demonstration of different simulations.

In total, 26 SHs (15 GR and 11 BG) participated in the 4th WS. Their distribution according to the institution/sector they represent is presented in Table 13.

Table 13: SHs distribution according to the institution/sector they represent (WS 4)

Institution / sector (according to the categories for the SH register)	No. of participants (registrations)			
	In total	Male	Female	Non-binary
External stakeholders (outside of the project partners):				
1. Civil society	1	1	-	-
2. Public initiatives	-	-	-	-
3. Policy makers at local level/municipalities	12	9	3	-
4. Policy makers at national level	-	-	-	-
5. Agricultural authorities and representatives	-	-	-	-
6. Energy authorities and representatives	-	-	-	-
7. Water management authorities and representatives	-	-	-	-
8. River basin authorities and representatives	-	-	-	-
9. Environmental protection authorities & representatives	1	-	1	-
10. Business/private or public enterprises	5	4	1	-
11. Media/science communicators	-	-	-	-
12. Other (Academic/Research Institutes)	7	5	2	-

The fifth workshop took place in November 2024 in the Municipality of Nestos (GR) (21 November) and in the Municipality of Gotse-Delchev (BG) (22 November). It was co-organised by NTUA, UTH, Municipality of Nestos (GR), Municipality of Gotse-Delchev (BG) and AVA. The WS focused on: (i) the presentation of the final SDM version and the demonstration of the NEPAT (assessment of policy impacts and policy recommendations by testing the DSS), (ii) the validation of policies included in the NEPAT, (iii) introducing the process of designing a governance roadmap with the support of results chains and (iv) the presentation of updates concerning the SHE process and the re-assessment of the process by SHs (questionnaire).

The presentation of the SDM targeted at the better understanding of technical issues related to the modelling of the physical system and the interactions between the WEFE nexus sectors as this forms the basis for policy quantification and calculations of numerical values and indicators reflecting policy impacts. The demonstration of the NEPAT included indicative example simulations (a) without implementing policies, (b) by implementing policies in order to explore policy impacts and how the implementation of different policies affects the achievement of the policy goals set and (c) a simulation of the DSS for eliciting policy recommendations on how to achieve specific goals (details presented in section 3.4.1 “NEPAT development”). SHs were impressed by the functionalities of the tool and the type of outcomes it provides as it is based on numerical data. They said that they would like to further test the tool and explore its

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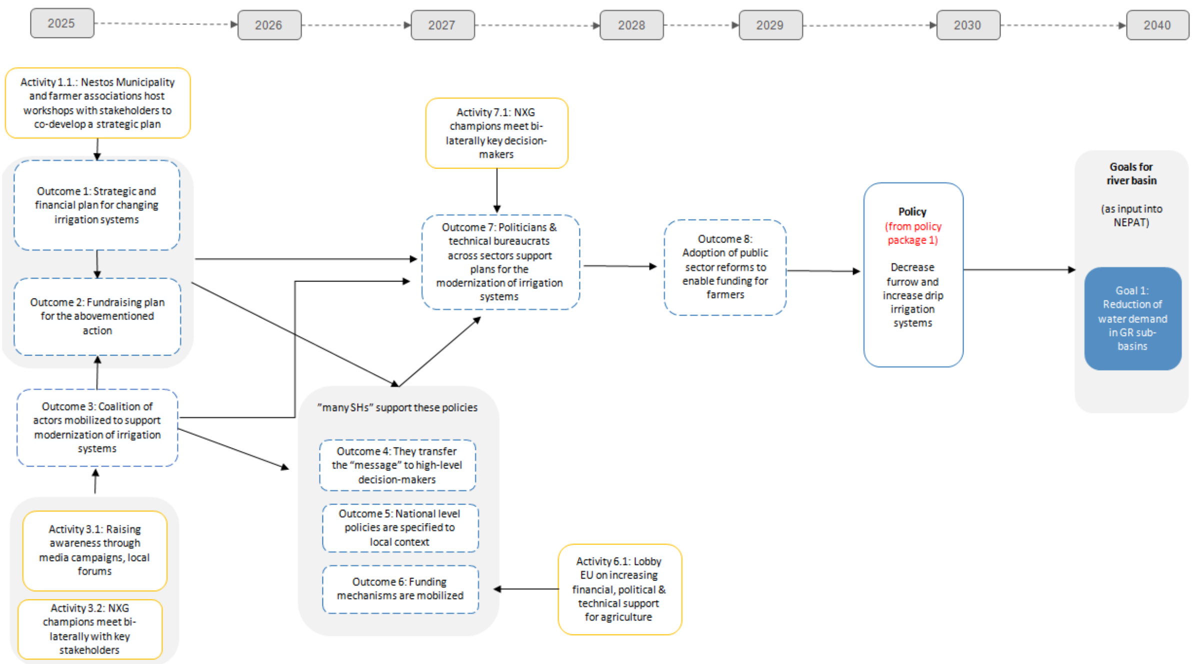
possibilities as it seems to be useful for supporting future decisions for the development of the river basin under climate change conditions. Regarding policy validation, despite the fact that they are in favour of exploiting RES for energy generation, they were mostly interested in policy packages related to the sustainable management of the available water resources such as the modernisation of irrigation systems and the sustainable use of water by the sectors of agriculture and livestock. Thus, policy packages including policies P1/P2 “Change of irrigation systems in Bulgarian/Greek sub-basins”, P3 “Replacement of open irrigation canals that transfer water from the river to the crops by closed pipelines”, P6/P7 “Cultivation of less water-demanding crops in Greek/Bulgarian sub-basins”, P8 “Extensive use of water saving infrastructures by the sector of livestock”, and contributing to the achievement of goals for increasing “crop per drop” irrigation and decreasing water demand were prioritised.

The governance roadmap presentation that followed included an indicative example of results chain towards achieving the goal “Reduction of water demand in Greek sub-basins”[3] (Figure 18).

Figure 18: Indicative example of “results chain”



The finalisation of this “results chain” is in progress and its final version will be presented to SHs during the sixth (final) SHs’ workshop (spring 2025) for validation. It will form the basis for the final SH agreement as it will explicitly describe the steps towards policy adoption and implementation by involving local SHs in the decision making process. This chain consists of a series of steps (outcomes) where the realisation of each of them presupposes that the previous outcome (reading from left to the right) has been achieved. In the case of the Nestos/Mesta CS, the starting point of the chain concerns the establishment of local coalitions between local SHs who have common interests and cooperate with each other for developing

[3] The same example was also presented to Bulgarian SHs but in that case, the results chain referred to the goal “Reduction of water demand in Bulgarian sub-basins” and was adapted accordingly.

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strategic/financial plans that will be further promoted to high-level decision makers (decision makers at national or even at EU level). Such plans should include explicit requirements and justify the importance of the proposed activities in order high-level decision makers to be convinced for their necessity and support the adoption of relevant policies as well as the mobilization of the necessary funding mechanisms that will allow for their implementation.

The final session of the 5th WS had been prepared by AVA and was dedicated to the SHE process and its re-assessment by SHs (the first round of assessment was conducted after the 3rd WS). A brief presentation concerning the approach adopted for knowledge development and co-design/co-development of solutions and policies took place and then, SHs were given the opportunity to re-assess it by filling a relevant questionnaire. Statistical results from the answers received after the 3rd WS were sent to our SHs right after the end of the 5th WS in order to ensure that their answers to the questionnaire shared during the 5th WS would be not biased.

The main achievements of the 5th WS refer to:

- feedback as to policy validation/implementation – SHs suggested policies to be further elaborated in the results chains;
- positive feedback as to the NEPAT and willingness of SHs to use it;
- positive feedback as to the models (SDM) and the validity of numerical data; and
- SHs appreciate that quantitative data reflect the current situation in the river basin.

In total, 53 SHs (38 GR and 15 BG) participated in the 5th WS. Their distribution according to the institution/sector they represent is presented in Table 14.

Table 14: SHs distribution according to the institution/sector they represent (WS 5)

Institution / sector (according to the categories for the SH register)	No. of participants (registrations)			
	In total	Male	Female	Non-binary
External stakeholders (outside of the project partners):				
1. Civil society	3	1	2	-
2. Public initiatives	-	-	-	-
3. Policy makers at local level/municipalities	11	7	4	-
4. Policy makers at national level	-	-	-	-
5. Agricultural authorities and representatives	6	6	-	-
6. Energy authorities and representatives	-	-	-	-
7. Water management authorities and representatives	4	3	1	-
8. River basin authorities and representatives	-	-	-	-
9. Environmental protection authorities & representatives	4	1	3	-
10. Business/private or public enterprises	1	1	-	-
11. Media/science communicators	2	2	-	-
12. Other (Academic/Research Institutes, civil/public servants, N/A)	22	14	8	-

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A final sixth SHs' workshop is going to be organised in spring 2025. This workshop will focus on: (i) the validation of the governance roadmap – results chain by the SHs, (ii) the demonstration of a NEPAT simulation including the validated policy package, (iii) the re-assessment of policy impacts as to the achievement of the several goals and (iv) the validation of the SH agreement. Most probably, it will be an international WS between Greece and Bulgaria that is expected to strengthen ties between SHs and further promote the undertaking of common actions and initiatives.

Open/plenary discussion was adopted as the moderation technique of all five WSs as SHs need space to openly express their needs, aspirations, preferences and opinions regarding existing problems and possible/desirable solutions. They want to "be heard" by all the other participants and in some cases they also start exchanging views with each other. The mode of presentation of the SDM and the tool was simple in order non-technical and non-expert stakeholders (e.g., farmers) to be able to understand the functionalities and the usability of such tools. Trust-building has been developed as SHs appreciate that CS leaders incorporated their input into the suggested solutions and are in favour of offering their support in order the necessary reformations to be further promoted.

As already mentioned, in addition to the five SH workshops, a series of interviews with local stakeholders-practitioners took place in Greece and Bulgaria on 22 July 2022. The interviews were organised by WP1 (University of Tours, KWR), Municipality of Nestos, Municipality of Gotse-Delchev and NTUA. The focus of these interviews was on WEFE nexus governance and policy implementation and integration. Finally, two online focus groups with targeted stakeholders took place in March and May 2023. Greek and Bulgarian stakeholders (representatives of the WEFE nexus sectors – one representative per sector) were asked to validate the results of policy coherence analysis and elaborate on the implementation of specific policy instruments. The focus groups were organised by KWR, NTUA, Municipality of Nestos and Municipality of Gotse-Delchev. It should be mentioned that it was the first time that a high-level decision maker (GR), representative of the water sector, joined a participatory meeting of the project. Results enriched the analysis of policy coherence and were further elaborated by WP1.

Adjusting the SH engagement plan

The SHE plan was provided for the first time in October 2022 to Nestos/Mesta CS leaders and updated in September 2023 and in September 2024. The plan summarises the results of the SHE aims and the SH analysis and provides recommendations about the engagement strategies to be followed based on the identified modes of co-creation.

The aims of the SHE in the Nestos/Mesta river basin set out in the stakeholder register (MS6) are:

- To generate system knowledge:
    - Deepen into existing problems
    - Explore possible conflicts and synergies among stakeholders
    - Identify pressures in all sectors (water availability/quality, ecosystem, climate/storms, extreme events etc.)
    - Provide data for model development
    - Inform the research team about plans/projects that are in progress

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- To generate target knowledge:
    - See which are SHs' future expectations/perspectives
- To generate transformation knowledge:
    - Design suggestions and a river contract/stakeholder agreement proposal
- To build a trustful relationship among project partners and local SHs

The SHE plan (Oct 2022) recommended actively increasing the interest of other stakeholders while maintaining the interest of the current high interest stakeholders. This is because focusing away from high interest stakeholders towards low interest stakeholders may allow discovering currently missing marginalised stakeholders.

Such objectives were achieved through constant contact between CS leaders and SHs, frequent updates on the CS progress, fruitful discussions and reflections on the outcomes of the co-creation process during SHs workshops, and maintenance of SHs interest. The fact that the Municipality of Nestos (GR) and the Municipality of Gotse-Delchev (BG) are partners of the NXG project is essential as they actively support the organisation of the several events while they are in touch with many local stakeholders, something that facilitates the co-creation activities. Efforts towards increasing SHs participation in the workshops have been reinforced while stakeholders' fatigue should be avoided in order not to "miss" them until the end of the project. An important challenge is keeping their interest "alive" and persuading them that their participation is crucial for achieving the project's objectives. In other words, they should realize that they are part of the project, their voice is "heard" and their suggestions are not ignored. Another issue is the willingness of SHs to fill in complex questionnaires after the workshops; for that reason, it has been decided (and done) that the surveys would be shared with the stakeholders during the workshops in order for more responses to be acquired. Finally, it should be mentioned that a lot of effort should be dedicated in order to convince them to join the stakeholder agreement and retain their commitment; especially after the end of the project.

CS leaders worked towards the directions indicated by the SHE plan and reported on the progress of the issues raised in the new updated SHE plan. As the CS was developing, the aims of the SHE in the Nestos/Mesta river basin were updated (SHE plan – October 2024), based on the acquired experience and SHs' expressed needs.
Such updated aims are:

- To generate system knowledge:
    - Explore possible conflicts and synergies among SHs
    - Inform/update the research team about plans/projects that are in progress
    - Assessment of NEPAT results – Do they correspond to local needs?
    - Hot-spots and establishment of (local)-scale collaborations among SHs
- To generate target knowledge:
    - Assessment of policy impacts – NEPAT
    - Focus on common interests that may foster future collaborations
- To generate transformation knowledge:
    - Design suggestions and a river contract/SH agreement proposal
    - Re-design solutions (if needed) based on NEPAT outcomes
    - To build a trustful relationship among project partners and local SHs

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The updated SHE plan (October 2024) recommended that CS leaders should focus on: convincing high-power SHs (e.g. high-level decision makers) of the value of the project and its outcomes; maintaining the interest of the engaged SHs; enhancing collaboration between them; providing system knowledge (emphasis on SDM, NEPAT – results of the biophysical and socio-economic modelling); conveying inputs from marginalised SHs to powerful SHs; "pushing" for the creation of local coalitions and the adoption of a final SH agreement; co-developing activities and further planning of SH sustainment based on defined agreements; providing robust scientific evidence as to the research outcomes of the project; and integrating policy suggestion from the NEPAT.

3.6 From policy recommendations to impact maximization (WP6)

WP6 has provided the Nestos/Mesta CS with dissemination material such as: a flyer which was translated into Greek and Bulgarian, printed and shared with the stakeholders; a project banner; and a project poster. This material supports dissemination of the project's goals and expected outcomes, and provides information for the 5 CSs. An introductory video about the Nestos/Mesta CS was also developed and the transcript was translated in Greek and Bulgarian. Content for the NXG website, i.e. a brief description of the Nestos/Mesta CS was sent to WP6 at an early stage of the project, and CS leaders also received all the relevant communication guidelines. Communication material like NXG social networks, the NXG webpage, CS leaders' e-mail addresses and flyers are all shared with the involved stakeholders during and after each workshop. Before workshop 4, WP6 published a YouTube video (prepared by EURECAT) with the presentation of the NEPAT (Greek and Bulgarian subtitles) that was shared to the stakeholders. Also, a factsheet including a brief description of the NEXOGENESIS concepts and tools, was prepared with contributions from all WPs and shared by WP6, and was translated into local languages (Greek and Bulgarian). This factsheet includes a simple presentation of the NEPAT, the biophysical and socio-economic data used within the project, the adopted modelling approach, and the climatic and socioeconomic pathways that were used as the basis for the NEPAT simulations. The factsheet was shared with technical and non-technical stakeholders before and during the fifth SH workshop. The preparation of CS factsheets, as a joint effort of all WPs, CS leaders and WP6, is now in progress. Such factsheets will support communication with SHs and dissemination of project outcomes by raising awareness and promoting the achievements of CSs. The target audience in the case of Nestos/Mesta CS is going to include high-level decision makers (at national level), local and regional authorities, farmer associations, academic/research institutes, environmental organisations and water management authorities.

3.6.1 Impact maximization

As the project develops, impact maximization is enhanced, mainly through co-creation processes and activities between CS leaders and SHs. Trust-building has been strengthened, mainly because SHs understood that their input is taken into consideration and it is incorporated in the several outcomes of the project, i.e. list of policies, conceptual model/map,

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SDM, NEPAT. Their motivation to contribute to the design of effective policies governing the WEFE nexus and to further exploit the outcomes of the project has been empowered while a rich knowledge background, concerning local pressures and priorities, has been created through raising awareness activities and sharing of experiences. In addition, SHs are more willing to create local coalitions, promoting specific solutions that are adapted to the particular characteristics of the Nestos/Mesta river basin; they are more mature and well-informed on what is called “integrated resource use”.

More analytically:

- **Trust building**: After the third international workshop, trust between CS leaders and SHs was strengthened. Stakeholders seemed more willing to contribute to possible future changes and take action at local scale. Moreover, a dialogue between Greek and Bulgarian SHs started and common interests were sought. In other words, the international mode of the 3rd workshop gave them the chance to start interacting with each other and understand that there are common problems and interests.
- **Motivation**: The fact that SHs’ expectations and preferences were incorporated in the final list of policy packages and the tools that developed at a next stage, was a significant encouragement for them.
- **Co-assessing WEFE nexus governance**: SHs understood that their contribution to the field visit-interviews (July 2022) has been taken into consideration in the final nexus governance assessment.
- **Exploitation**: SHs are willing to explore and further exploit the scientific outcomes of the project as they believe that the future development of the study area should be based on robust and sound scientific evidence (trust in quantitative data and calculation of relevant indicators). The degree to which they are “convinced” has been increased since the beginning of the project as CS leaders give SHs space to express their preferences and take into account their opinion at every step of the CS development (e.g. design of policy packages, design of the conceptual model/map, design of the SDM, design of the NEPAT, validation of policies included in the NEPAT).
- **Increased interest – Raise awareness**: There is an increased interest of SHs to join international workshops where both Greek and Bulgarian SHs, representatives of the WEFE nexus sectors, will participate. Their willingness to be more aware of issues concerning the two countries and to cooperate with each other by undertaking initiatives at local scale, e.g., protection of ecosystems, was rather unexpected as so far there are no synergetic actions, initiatives and cooperations between the two countries at local scale. People are not aware of common problems and issues on which they could work together. As participatory planning is not a common practice in Greece and Bulgaria, the co-operation and interaction of the involved SHs was really an achievement of the project. It should be underlined, that it is the first time that such participatory activities are taking place in the area.
- **Understanding policy impacts**: Regarding policies, the main policy impacts that the CS will focus on have to do with the limitation of water losses by the agricultural sector and the increase of renewable energy generation. Such policies were validated by SHs during the fifth WS. Despite the fact that energy generation from PVs (installed above irrigation canals) is already discussed, SHs prefer starting from the modernization of irrigation systems/infrastructures as a way to confront reduced precipitation rates and

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to minimise water losses. Such policy option is now being further elaborated under the governance roadmap/results chain framework.

- **Knowledge co-creation and roadblocks**: Regarding roadblocks related to the way knowledge co-creation is being carried out, we could possibly refer to the limited participation of SHs representing the energy sector and especially the operator of the two dams located in the Nestos river basin. However, the process of knowledge co-creation is developing normally and a "strong" knowledge background has already been built.
- **CS leaders support**: CS leaders can support impact maximisation as they represent an academic institution bringing the potential to suggest solutions and policies based on scientific data and research. However, academia is not responsible for implementing and funding the respective solutions. Decision-making and policy implementation are the responsibility of the national and regional decision makers / administrative organisations. SHs do not have the power to trigger large-scale interventions, despite the fact that among them there are representatives of regional / local organisations (e.g., municipal authorities). Most decisions are taken and funded by the central government and this is something that limits the available means of decision-making power. However, the governance roadmap that is now in progress will support the promotion of local needs and suggested solutions as it will be on the disposal of Nestos and Gotse-Delchev Municipalities. Apart from being members of the Consortium, the two municipalities are also important local stakeholders who can mobilise local communities for establishing coalitions and promote local plans to regional authorities (NUTS 2 level) and the national government (NUTS 1 level).
- **Use of NEPAT**: Promoting NEPAT is an important factor that can increase impact maximisation as it is a tool supporting decision-making based on scientific evidence and reflects local priorities. SHs are very positive towards getting more familiarised with the tool and explore/use the outcomes it produces.
- **Local coalitions**: A core group of SHs has been established, consisting of representatives of municipal authorities, regional authorities, farmer associations, academic/research institutes, environmental organisations and water management authorities. These SHs have attended almost all five WSs having been organised so far and are positive towards the creation of local synergies and the promotion of the necessary changes.

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4 Lessons learned and experiences

4.1 Implementing the SHE process

The SHE process includes five distinct steps that "guided" the design and organisation of all the engagement activities. It facilitated stakeholder coordination and engagement while its regular updates shed light on possible improvements as to the strategy implemented and priorities set by CS leaders.

The first step, i.e. stakeholder engagement aim, helped to define the goals of the SHE process in the Nestos/Mesta CS (e.g., knowledge sharing, delve into existing problems and pressures, co-design future targets, co-decide on possible policies to be implemented).

The second step, i.e. stakeholder analysis, guided the process of selecting stakeholders and filling the SH register, and understanding the interactions among them (synergies, conflicts, common goals), as well as their interest on the project outcomes and their means of power (how they can affect decisions and at which level).

The third step, i.e. stakeholder engagement plan, supported the process of understanding which stakeholders are the most powerful ones and which of them belong to the so-called "marginalised stakeholders" (based on the feedback gained from the previous step), the exploration of common and broadly-accepted solutions, the need to empower less-powerful stakeholders, and the most effective mode of participation / workshops' organisation.

The fourth step, i.e. stakeholder management and sustainment, contributed to the clarification of the most important issues that capture stakeholders' interests (hot-spots) and the most essential future priorities in order to keep them committed.

The fifth step, i.e., stakeholder process evaluation, helped WP5/CS leaders to understand whether SHs are satisfied by the stakeholder engagement process and see what could be improved. In general, stakeholders prefer: (a) open discussions during the workshops, (b) brief and simple presentations, and (c) brief and simple questionnaires. They are willing to participate in the workshops but they feel that their voice will not reach high-level decision makers. They appreciate scientific results but they want to see how these can be exploited in practice.

Overall it was good and helpful to guide the SHE activities and find some specific points that focus should be placed on, such as the type of information needed from SHs and how such information could be managed and systematised.

The evaluations helped NXG consortium deepen its understanding on SHs' interests, preferences and requirements. They also revealed what SHs expect from such a process, which specific issues capture their interests, which is the most preferred mode of participation, which are their main priorities, and which are the solutions and outcomes that they expect from the project. Finally, evaluations shed light on the identification of marginalised stakeholders that should be encouraged to express their opinions openly and to become more active.

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There are people with high interest and who would like to be involved, but their power is low. Marginalised SHs have high interest and low power. They feel that *"I'm not the mayor"* or that *"I will tell you my opinion but I do not have the official role to give me the power to change things"*. CS leaders have discussed with AVA that marginalised SHs should have the opportunity to be more active. There are some options for co-operation at the local level and with other associations, perhaps a compact team of SHs who will co-operate at the local level to promote local activities in their region in the future. The SHE process made WP5/CS leaders more aware of these marginalised SHs and their needs because there was a question about people's perception of their power to change things. If the power value was low it was an indication that the SHs are marginalised and that attention should be paid to that. Involving them in the final governance roadmap and activities that will be included in the results chain of the Nestos/Mesta CS is an important step towards their empowerment and their active participation in local coalitions aiming at "pushing" administrative authorities towards the implementation of effective solutions and desirable policies.

4.2 Improving the SHE process

Based on the experience from conducting the SHE process in CS1, some general comments on how to improve the process per se refer to:

- reinforcing SHs commitment and sustainment;
- keeping their interest "alive";
- increasing the representatives of the WEFE nexus domains (especially high-level decision makers and the operator of the dam); and
- updating SHs on the progress of the CS.

Overall, the workshop activities to date have been aligned with CS leaders' and SHs' expectations at a satisfactory level, as CS leaders encourage SHs to express their opinions without putting any restrictions on their input. Also, SHs have understood that their expectations are incorporated in the proposed solutions and policies; as a result, a trustful relationship among CS core team and SHs has been achieved and the expectations of the two sides seem to align well. SHs are keen to exploit the scientific outcomes and see the work leading to something in practice. They wish to further test the NEPAT in order to get more familiarised with the tool and explore additional policy options/solutions for the development of their region. On the other hand, CS leaders are continuously getting feedback from stakeholders concerning local advantages and peculiarities that they do not keep in mind.

In addition, in transboundary CSs it is very important that SHs from both countries meet each other, discuss all together and exchange their views, share problems and experiences. Such international events increase mutual understanding and could be the beginning for a closer and stronger collaboration at local level. In the case of the Nestos/Mesta CS, the priorities vary between the two countries, e.g. ecological flow is a priority in Greece, while solid waste management is much more critical in Bulgaria. There are also different speeds at the administration level, creating a challenge when trying to address common (transboundary) issues. But participating in NXG workshops (first time for the majority of SHs from both countries) proved that when people "sit at the same table", exchange knowledge and views, and are aware of existing pressures, it is possible that common interests will come to light; especially when the focus is on transboundary rivers where water is a shared natural resource,

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crucial for the development of the entire transboundary area, common interests can be a starting point for broader synergies and collaborations at local/transboundary scale.

A key element in the success of the Nestos/Mesta CS was the participation of the two municipalities as partners in the NXG consortium. CS core team could not have achieved the current level of engagement without having them actively involved in the project. A lot of the talking with people, organising the workshops, etc. has been done by the local municipalities, by people that SHs already knew and trusted, and that is hugely valuable. This relationship enabled discovery of common interests and problems from the outset.

Undoubtedly, stakeholder engagement is an essential dimension of the planning process and the design of future solutions / policies affecting local communities, as their successful implementation presupposes that local communities agree with the proposed solutions and are willing to contribute to the implementation of relevant policies (Papadopoulou et al., 2025). Co-design and co-decision processes facilitate the design of broadly-accepted solutions; knowledge sharing helps researchers to delve into local needs while it enriches stakeholders' knowledge background (bilateral process); international workshops, in the case of transboundary river-basins, support trust building between stakeholders coming from neighbouring countries and establish a base for future collaborations; while, face-to-face workshops are more operational.

However, SH sustainment is the most difficult part of the SHE process. It is difficult to have the same participants in all six workshops, keep them engaged between workshops, and find common dates and times that all stakeholders can be present. Understanding complex technical issues, especially when it comes to scientific data, modelling processes and digital tools is a quite challenging process if technical background is absent. Simplified and brief presentations as well as realistic solutions can keep SHs interest "alive".

An extremely difficult step in the evolution of the CS was to approach high-level decision makers and having them in the WSs as they are people with packed agendas, limited time availability while they do not value as "important" the involvement in such a process. The design of a robust governance roadmap including specific steps towards policy adoption and policy implementation will facilitate municipal authorities to promote specific actions for their area of interest to higher governance levels.

4.3 Integrating sectors in the NEPAT

A beta version of the NEPAT for the Nestos/Mesta CS was prepared by EURECAT, tested by the CS core team and demonstrated to the stakeholders during the 5th workshop (November 2024). Feedback regarding its functionalities, its outcomes and the level to which sectors are integrated was collected.

The Nestos/Mesta version of the NEPAT is based on a quite complex SDM, including a high number of variables simulating interlinkages among the WEFE nexus sectors, as well as on a set of quantified policies. UTH (WP3) dedicated strong efforts to prepare the SDM by exploiting all the available data from WP2 and other data sources (e.g. Eurostat, Corine Land Cover) whereas hydrological parameters were estimated via an explicit hydrological model developed by NTUA; for the first time and covering the entire transboundary river basin. CS leaders along with the involved SHs developed a list of WEFE nexus-related policies considering existing pressures, future challenges, local priorities and SHs' expectations/preferences. CS core team (NTUA and UTH) worked together on policy quantification, i.e. translation of policies into model

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terms and design of indicators measuring policy impacts. The final result was rather satisfactory but limited due to data availability.

Data availability and dissemination is a fundamental issue regarding the effective management of the WEFE nexus and the possibilities to quantify as much policies as possible. It constitutes a critical dimension affecting policy performance assessment and consequently the level of sectoral integration, the support of decision-making processes, and the design of timely and informative policies. However, the current level of sectoral integration in the NEPAT sheds light on existing gaps and shortcomings, and indicates areas where there is space for improvement; thus, making NEPAT a useful tool for decision makers and practitioners.

4.3.1 Using the NEPAT

CS leaders, along with stakeholders, experimented with the NEPAT and explored its usability, its functionalities and the produced outcomes during the 5th workshop. Moreover, a specific policy package, recommended by the DSS, was validated by SHs and then the impacts from implementing the specific policies on the WEFE nexus sectors were explored. NEPAT is generally a user-friendly tool that enables the end-user to test several policies under different contexts, i.e. combinations of RCPs and SSPs, and different combinations of policies (policy packages). Setting up NEPAT by, selecting policies, accessing the necessary data, and reviewing the outcomes is a rather easy process for both technical and non-technical users. However, deep understanding of the models and exploration of causalities presupposes that the end-user is more experienced and has a relevant knowledge background. The interpretation of the outcomes is rather easy for non-experts and much easier for expert/technical end-users. The NEPAT link (https://nepat-dev.nexogenesis.eu/#/login) has been sent to all SHs in order to further test it and get more familiarised with its use. During the 6th workshop, a session regarding further experimentation with the NEPAT will be organised and suggestions for its further exploitation will be discussed.

SHs appreciate the efforts dedicated to the design of the NEPAT. According to what they reported during the 5th workshop, such type of tool that exploits quantitative data and produces numerical values reflecting policy impacts at local scale was missing. They found it very useful, despite the fact that not all policies have been inserted in the tool as they understand the issues related to data availability, and they wish to further test it for exploring several alternatives for the future development of the river basin.

4.3.2 Motivating stakeholders to use the NEPAT

SHs' motivation for using the tool starts from the demonstration of its functionalities and the promotion of its usability. This is strongly connected to the outcomes the NEPAT provides and the possibilities for further exploitation; critical dimensions for capturing SH interest. In addition to the presentation of the tool to SHs, hands-on exercises and further training are rather necessary so that SHs are able to use the tool without help from the scientific team. The "NXG Guidebook" – D1.5 "Consolidated nexus governance framework and guidance for co-creation of nexus governance" (M46) – will facilitate such a process as it will build on lessons learned as to the holistic management of the WEFE nexus resources and policies. However, the most

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important factor affecting SH willingness to test and use the NEPAT is the quality of the outcomes and its usefulness according to SHs' interests. After the 5th workshop, SHs became convinced that NEPAT will help them design effective solutions, detect hot-spots and confront future challenges. Based on the experience and the feedback gained during the WSs, the most important factor that stimulates SHs to use NEPAT is the fact that policies proposed and validated by them, and representing core local priorities are incorporated into the tool. This is an important lesson learned regarding the effectiveness of the co-creation approach adopted by NXG as it allowed partners to design tools ***for*** local stakeholders by using feedback gained ***from*** them. In other words, SHs are in favour of using NEPAT since it has been designed ***for them*** and ***with them***, they feel "part" of such a design process ***for the first time***.

4.4 The overall NXG co-creation approach

Co-creation with local stakeholders significantly contributes to knowledge acquisition and understanding of existing problems and pressures. At the same time it brings an added value to the designed solutions because finally, the proposed solutions reflect local needs and perspectives.

Exploring the WEFE policy framework and assessing policy coherence is a critical factor that also needs to be analysed as it sheds light on gaps that should be addressed. This process goes hand-in-hand with the investigation and analysis of physical interlinkages between the different nexus sectors, as physical interactions should be considered during decision making in order to achieve the integrated management of the WEFE nexus sectors also at policy-making level.

The Nestos/Mesta CS experience indicated that the overall NXG co-creation approach set the basis for: a) initiating dialogues with local communities and incorporating local pressures and expectations into the NXG outcomes and b) effective coordination among the several WPs of NXG.

Regarding the coordination of WPs, technical WPs worked in close collaboration with WP5 and CS leaders, and supported CS development. Nexus governance and policy coherence assessment, provision of biophysical and socio-economic data, as well as WEFE nexus modelling and SDM design, illustrate the main inputs provided to CSs by WP1, WP2 and WP3. WP4 worked on the development of the NEPAT based on the data shared by WP3 and CS leaders. CS leaders are responsible for conducting SH workshops based on the plan prepared and shared by AVA, organising any other important meetings with SHs, collecting data and policies and keeping the overall control of CS progress.

In addition, co-creating with SHs includes consultation and knowledge sharing, co-exploration of pressures and problems, co-design of solutions, and co-decision on policies to be implemented. Such processes are taking place through the organisation/implementation of SH workshops, interviews and focus groups, where knowledge is shared and solutions are built. In the case of Nestos/Mesta CS, the application of the co-creation approach was successful as several issues were analysed and clarified, while a core group of SHs has been created and is willing to promote the NXG outcomes and the suggested solutions.

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Stakeholders contributed to: a) the identification of existing problems/pressures, and of hot-spots that need special attention, b) the analysis of policies and the assessment of WEFE nexus governance, c) the design of effective solutions and policies that are adapted to local needs, d) the initiation of a "transboundary" dialogue between Greece and Bulgaria, and e) the identification of administrative gaps. This two-way approach (feedback process) helps researchers to delve into local needs and to adapt the proposed solutions to SHs' priorities and expectations. Trust building was achieved, SHs' co-operation and involvement seems to increase, their interest as to NXG outcomes remains 'alive' while the most important challenges at this stage are:

a) the achievement of an agreement and its promotion to high-level decision makers, and
b) the sustainment of SHs after NXG completion.

From a SH perspective, stakeholders from both countries are willing to exploit NXG outcomes, to gain more knowledge on transboundary issues and to establish cooperation at local scale. They are satisfied by the participatory activities taking place during the CS implementation and they are in favour of establishing local coalitions that will enhance cooperation and will allow them to work on a plan based on common interests and goals. However, they are feeling that it is difficult to approach high-level decision makers as governmental systems in both Greece and Bulgaria are top-down and administrative processes are very complex while, responsibilities are fragmented. During this last year of NXG, a governance roadmap is under construction including specific goals to be achieved through policies included in the NEPAT. The steps towards policy adoption/implementation will be described in detail, i.e. creation of local coalitions that could work on a common strategic plan that in turn will be presented to high-level decision makers. Possible channels of promoting such a plan could be the Municipalities (NUTS 3 level) and Regional Authorities (NUTS 2 level) that in turn, and along with local stakeholders, will try to "push" central/national governmental authorities. An effort towards that direction should be forced by EU authorities and targeted to national level administrative authorities in order to overcome the communication barriers between the local/regional administrative level and the central decision-making level.

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5 Conclusions

Nestos/Mesta is a transboundary river basin shared between Greece and Bulgaria and facing important challenges as to the sustainable resource use under climate change conditions. In this context, NXG H2020 project contributed significantly to:

a) the organisation of participatory workshops through which the co-creation process was developed;
b) the identification of local pressures and problems through a collaborative process between CS leaders and local SHs;
c) the design of an advanced hydrological model supporting future forecasts as to precipitation and runoff;
d) the design of a conceptual model/map describing WEFE nexus interactions in a qualitative manner and being thus easily understandable by non-experts;
e) the extensive analysis of policies governing the WEFE nexus sectors and the assessment of their coherence;
f) the co-development of a set of policies regulating important local priorities and capturing SHs interests and needs;
g) the design of a complex SDM including quantitative data and quantifying interactions among the sectors of water, energy, food/agriculture, ecosystems, land uses and climate;
h) the design of the Nestos/Mesta NEPAT allowing for policy impact assessment and the “production” of policy recommendations by using artificial intelligence techniques;
i) the establishment of a core group of SHs;
j) the enhancement of trust-building between CS leaders and local communities;
k) the initialisation of a dialogue between Greek and Bulgarian SHs for the first time as to local problems related to WEFE interactions at the river basin scale and the potential to establish local coalitions and collaborations; and,
l) the co-design of a governance roadmap including specific steps towards policy adoption/implementation by also involving local SHs.

NXG project was a first important step to bring to light local challenges and initiate discussions on possible solutions. However, a lot of work remains to be done as the confrontation of such challenges presupposes the active participation of the national government.

Finally, and regarding the achievements of the CS, these are classified into technological achievements and social achievements, briefly presented in Table 15.

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Table 15: Technological and social achievements of the Nestos/Mesta CS

Technological achievements	Social achievements
• Advanced hydrological model - 11 sub-basins of the Nestos/Mesta river basin. • 4 SDM versions per each RCP/SSP combination, describing the physical/socio-economic system and the interactions among the WEFE nexus sectors. • Quantification of policies in the SDM. • Nestos/Mesta NEPAT version supporting policy impact assessment and the formulation of policy recommendations via the DSS. • An integrated WEFE nexus index, synthesis of individual water-, energy-, food- and ecosystem-related indicators, measuring the status/progress of the WEFE nexus at CS scale (level of integrated management of the WEFE nexus) and at a specific time (2030, 2040, 2050).	• For the first time co-creation/participatory activities took place in the Nestos/Mesta river basin to address complex resource management issues. • For the first time a core group of local stakeholders from Greece and Bulgaria was established. A trustful channel to discuss on common problems and possible solutions was initiated. However, the language barrier creates difficulties. • Willingness of SHs to cooperate and work on the undertaking of local initiatives (local coalitions). • Willingness of SHs to learn more about water diplomacy issues concerning the management of the river. • Trust building between project team and local stakeholders – Common understanding. • Willingness of stakeholders to further exploit NXG outcomes (NEPAT, SDM, suggested solutions, suggested policies). • Exchange of knowledge regarding local needs, pressures, problems and aspirations. • Establishment of a core group of stakeholders at each country interested in the evolution of NXG by attending all the workshops organised so far. • Stakeholders are convinced for the utility of tools (e.g. NEPAT/DSS and WEFE footprint) and the validity of data included in these tools – They “trust” quantitative numerical data and scientific outcomes. • SHs expressed their interest in contributing to co-shaping the future of “their” region. • Design of a governance roadmap, explicitly determining the necessary steps and activities towards policy adoption and policy implementation.

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References

Kourtis, I. M., Papadopoulou, C.-A., Papadopoulou, M. P., Mellios, N., Laspidou, C. and Tsihrintzis, V. A., 2023. Evaluation of climate change impacts on a basin in Northern Greece, 12th World Congress on Water Resources and Environment (EWRA 2023) “Managing Water-Energy-Land-Food under Climatic, Environmental and Social Instability”, 27 June - 1 July 2023, Thessaloniki, Greece.

Kourtis, I. M., Papadopoulou, C.-A., Trabucco, A., Peano, D., Sangelantoni, L., Mellios, N., Laspidou, C., Papadopoulou, M. P. and Tsihrintzis, V.A., 2025. Methodological framework for the evaluation of climate change impacts on rural basins using the GR2M model, *Environmental Processes* (under review).

Laspidou, C. et al., 2022. Conceptual models completed for all case studies. Deliverable 3.1, NEXOGENESIS Project (H2020), Grant Agreement No 101003881.

Mooren, C.E., Papadopoulou, C.-A., Munaretto, S., Levedi, K., Papadopoulou, M. P., 2025. A methodological framework for assessing the coherence of WEFE nexus policies: illustration and application in practice, *Environmental Science and Policy* (under review).

Nilsson, M., Griggs, D., Visbeck, M., Ringler, C., & McCollum, D. (2017). A framework for understanding sustainable development goal interactions. A Guide to SDG Interactions: From Science to Implementation; International Council for Science: Paris, France.

Nilsson, M., Zamparutti, T., Petersen, J. E., Nykvist, B., Rudberg, P., & McGuinn, J. (2012). Understanding policy coherence: analytical framework and examples of sector–environment policy interactions in the EU. *Environmental policy and governance, 22*(6), 395-423.

Papadopoulou, M. P., Avellan, A. and Papadopoulou, C.-A., 2025. Challenges in the implementation of a WEFE Nexus co-creation process in a trans-boundary context, WaterEnergyNexus (WEN) Conference, 17-19 February, Abu Dhabi, U.A.E.

Papadopoulou, C.-A., Kourtis, I. M., Laspidou, C., Tsihrintzis, V. A. and Papadopoulou, M. P., 2025. An integrated methodology for systematic stakeholder engagement in environmental decision-making under the Water-Energy-Food-Ecosystems nexus framework, *Environmental Development* (under review).

Papadopoulou, M. P. and Papadopoulou, C.-A., 2023. Water-Energy-Food-Ecosystems (WEFE) nexus: An assessment of policy integration stepping to improve water governance, Joint Congress of the 9th International Water Industry Conference and the 4th Water-Energy Nexus Conference (IWIC- WEN 2023), 5-8 December, Daegu, Korea.

Papadopoulou, M. P., Papadopoulou, C.-A., Mellios, N., Laspidou, C., Teutschbein, C., Blicharska, M., Ryfisch, S., Glass, J., Avellan, T. and Müller, A., 2024. Second intermediate report on case study implementation and co-creation activities for the Nestos/Mesta CS, Milestone 23, NEXOGENESIS Project (H2020), Grant Agreement No 101003881.

Weitz, N., Carlsen, H., Nilsson, M., & Skånberg, K. (2018). Towards systemic and contextual priority setting for implementing the 2030 Agenda. Sustainability science, 13, 531-548.

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Annex 1: WP5 – Description of Case Study Coordination

Work Package 5 (WP5) supports the implementation of the NXG approach in the five CSs through:

a) the development of a roadmap that guides the work of CSs in NXG;

b) the management of internal communication between CSs and WPs;

c) the development and implementation of a stakeholder engagement strategy;

d) the continuous coordination and monitoring of all CSs activities.

Special emphasis is placed on the provision of guidelines and training to support stakeholder engagement processes in the five CSs, as stakeholders provide valuable inputs to the WPs (WP1-4). The WP5 guidance leads to better integration of the project results coming from the different WPs. This work helps to maximize the impact of the project (WP6).

The work of WP5 is complementary to Task 1.3 in WP1. Task 1.3 ensures the coordination of WPs1-4 and in particular the timely and effective flow of information between the technical WPs (2, 3, 4) and the policy and governance work package (WP1) based on the input received from stakeholders from CSs. As such, WP5 connects all the other WPs in the project. An overview of the links between WP5 and other WPs is presented in Figures 7 and 8 in MS2 - *Roadmap for Case Study Work/Activities in NEXOGENESIS*.

Throughout WP5 (months 1-48), five (5) tasks, seven (7) deliverables and six (6) related milestones are set with specific dates and timelines. A timeline of these WP5 activities can be found in Figure 9 in MS2 - *Roadmap for Case Study Work/Activities in NEXOGENESIS*. They all require close collaboration of the WP5 team with each CS lead and coordination with other WPs. CS leaders play a critical role in co-developing the guiding documents (e.g., the CS roadmap) by expressing their needs, their preferred mode of communication, their ability to contribute with local knowledge, and by validating the developed guidelines, documents, and roadmap.

The first milestone of WP5 (MS2 – *Roadmap for Case Study Work/Activities in NEXOGENESIS*) concerns the development of a roadmap for CS work with the aim of guiding CSs in NXG and more particularly their contribution to each WP. It constitutes a timeline for all relevant activities described in relation to the work and needs of all relevant WPs (WP1-4).

The second milestone of WP5 (MS5 – *Internal Communication Strategy*) is a practical resource that fosters the communication between CS leaders and WP leaders, but also supports the exchange of relevant information/experience among the leaders of different CSs as further explained below.

The third milestone of WP5 (MS6 – *Stakeholder Register*) presents the stakeholder (SH) identification process to generate the SH register for each CS. This document reports on the steps and considerations given to CS leaders for the identification of the respective relevant SHs. It also provides preliminary results for each CS, including the categorization of different SH groups according to their engagement interest and function.

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The fourth milestone (MS8 – *CS Monitoring Plan*) includes activities to enable WP5 to monitor the CSs work and potential amendment actions (if needed, in the case of delayed work). Its aim is to facilitate the progress of the CS activities, thereby ensuring successful implementation of the project work in each CS.

The fifth milestone (MS15 – *Intermediate report on case study implementation and co-creation activities*) provides detailed internal monitoring of case study implementation activities during months 1-18 of project (September 2021-February 2022).

The sixth milestone (MS23 – Second i*ntermediate report on case study implementation and co-creation activities*) provides detailed internal monitoring of case study implementation activities during months 18-36 of project (February 2022-August 2024).

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Annex 2: Schedule of all activities performed

The table below provides an overview of the activities performed so far throughout the project (October 2021 to February 2025).

Date	Type of Activity	Purpose	Participants
Oct-Dec 2021	Detailed description of the Nestos/Mesta CS	Input to milestones and to WP6 for preparation of promotion and dissemination material	NTUA
Oct-Dec 2021	Preliminary list of SHs to be engaged in the CS	Preparation of the SHE process	NTUA
Oct-Dec 2021	Preparation of a draft conceptual model/map	Presentation of the conceptual model/map to SHs and discussion about critical interactions	NTUA, UTH
Dec 2021-Mar 2022	Preparation of the first SHs' workshop	Conducting the first SHs' workshop	NTUA, UTH, Nestos Municipality, Gotse-Delchev Municipality
Jan 2022-Mar 2023	Preparation of the hydrological model	Input to the SDM	NTUA
Jan-Apr 2022	Policy inventory and policy analysis	Assessment of policy coherence	NTUA
Jan-Apr 2022	Data required by WP2 (completion of the relevant excel file)	Data provided by WP2 in order to "feed" the SDM	NTUA, UTH, WP2
Mar-Apr 2022	Conducting SHs' workshop 1 (on-site)	Gain SHs' input	NTUA, UTH, Nestos Municipality, Gotse-Delchev Municipality
Apr-May 2022	Reporting on the outcomes of the first SH workshop	Incorporate SH opinions and preferences into the conceptual model/map and start thinking about relevant policies	NTUA, Nestos Municipality, Gotse-Delchev Municipality
Jan-Apr 2022	Further elaboration of the conceptual model/map	Conceptual model/map refinement and validation by the SHs during the second workshop	NTUA, UTH
May 2022-Feb 2024	Preparation of policy packages and relevant indicators	Refinement of policies to be quantified in the SDM and incorporated in the NEPAT	NTUA, UTH
May-Jul 2022	Preparation and organisation of the first field visit in Nestos/Mesta river basin	Governance assessment (WP1)	NTUA, UTH, WP1, Nestos Municipality, Gotse-Delchev Municipality
Oct-Nov 2022	Preparation of the second SHs' workshop	Conducting the second SHs' workshop	NTUA, UTH, Nestos Municipality, Gotse-Delchev Municipality

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Date	Type of Activity	Purpose	Participants
Nov 2022	Conducting SHs' workshop 2 (on-site)	Gain SHs' input	NTUA, UTH, Nestos Municipality, Gotse-Delchev Municipality
Dec 2022	Reporting on the outcomes of the second SHs' workshop	Validation of the conceptual model/map (final version) and exploration of possible solutions to existing pressures – Co-design policy packages for the NEPAT	NTUA, Nestos Municipality, Gotse-Delchev Municipality
Jan-Feb 2023	Preparation of a list of policy packages for the NEPAT	The suggested policy packages to be presented to and validated by SH during the 3rd SHs' workshop	NTUA
Feb-Mar 2023	Preparation of the third SHs' workshop	Conducting the third SHs' workshop	NTUA, UTH, Nestos Municipality, Gotse-Delchev Municipality, AVA, WP1, WP2, WP3
Mar 2023	Conducting SHs' workshop 3 (On-site international workshop GR-BG)	Nexus governance assessment – Presentation of results, validation of policy packages by SHs, evaluation of the SHE process by SHs	NTUA, UTH, Nestos Municipality, Gotse-Delchev Municipality, AVA, WP1, WP2, WP3
Apr 2023	Reporting on the outcomes of the third SHs' workshop	Validation of the nexus governance assessment process and next steps – Finalisation of policy packages for the NEPAT – Assessment and if necessary re-organisation of the SHE process	NTUA, Nestos Municipality, Gotse-Delchev Municipality
Apr 2023	Update of the SH register	New updated list of SHs	NTUA, Gotse-Delchev Municipality
March-May 2023	Preparation of two Focus groups on policy coherence analysis	Validation of policy coherence analysis by a targeted group of SHs (experts)	KWR, NTUA, Nestos Municipality, Gotse-Delchev Municipality
March and May 2023	Conducting focus groups (online)	Validation of policy coherence analysis – Feedback from SHs	KWR, NTUA, Nestos Municipality, Gotse-Delchev Municipality
May 2023-Feb 2024	Design of the SDM	WEFE nexus modelling – Quantitative representation of sectors and interlinkages	UTH
May 2023–Jan 2024	Definition of policy goals, targets and instruments to be included in the NEPAT	Creation of a list of policies to be quantified in the SDM and to be included in the NEPAT	NTUA

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Date	Type of Activity	Purpose	Participants
Sep 2023	Update of the SH register based on who has signed the PPCF	Creation of a list of SHs that have been "officially" involved in the project	NTUA, AVA
Oct-Dec 2023	Exploration of possible indicators for assessing policy impacts	Assessment of policy impacts by the NEPAT – Facilitating the design of improved policies	NTUA, UTH
Dec 2023-Feb 2024	Preparation of the fourth SHs' workshop	Conducting the fourth SHs' workshop regarding the first version of the NEPAT	EURECAT, NTUA, Nestos Municipality, Gotse-Delchev Municipality
Jan 2024	First versions of the SDM (without policies)	WEFE nexus modelling – Quantitative representation of sectors and interlinkages	UTH
Feb 2024	Conducting SHs' workshop 4 (online along with Jiu and South Africa CSs)	Presentation of the first version of the NEPAT – Feedback from SHs	EURECAT, NTUA, Nestos Municipality, Gotse-Delchev Municipality, BDG, Jones and Wagener Ltd.
Feb 2024	Reporting on the outcomes of the fourth SHs' workshop	Analysing SHs (general) input as to the NEPAT	NTUA, Nestos Municipality, Gotse-Delchev Municipality
Feb-Mar 2024	Quantification of policies in the SDM	Assessment of policy impacts by the NEPAT	NTUA, UTH
Mar 2024	Second versions of the SDM (including policies)	Assessment of policy impacts by the NEPAT	UTH
Apr 2024	Translation (GR, BG) of NXG factsheet: "In Brief – NEXOGENESIS concepts and tools"	Brief and simple illustration of NXG concepts and tools in order to be easily understandable by SHs	GAC, NTUA, Gotse-Delchev Municipality
Apr-May 2024	Contribution to the preparation of D5.7 draft	Support UU in the preparation of D5.7 draft	UU, NTUA, CS leaders
Apr-Aug 2024	Preparation of the NEPAT beta version for the Nestos/Mesta CS	First (beta) version of the NEPAT for the Nestos/Mesta CS to be ready for testing and demonstration	EURECAT, UTH, NTUA
Aug 2024-Nov 2024	Testing NEPAT	CS leaders run and tested several simulations in the NEPAT so that they explore its functionalities and they get ready to present it to SHs (5th workshop)	NTUA, UTH
Aug-Nov 2024	Preparation of a Governance Roadmap for the Nestos/Mesta CS based on the "theory of change" and results chains	Preparation of a roadmap including explicit steps towards adoption and implementation of SH validated policies (bottom-up approach)	NTUA, WP1
Sep-Nov 2024	Preparation of the fifth SHs' workshop	Conducting the fifth SHs' workshop	NTUA, UTH, Municipality of Nestos, Municipality of Gotse-Delchev, AVA

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Date	Type of Activity	Purpose	Participants
Nov 2024	Conducting SHs' workshop 5 (on-site)	NEPAT demonstration – Validation of policy packages – Presentation (indicative example) of governance roadmap (results chain) – Assessment of the SHE process	NTUA, UTH, Municipality of Nestos, Municipality of Gotse-Delchev, AVA
Nov 2024	Reporting on the outcomes of the fifth SHs' workshop	Analysis of SHs' feedback as to the Nestos/Mesta version of NEPAT – Validation of policy packages included in the NEPAT – Assessment of the SHE process – Understanding the content of a governance roadmap through an indicative example for the study area	NTUA, Municipality of Nestos, Municipality of Gotse-Delchev
Dec2024-Jan 2025	Further refinements of the Governance Roadmap	Refining the steps towards the adoption and implementation of specific SH validated policies	NTUA, WP1
Dec2024-Feb 2025	Further refinements of the NEPAT	Improving the functionalities of the NEPAT	EURECAT, UTH, NTUA
Feb-March 2025	Preparation of the sixth (final) SHs' workshop	Conducting the sixth (final) SHs; workshop	NTUA, UTH, Municipality of Nestos, Municipality of Gotse-Delchev

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