NEXOGENESIS
STREAMLINING WATER RELATED POLICIES

Deliverable 3.1

Conceptual models completed for all the case studies

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Project Technical Report

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Abstract

This Deliverable details the conceptual graphs related to the Water-Energy-Food-Ecosystem (WEFE) nexus for all the Case Studies (CS) of the NEXOGENESIS project. It is the first and very important step in the development of fully quantitative complexity science System Dynamics Models (SDMs) for each CS, which will follow later in the project.

In this Deliverable, all Case Studies went through the process of identifying the major components that create interlinkages in their WEFE nexus systems. Building on the experience of other previous projects that had worked on the Water-Energy-Food (WEF) nexus (i.e., the SIM4NEXUS project), partners went through a brainstorming exercise to identify ways to integrate the Ecosystem element in the nexus, essentially going from a WEF system to a WEFE system. The results of this exercise were decoded and were used as a guidance for partners to develop their conceptual models.

All these models are a result of stakeholder consultations that are taking place locally in workshops and have been updated with input from stakeholders, including the elements and modules that are identified as important from the stakeholders' point of view. Case Studies present initially an overall high-level conceptual map that also captures the transboundary element and the complexity that is added to the system due to the fact that two countries are sharing a water body, identifying the effect that upstream activities have to downstream communities. Then, the analysis is extended by describing each of the nexus elements separately providing greater detail as needed to describe the complex interlinkages of the biophysical and socio-economic system.

These conceptual maps will be the starting point of the complexity science models that will follow in NEXOGENESIS, where data and quantitative modelling will be employed and will be combined with climatic and socio-economic scenarios and policies to assist the case studies in preparing a sustainable river contract that will optimize river use (Deliverable 3.4).

Contribution to EU policies: Although this Deliverable is not the final version of the complexity science modelling work in NEXOGENESIS, it is important to point out that the conceptual models show the main interlinkages among the WEFE nexus components, especially since they have been drawn through the stakeholders. They show, particularly in the transboundary CS, what the stakeholders think as relevant and important in these domains. As such, they may play a role in influencing national policies, but also for EU policy recommendations that enhance the cooperation between neighbouring countries in the development and implementation of environmental strategies.

Related Deliverables:

- Deliverable D3.4 (Due in M23) - Complexity science models implemented for all the Case Studies - Prototypes and explanatory report/manual for each CS.

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List of abbreviations

CLD – Causal Loop Diagram
CS – Case Study
ES – Ecosystem Services
GHG – Greenhouse Gas
IUWMA – Inkomati-Usuthu Water Management Area
SDM – System Dynamics Modelling
SLNAE – Self Learning Nexus Assessment Engine
WEFE – Water-Energy-Food-Ecosystems
WEFLC – Water-Energy-Food-Land-Climate

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1. Introduction and purpose of the Deliverable

The purpose of this Deliverable is to present the finalised conceptual maps for each of the five NEXOGENESIS Case Studies (i.e. Nestos River Basin, Lielupe River Basin, Jiu River Basin, Adige River Basin, Inkomati-Usuthu Basin). Each of the conceptual maps was developed in close cooperation with dedicated case study lead institutes (NTUA, NESTOS, GotseD, BEF, BDG, EURAC, JAWS) with the input of local stakeholder groups through stakeholder workshops in the case study regions, and supported particularly by UTH and IHE.

The development of these conceptual maps is an integral element in NEXOGENESIS for a number of reasons. They help to frame the core nexus issues in each of the study areas. They elucidate the interactions between nexus sectors in the case studies, both from a high-level perspective, and from a more detailed sectoral perspective. They thus give structure to the different nexuses being considered in the case studies. They start to offer a glimpse into where and how relevant WEFE policies 'enter' the nexus, as well as starting to allow the wider systemic impact of potential policy implementation. Through analysis of the nexus system, the conceptual maps also offer an entry point for the discussion of data requirements (from NEXOGENESIS Work Package 2) aligned with the focal points for each CS, and can therefore aid expectation management regarding what can or cannot be quantified.

The conceptual maps in this Deliverable form the basis for the development of the NEXOGENESIS complexity science models, using SDM (in WP3). The SDMs will seek to translate the conceptual maps into a quantitative modelling framework (including causal loop diagrams) and then attempt to quantify the systemic trends and behaviour modes in response to potential implementations of identified policies in the WEFE nexus. These SDM models will ultimately feed the SLNAE development to assess the impacts multiple policy implementations against multiple (competing) objective (WP4).

Through the development and implementation of the holistic and integrated SDMs, along with the machine learning/artificial intelligence techniques to be exploited in WP4 in the SLNAE, NEXOGENESIS will: i) integrate the concerns of ecosystems and their services into nexus assessments; ii) streamline the effectiveness of multiples WEFE-related policies into resources and environmental management and; iii) advance the scientific state-of-the-art on ecosystems integration into the WEF nexus, policy considerations, and complex systems analysis. The conceptual maps presented in this Deliverable form a cornerstone of these advances.

The document is structured as follows: Section 2 introduces the idea of conceptual maps: what they are, how they are built, and how they will be useful throughout NEXOGENESIS. Section 3 shows how the ecosystems component is important, and demonstrates progress made so far in NEXOGENESIS in terms of including ecosystems into nexus assessments. Section 4 then presents all the developed NEXOGENESIS conceptual maps. The section is broken down by case study. For each study, first a short description of the main nexus issues is presented, followed by a detailed description of the conceptual maps, going from a high-level, abstract

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nexus map down to the detailed WEFE nexus sectoral maps. Section 5 discusses how these maps will be used throughout the rest of the modelling process chain in NEXOGENESIS, further reiterating their importance. The report concludes with the reference list.

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2. Introduction to conceptual maps

A conceptual model or maps is an abstract system representation that can aid understanding of the system under study (e.g. Helmig, 1997; Sterman, 2000; Dullea et al., 2003; Sokolowski and Banks, 2010). Conceptual maps allow for modelling teams, including wider stakeholder groups, to start considering issues critical to systems analysis and modelling, including consideration of the system boundaries and the focal issues of anaylsis, the structure of the system and sub-systems (resource sectors) and the nature of sector connections, both in terms of connections within the system boundaries, and of connections outside of the system boundaries. Conceptual maps are system representations that include key variables and describe how they are they connected. They usually take the form of a 'map' of the system, and will form the basis of subsequent SDMs to be developed in NEXOGENESIS.

Here, conceptual model development aimed to represent the interconnections within and between the WEFE sectors in each NEXOGENESIS case study (described fully in Section 3). For each case study, a high-level conceptual map is developed showing the major links between nexus sectors. In addition, each nexus sector is developed with its own conceptual sub-model (i.e. a set of connected conceptual models, one per nexus sector) describing the main interconnections within each sector and to other nexus sectors.

Conceptual model development, as well as policy identification, was carried out with stakeholders by the case study leaders and supported through the activities in NEXOGENESIS Work Packages 1 and 5. Conceptual model linkages were identified, designed and validated by stakeholders. Developing the conceptual maps is a creative and open-ended process that usually starts with a group discussion of experts and stakeholders (Freebairn et al., 2019), facilitated via activities in WP1 and 5, and through Case Study leaders. Ultimately, the purpose of this process is to have a common vision of the system among the stakeholders.

A comprehensive conceptual map can synthetize an important amount of information that will be useful in later NEXOGENESIS modelling stages. In the maps below, a hierarchal approach is adopted. First, a high-level map is presented that shows the major connections between nexus sectors, but which is low in detail. Following from this, sectoral-specific maps are shown which go into more detail about the processes within each nexus sector, and how they relate to the other sectors. Examples of the use of conceptual maps are available throughout the literature, demonstrating this exercise to be very valuable in wider systems understanding and model development (e.g. Purwanto et al. 2019; Bakhshianlamouki et al. 2020; Sušnik et al. 2021; Ioannou and Laspidou, 2022).

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3. From WEF to WEFE: Adding the Ecosystem nexus component

The five dimensions/components of the nexus (Water, Land, Food, Energy and Climate) were well established through the Horizon 2020 project SIM4NEXUS—https://sim4nexus.eu/ and the complex net of interlinkages of the five domains is thoroughly defined in the literature (Laspidou et al., 2019, Laspidou et al., 2020). However, ecosystems have been identified as a missing element of the nexus approach (Hülsmann et al., 2019). In the Ramos et al. (2022) publication, a vision was presented of WEFLC components being at the centre of the nexus approach, where all spheres overlap, with a focus on resource efficiency. Additionally, in the same publication, they added the ecosystem at the main sphere showcasing the need and the added value to include the ecosystems as a nexus component (Figure 1). This publication shows the culmination of the research conducted in SIM4NEXUS and denotes the scientific extension(s) and improvements that NEXOGENESIS is bringing about, mainly in terms of adding, linking and (ultimately) quantifying the “Ecosystems” to the other nexus components.

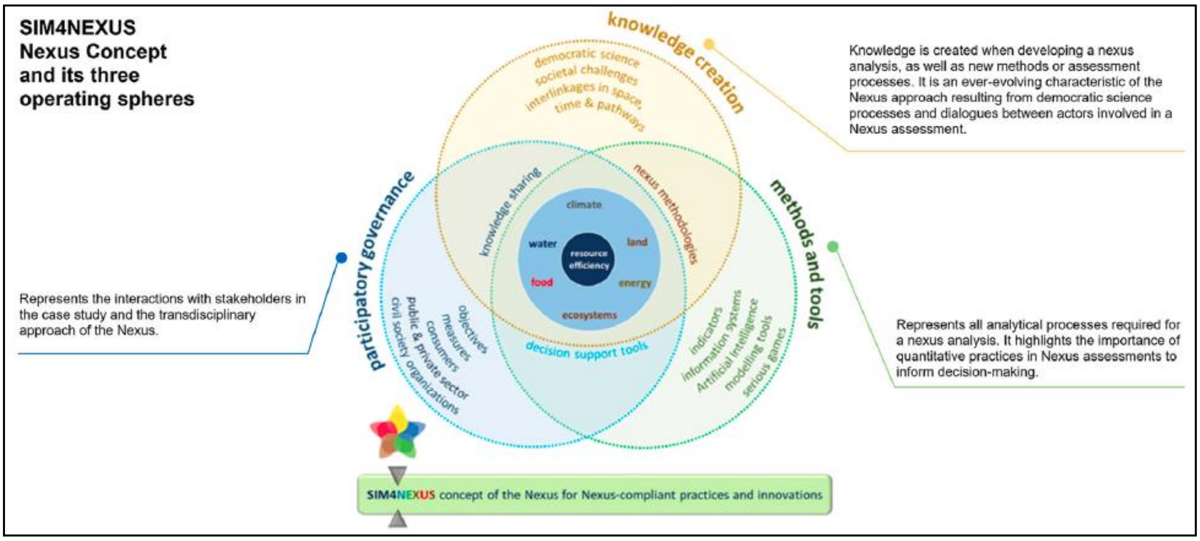

Figure 1. Illustration of the nexus concept from SIM4NEXUS Nexus (Ramos et al., 2022).

Ecosystems provide essential services to society, from pollination and flood protection to climate and water regulation (Winterbottom et al., 2015). The literature on ecosystem services evaluation refers to multiple types of value, including ecological, economic, social, cultural, spiritual, symbolic, therapeutic, insurance and place values (EU FP7 OpenNESS Project Deliverable 4.1). Until recently these services have largely been treated as if they had no value and were not considered in the analyses.

To this end, in the context of the NEXOGENESIS project, the Ecosystem was investigated as a nexus component, as well as the additional interrelationships arising with the other components. The water, land, food, energy, and ecosystem components/dimensions of the nexus are related to one another, through numerous direct and indirect interlinkages. To map these interlinkages, an exercise was developed involving all the CSs, aiming to investigate how the ecosystems affect the water, energy, food, and land uses, and vice versa how all

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these components affect the ecosystem and document the synergies and trade-offs among them. For the development of the exercise the collaborative digital tool Miro (https://www.miro.com/) was utilized. It is an online whiteboard that you can use to visualize your ideas and work on projects either individually or with a team, allowing partners to connect, collaborate, and create — together in synchronous and asynchronous mode. Two tables were constructed in the Miro board, the first one of which consisted of sticky notes presenting the CS partner brainstorming ideas on how the ecosystem affects the water, energy, food, and land uses, while the second table portrayed the opposite (shown in the pages that follow). The notes of the two tables where remoulded into interlinkages between the nexus components as presented in Tables 1 and 2.

Table 1. Decoding partner input regarding the interlinkage of Ecosystems with all nexus elements

nexus	interlinkage
Ecosystem- WATER	Water purification in wetlands. (https://www.unwater.org/water-facts/water-and-ecosystems)
	Flood regulation in wetlands
	Sediment retention and erosion control in wetlands (Blicharksa & Johansson, 2016).
	Aquifer recharge and water infiltration in wetlands
	Forests affect **hydrology at watershed level**. They increase soil infiltration, and subsurface runoff. They reduce surface runoff and soil erosion during extreme rainfall events.
	Urban Nature Based Solutions (NBSs) purify **urban water run-off**
Ecosystem - ENERGY	Terrestrial ecosystems are essential for **wood and energy crop production**.
	Ecosystem health fosters Gross and Net Primary Productivity of ecosystems and therein **biomass production**.
	Hydropower generation is one of the most ecosystem dependent energy production schemes.
	Services from healthy ecosystems, **water balance, pollination,** enhance food production in agro-ecosystems
	Utilizing a range of species and within-species diversity helps to ensure **continuity in the food supply** as conditions change with the season or because of shocks such as droughts or disease outbreaks. **Small-scale producers** are often highly **dependent on their local ecosystems** for the supply of the inputs they require (water, livestock feed, etc.).
	Access to **wild foods** potentially serves as a means of maintaining food intakes in the event of shocks that affect food output from domesticated species or otherwise affect access to food (e.g. because of reduced cash income).
	Genetic diversity provides the raw material for breeding new varieties and breeds of plants and animals that **produce more food or more nutritious food**, use inputs more efficiently or are better adapted to their production environments.
	Biodiversity based management practices can help reduce negative environmental impacts, for example by reducing the need to use large amounts of inputs such as pesticides and mineral fertilizers.
	Diversity of habitats in and around production systems encourages the presence of useful species such as pollinators and the natural enemies of pests. Diversity among these species helps to ensure that the services they provide are maintained over time.
	Genetic diversity within species, including domesticated biodiversity, is the **raw material for evolution by natural selection and for breeding programmes** aimed at developing plant and animal populations that can produce more or are better able to cope with harsh conditions
Ecosystem - CLIMATE	Land Use, Land-Use Change and Forestry (LULUCF) play an important role in greenhouse gases - **CO_2 sequestration**
	Biodiversity makes our ecosystems more resilient to climate change and secure ecosystem services for years to come
	Ecosystems provide filtering of pollution, **air quality regulation**, climate regulation (http://www.nbsapforum.net/sites/default/files/Revaluing_Ecosystems_April_2015_2.pdf)
	Vegetation provides **cooling** effect and balances out heat waves. Urban green/blue spaces, NBSs, contribute to **urban heat island mitigation.** Ecosystems provide climate change adaptation solutions.

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Ecosystem – LAND USE	Ecosystems provide for all necessary **services,** such as soil fertility**, and raw material**, such as water and nutrients, for all land uses.
	Ecosystem conservation requirements force to the reduction of agricultural land up to 20% (NEW CAP)
	Degradation of ecosystems may alter microclimate conditions. Desertification is an extreme example of ecosystem degradation.
	Soil fertility, salinity and acidity impact cultivated crop (and other cultures) production (e.g., yield, quality)

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Table 2. Decoding partner input regarding the interlinkage of all nexus elements with Ecosystems

nexus	interlinkage
WATER -ecosystem	Water scarcity leads to inadequate **environmental flows** in surface water bodies and affects biodiversity
	Water pollution leads to biodiversity degradation, affects ecosystem health, and also may affect the aquaculture activity
	Water deficit affects vegetation and ecosystem biodiversity.
	Water deficit has important effects on groundwater recharge and degradation of aquifer level and indirectly affects the groundwater quality through salinization and other mechanisms. **Groundwater dependent ecosystems** (GDEs) are particularly vulnerable to changes in groundwater supply and groundwater contamination. (https://www.un-igrac.org/groundwater-and-ecosystems)
	Water pollution leads to **eutrophication and harmful algal blooms**, which can influence the food webs in water bodies and degrade biodiversity
	Water use in agriculture affects ecosystems and the services they provide not just by reducing the amounts of water available, but also by polluting water, altering river flow patterns, and reducing habitat connectivity by drying up parts of rivers and streams. Investing in water for food, ecosystems and livelihoods. (Molden & de Fraiture, 2004).
	Excess water, floods impact on biodiversity and endanger wildlife.
	Higher abstractions or restitutions of water alter river **morphological status** affecting aquatic and terrestrial habitats.
ENERGY -ecosystem	**During the extraction phase of fossil fuel** exploitation, there are two main impacts on biodiversity: directly through conversion, degradation, pollution, or disturbance of habitats at extraction sites and indirectly by increasing access for loggers, farmers, hunters, and settlements. These impacts extend beyond terrestrial surface-dwelling organisms, and marine ecosystems. (Harfoot et al., 2018).
	After extraction of fossil fuel, the distribution, refinement, and use of fossil fuels impacts biodiversity directly through habitat destruction associated with infrastructure development and pollution. (Harfoot et al., 2018).
	Hydro-power dams can destroy habitats of aquatic life as well as inhibit the migration of fish (Duguma et al., 2020). The definition of the **minimum ecological flow** is an important step for the impact on the biodiversity of rivers and requires exchanges with energy producers when dams are storing the water during drought periods. (Harfoot et al., 2018).
	Energy development can result in wildlife **mortality because of collision, contamination, or electrocution**. In addition to turbines, wind facilities employ meteorological towers that are known to result in avian collision mortality
	Land use & intensive forest management for **biomass production** reduce ecosystems complexity, landscape diversification, soil fertility & biodiversity
	Energy infrastructure may cause disturbances in **noise-sensible** biodiversity species
FOOD - ecosystem	Intensive and single-crop farming leads to **loss of genetic diversity in crops**
	Use of **pesticides and herbicides** leads to biodiversity loss
	Land use change for food production leads to habitat degradation, landscape fragmentation (lack of connectivity between habitats), which has impacts on biodiversity
	Nutrient loading, primarily of nitrogen and phosphorus found in fertilizers is a major and increasing cause of biodiversity loss and ecosystem dysfunction. In surface water bodies, nitrogen compounds lead to eutrophication of ecosystems
	Field homogenization for food production reduces biodiversity
	Agriculture mechanization and intensification induce **land clearing**. Nature based solutions, such as tree inclusion over agriculture (i.e. agroforestry, tree windbreaks or along canals) is now advocated to reestablish multiple ecosystem functions of **agro-ecosystems** and biodiversity.
	Ditching for agricultural purposes leads to changes in water regimes that can negatively impact biodiversity (e.g. species depending on over flooded areas)
	Agricultural infrastructure (drainage systems, drains networks, irrigation channels, derivation channels for irrigation, etc.,) involve embankments and river regulation contributing to **habitats alteration**, modifying vegetation structure, altering the bank erosion natural process, the transport and sedimentation of sediments and the hydraulic conditions.
CLIMATE ecosystem	Climate change affects precipitation and leads to extreme drought and **desertification.** Due to droughts induced by CC some species may die out in some locations, or be weakened and subject to pest attacks (e.g. bark beetle for spruce)
	Climate change leads to persistent and long and intense heat waves that may lead to **forest fires**, which can be damaging for some species and whole ecosystems, but can also promote specific fire-dependent species

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nexus	interlinkage
	Climate change affects growth of typical plant and insect species
	Climate change may promote **invasive species** in some areas, impacting the existing species
	Climate change affects the ability of ecosystems to mitigate flood and drought effects due to frequent, intense and extreme weather events.
	CC is shifting **entire biomes** to higher latitudes and/or altitudes. It means 'what is where' is changing
	Climate change may affect ecosystems through changes in **timing** of seasonal life cycle events, range shifts (e.g. to colder environment after a warming period), food web disruption, buffer and threshold effects (CC can influence the ability of ecosystems' ability to temper impacts from extreme events), spread of pathogens, parasites and disease, contribution in extinction risks
	Climate change causes long-term alteration in temperature and precipitation that may affect food availability for the various species
	Extreme weather events may affect **migration routes**
LAND USE - ecosystems	Conversion of **forest land, grasslands and wetlands into agricultural land** affects biodiversity, water quality and environmental flows
	Land Use Changes affect ecosystems in terms of **carbon sinks and sources, erosion, air and water pollution, alteration of soil quality** (chemical and physical properties), **potential introduction of invasive alien species or spread increase of the one already in place**
	LUC induced by rapid **urbanization degrades the overall quality and quantity of agricultural land**. This has reduced the food provisioning services provided by agri- cultural ecosystems. LUC influences soil properties by affecting soil nutrient levels, and when these properties degrade, this increases soil degradation and soil erosion
	In heavily modified socio-ecosystems (i.e., Mediterranean basin) both **intensification of land use and rural abandonment** lead to ecosystem changes and the loss of ecosystem services
	Locating **protected areas** (social-economic activities' zonation) ensure sensitive biodiversity species
	Urban infrastructure and built environment shift habitats and disrupt biodiversity corridors.

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4. Conceptual maps developed for the NEXOGENESIS case studies

4.1 Case Study #1: Nestos/Mesta River Basin (Bulgaria – Greece)

4.1.1 Description of the Case Study

The Nestos/Mesta River Basin encompasses on area of 5479 km^2 and includes the Nestos/Mesta River that crosses the Bulgarian-Greek border in South-Eastern Europe (Figure 2). It should be noted that the River is called Mesta on the Bulgarian side and Nestos on the Greek side, so hereafter, we will be referring to the river basin as the Nestos/Mesta River Basin. The 243 km long Nestos/Mesta River is composed of many varying ecosystems throughout its course from the Bulgarian Rila mountains to its outlet at the Greek Thracian Sea and the large delta ecosystem there. The outlet is characterised by a delta that is protected by the Ramsar Convention and is considered a first-priority site under EU Nature 2000. Two dams are used for energy production and irrigation water supply affecting water availability along the Nestos River (Greek side). The main activities in the river basin relate to agriculture and livestock.

Figure 2: Location of the Nestos/Mesta River Basin

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The regional economy in both countries is highly dependent on the River. Nestos/Mesta river supplies water for irrigation systems, both in Bulgaria and in Greece. In the Greek territory, the majority of irrigated land from Nestos flow is situated in the south, at the Delta area. The irrigated agricultural area in Greece is approximately 130 km^2. The total irrigated land in the Bulgarian territory covers approximately 175 km^2. Nestos river is also used for energy production, with two dams being operational for energy production, by the Public Power Corporation, one with important power productivity of 425 GWh, and the second mainly used for water flow control. In Bulgaria the construction of dams is planned, but it is not certain when it will happen. The Delta of the river covers an area of 440 km^2 and is protected by the RAMSAR treaty on wetlands. For the dams operation, a minimum flow requirement in the Delta was set. The Environmental Impact Assessment study concluded to a minimum flow of $6m^3/s$. In the Delta area, several lagoons can be found that are used as fisheries.

The main WEFE nexus issues in the basin are related to the interactions and conflicts among several water uses, including water demanded for energy production (hydropower), irrigation water needs, domestic/urban water supply, maintenance of ecosystem health and food production. Local income is relatively low while the population of villages and small towns located within the basin are primarily occupied in agriculture and livestock. Agriculture represents a major water demand during the warm and dry summer months, potentially conflicting with ecosystem priorities, hydropower production, and domestic water needs. Groundwater over-pumping has recently emerged as a critical problem resulting in low groundwater levels and jeopardizing the health of wetland ecosystems within the delta area due to seawater intrusion. In addition, the hydropower dams, along the Nestos river, may also affect riverside ecosystems through their alteration of natural flow regimes.

4.1.2 Description of the conceptual map

4.1.2.1 High-level nexus map

The Conceptual model of the Nestos/Mesta case study presents a simple pictorial that captures the interlinkages between the water, energy, food, ecosystems, and climate components. The conceptual map is divided in two sub-systems, one for the upstream Bulgarian part (Mesta River) and another one for the downstream Greek part (Nestos River), where the water flows across the border of the two countries. There is an international agreement that defines the minimum quantity of water that will be allowed to flow down to the Greek side. The agreement sets as Greece's rights to the water of Mesta River the 29% of the total volume that is generated in the Bulgarian territories. The agreement was signed in December 1995 and will be in force for 35 years, up to 2028. The field will be open for renegotiations afterwards and NEXOGENESIS can be instrumental in working on the transboundary dimension, bringing both sides together and contributing towards a joint management of resources considering the new conditions that have been developed with climate change and socio-economic development across countries.

In this high-level map, we present all the nexus components and their interlinkages, without going into fine detail for each nexus component. Water is the element that connects the

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boundaries of both country-level conceptual model, shown in a dashed perimeter (red for Bulgaria and blue for Greece), while the maps extend on both sides of the "water connection". Climate is common for both countries and runs across boundaries, showing that indeed climate runs across boundaries and actions on both sides affect it equally. Same goes for biodiversity, which is common for both, as species exist and move across the river without any regard to national boundaries. Precipitation and Evapotranspiration are guided by the climatic conditions and result in water falling on land and water. Climate change will lead to extreme events, bringing floods and droughts and resulting in too much or too little water. Climate also affects ecosystems, as increased temperatures will have an impact on species and habitats in the long term.

Land is used for agriculture, producing food and impacts river water with water and nutrient run-off and infiltration to groundwater. Agricultural emissions are produced and burden the Climate sector with Greenhouse Gas emissions. Human settlements use land and produce wastewater from industries, untreated sewage, due to the lack of sewerage networks, while massive amounts of solid waste are disposed of in the river due to the lack of a solid waste management plan. Parts of land are given to nature through the "protected area" designation, safeguarding ecosystem quality, while agricultural land competes with land used by solar panels for energy production. Some of the arable land is used for the production not of food but of energy crops, while food waste can be used for biomass production for energy.

Water is used for food production through irrigation, impacts ecosystem integrity through its quality and is necessary for ecosystem function when it maintains a minimum ecological flow. In the Greek side, water is also used for power production through its hydropower use in the constructed dams. The two sides of the map are almost identical, showing how the nexus elements are interconnected in the two countries: this is shown in Figure 3. In the sections that follow, conceptual maps are developed for the nexus elements, providing greater detail and giving more information about the interlinkages. The Energy sector sub-model is omitted, as it is only considered for the River Basin District and not for the national grid, so only hydropower is critical to be considered and relevant. All energy interlinkages are captured in the other maps.

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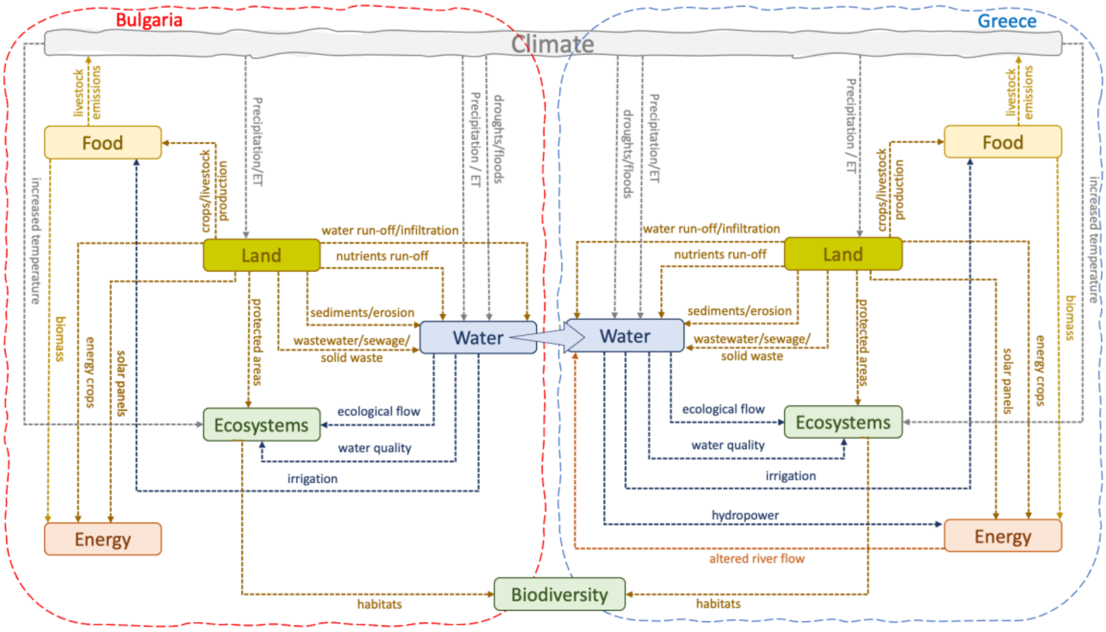

Figure 3: High-level conceptual map depicting the nexus interlinkages for the Nestos/Mesta River Basin.

4.1.2.2 Water sector map

Having developed the overall nexus map for the Nestos/Mesta Case Study, we now focus on the individual sectors and provide the conceptual maps in more detail. For water (Figure 4), it is important to view water quality and quantity separately in order to accentuate the importance of these two elements, with water quality being dominant when it comes to ecosystem degradation. As described before, Climate affects water through increased temperatures due to climate change and extreme events that may lead to altered precipitation patterns causing either droughts or floods. Increased temperatures will alter the thermocline of the river and will affect water quality and ecosystems, as different chemical and ecological conditions will follow the thermocline.

In terms of Water Quantity, there is a strong link with energy through the hydropower plant that operates in the River Basin. The dam alters the river flow, affecting the quantities and the times that they are released, producing energy that is fed in the grid. This has a strong influence on ecosystems, as it affects the flow and may drop below the mandatory ecological flow that is required at all times. At the same time, irrigation is another antagonistic use of water and shows a strong interlinkage with Food. Water Quality is also critical here, with influences from various land uses: agricultural releases nutrients and pesticides, and human settlements burden water quality with solid waste, plastics and sewage, as infrastructure is inadequate in both countries. On the other hand, forests enhance water quality through erosion control and withholding the sediments and wetlands provide water purification, pollutant retention and carbon sequestration. Poor water quality will definitely affect ecosystems, habitats and biodiversity, while it may also result in reduced yields in agriculture when used for irrigation.

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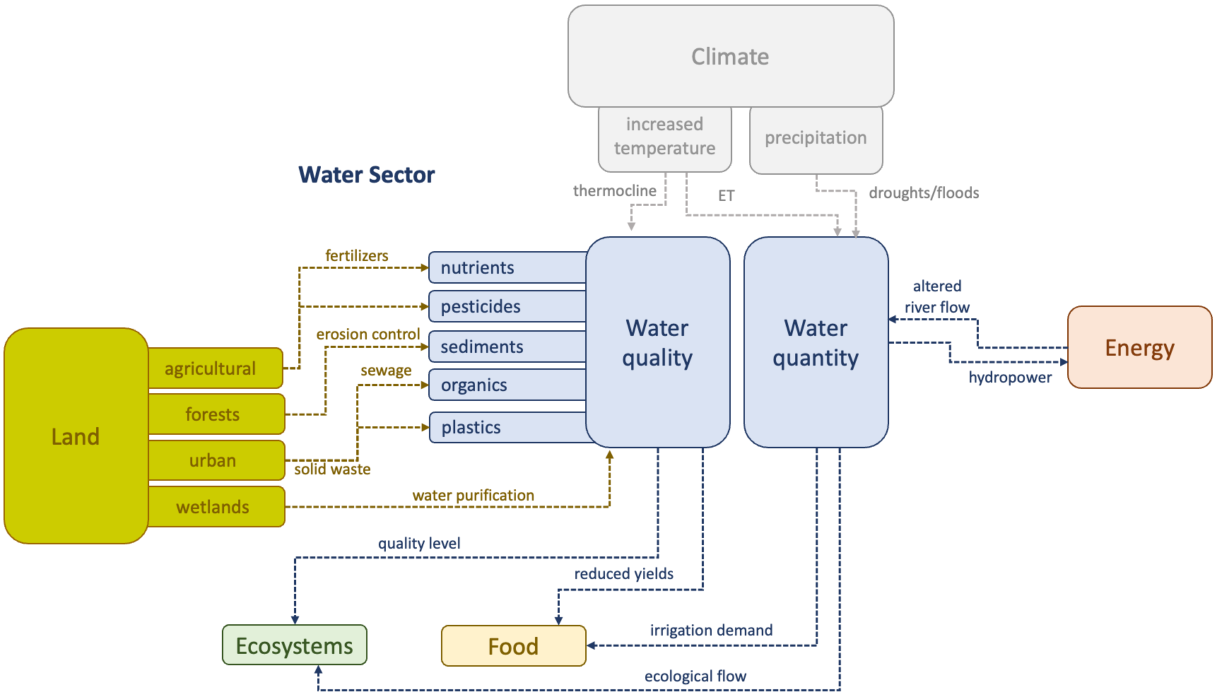

Figure 4. Water sector conceptual map for the Nestos/Mesta River Basin.

4.1.2.3 Food / Land Use sector map

The Food sector is presented together with the Land Use element, due to their close interconnection. Here again, Climate is important and affects food production and crop yields through increased temperatures and shifted seasons, with longer summer periods, earlier and warmer springs, etc. Extreme events create damages in crops in the form of heavy rains and flooding, but also hail, frost, etc. Food production in the Nestos/Mesta River Basin includes agricultural activities that produce crops (arable land), livestock (using grasslands and pastures) and fisheries in wetlands and lagoons around the river Delta in the south of the Basin. Food is also shown connected with the Ecosystem module that is listed as the “provisioning Ecosystem services” element, that is closely affected by the supporting service of biodiversity, which is in turn impacted by intense agricultural activity with fertilizer and pesticide use and practices such as large mono-cultures, or others that limit pollinators. Water is linked with Food through irrigation and other agricultural uses, while energy could show an antagonism with food production through land use that may be used for energy crops. Solar panels and built environment are also land uses that are antagonistic to crop land that would lead to food production. The Food / Land Use sector conceptual map for the Nestos/Mesta River Basin is shown in Figure 5.

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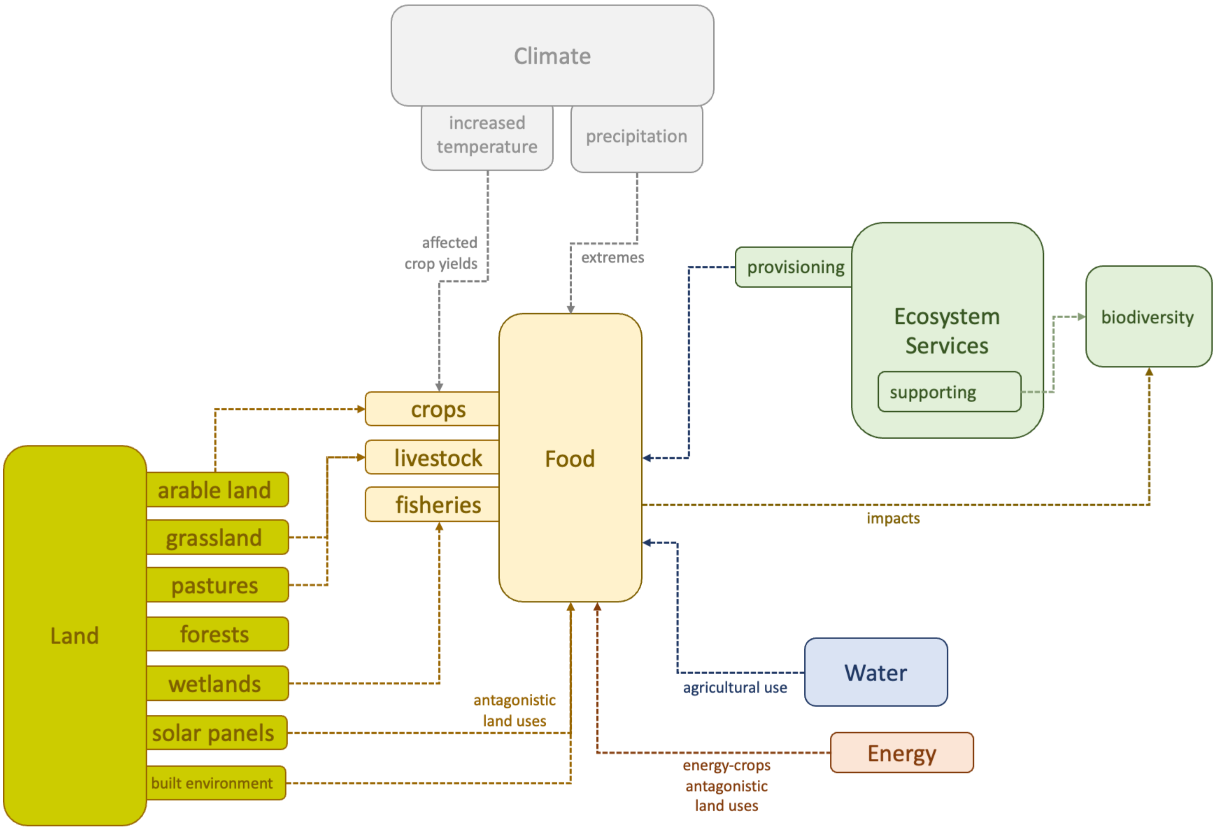

Figure 5: Food / Land Use sector conceptual map for the Nestos/Mesta River Basin

4.1.2.4 Ecosystem sector map

The ecosystem sector map shows a series of important interlinkages with other elements of the nexus. As said before, Climate affects ecosystems through increased temperatures, shifted seasonality and extreme events. The Ecosystem module is classified through its ecosystem services in Provisioning, Cultural, Regulating and Supporting, with the first three being more imminent and immediate, while the fourth service being more long-term. Provisioning ecosystem services include food production (as shown with greater analysis in Figure 5), but also providing the conditions for agricultural activities, for wood and fiber in forests and for all these goods to be consumed in the human settlements, shown as urban land uses. Wetlands provide regulating ecosystem services, regulating flows, pollutants, carbon, etc and acting as purifiers for water and air. Long-term supporting ecosystem services include biodiversity that is both terrestrial (linked to land) and freshwater (linked to water quality): both types of biodiversity are threatened by anthropogenic interventions that lead to habitat loss. An important impact to biodiversity is identified by the construction and operation of dams in the river for Energy production (hydropower) that alter river flow, alter sediments and flooding patterns and affect ecological flow, which fluctuates strongly and may be found to be inadequate to maintain minimum flows at all times. The Ecosystem sector conceptual map for the Nestos/Mesta River Basin is shown in Figure 6.

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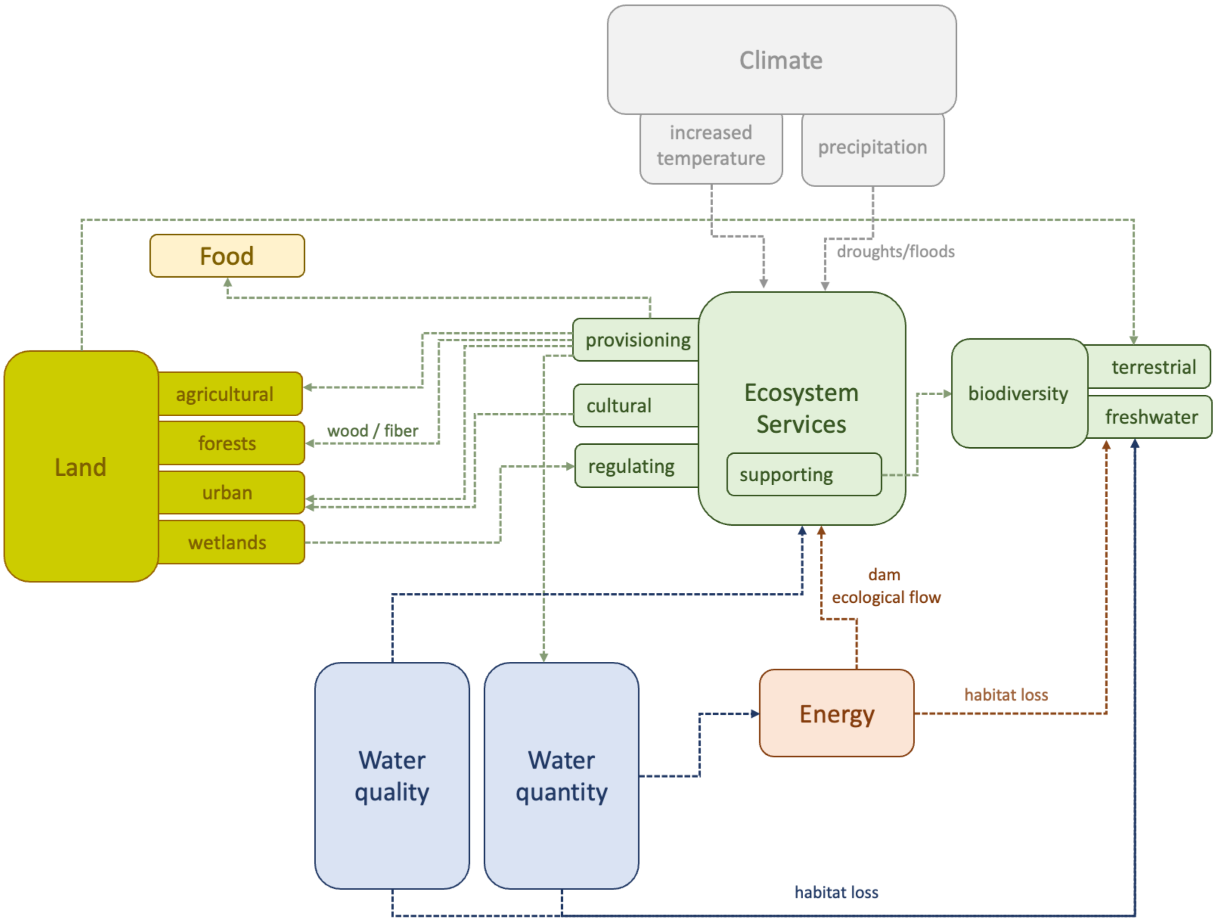

Figure 6: The Ecosystem sector conceptual map for the Nestos/Mesta River Basin.

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4.2 Case Study #2: Lielupe River Basin (Lithuania – Latvia)

4.2.1 Description of the Case Study

The Lielupe River Basin is located in North-Eastern Europe. The basin has an area of 17 788 km^2 and is shared between Latvia (8849 km^2) and Lithuania (8938 km^2; Figure 7). About 12% of the Latvian population and 11% of the Lithuanian population live in this basin (totalling about 800 000 inhabitants, with half in urban areas). The main economic activity in the Lielupe is related to trade and transport services, as well as process industries and public services (authorities and defence, education, health care), as well as agriculture activities. By land area, the basin is predominantly used for agriculture (62%), and includes large areas of forests (c. 30%) and urban areas, as well as wetlands and floodplain meadows including nature protected areas and Nature parks. The relief, climate, and high soil fertility make suitable conditions for agricultural activities. Agricultural activities have intensified recently at the cost of natural grasslands. Agriculture focuses on the cultivation of crops e.g., cereals, potatoes, and fodder crops, along with dairy farming. During the last decade, the area of croplands has increased while meadows and pastures have declined. According to forecasts of development in the agriculture sector by 2050, these trends will be maintained and coupled with increased volumes of fertilisers utilised in line with intensification of agriculture.

Figure 7: Location of the Lielupe River Basin

The Lielupe River Basin is characterized by homogenized fields (i.e., continuous arable land fields larger than 30 ha). The challenges in the Lielupe River Basin concern the interlinkages and trade-offs between intensification of agriculture and biodiversity. Expansion of arable lands on expenses of grasslands is putting pressure on grassland habitats, including the loss of semi natural meadows, leading to a decline in biodiversity and related ecosystem services. Homogenisation of land diminishes the quality of landscape and the stability of ecosystems. Heavy application of fertilisers to increase crop yield leads to increased nutrient leakage to water courses, thus posing a risk of deteriorating water quality and water ecosystem services. Alternative income sources such as tourism and recreational activities put additional pressure on ecosystems, while small hydropower plants affect ecological river flows and fish migration.

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Water diplomacy issues due to the transnational aspect of the basin, play a role because significant amounts of pollution from Lithuania are transported across the border to Latvia and add to Latvian pollution, deteriorating river water quality and resulting in excessive loads into the Baltic Sea.

4.2.2 Description of the Lielupe conceptual map

The Conceptual model of the Lielupe case study reflects the interlinkages between the water, energy, food, ecosystems, and climate components. In this attempt, the Lielupe River Basin conceptual map is divided in two sub-systems, one for the upstream Lithuania part and another one for the downstream Latvia part, where the connection is ensured by the flow of water across the border. This approach allows us to apply a transboundary dimension in the discussion to find pathways for improved joint management of resources considering the climate change and socio-economic development scenarios across countries.

4.2.2.1 High-level nexus map

Figure 8 shows the high-level map for the Lithuanian part of the basin, and Figure 9 shows the high-level map for the Latvian part of the basin. In these high-level maps, the critical connections between nexus sectors can be observed. The complex nature of the nexus is obvious through the nature of the links indicated in the maps. For example, nutrient loading and erosion impact negatively on the water sector, which in turns impacts on ecosystem services. Likewise, energy is produced from the food sector (biomass) but also consumed by that same sector. Changes to ecosystems, food production techniques, and energy generation technologies all impact on the climate sector, which in turn affects the demand for energy, food production capabilities, and ecosystem functioning. In both nations, land use is clearly a central sector for consideration. The sectoral details will be explained in the following sub-sections.

In this case study, to explicitly recognise the transboundary aspect of the river basin, a joint conceptual map linking the two countries is developed (Figure 10). Water is the core sector in which the countries are connected, as water, nutrients, and pollution flow from upstream to downstream, forming this link. In all the subsequent sub-sector maps, only one map is shown as the maps developed are identical for both nations.

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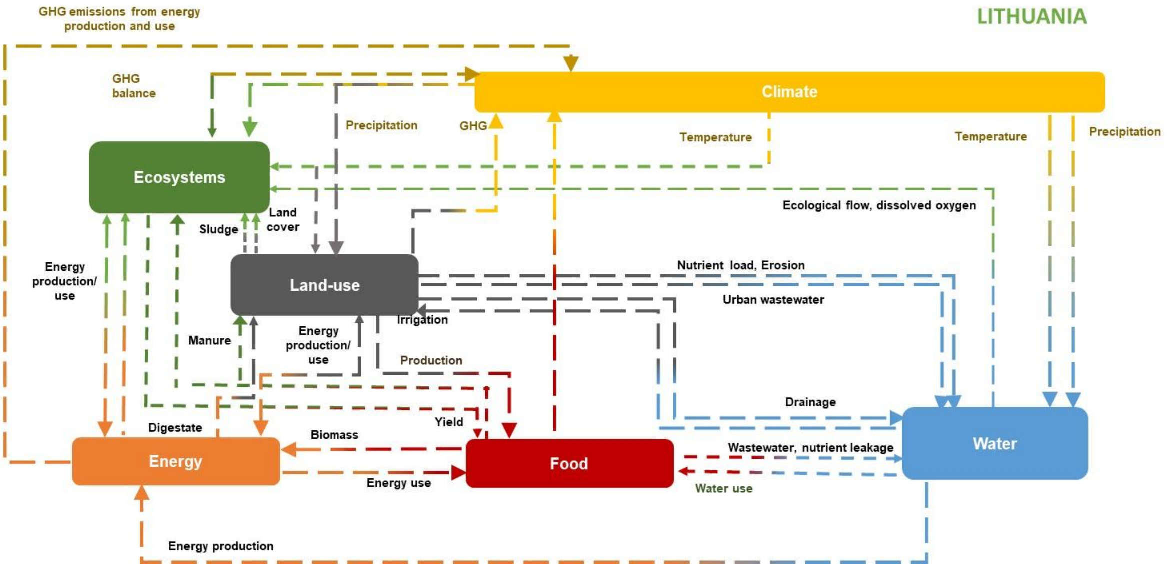

Figure 8: High-level map of the Lithuanian part of the Lielupe River Basin

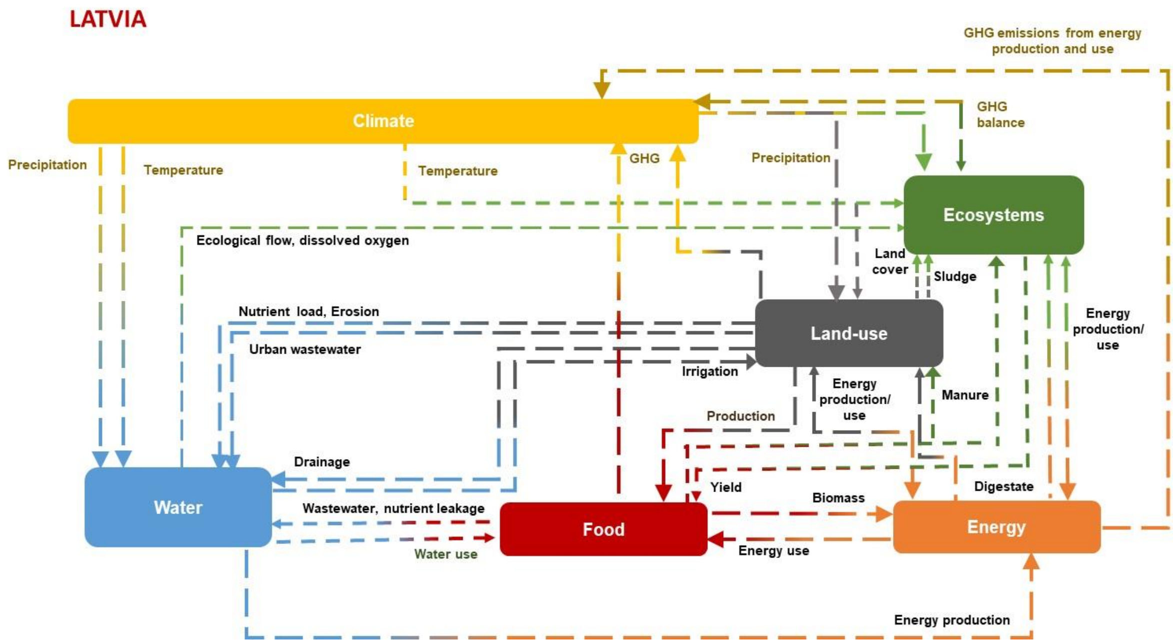

Figure 9: High-level map of the Latvian part of the Lielupe River Basin.

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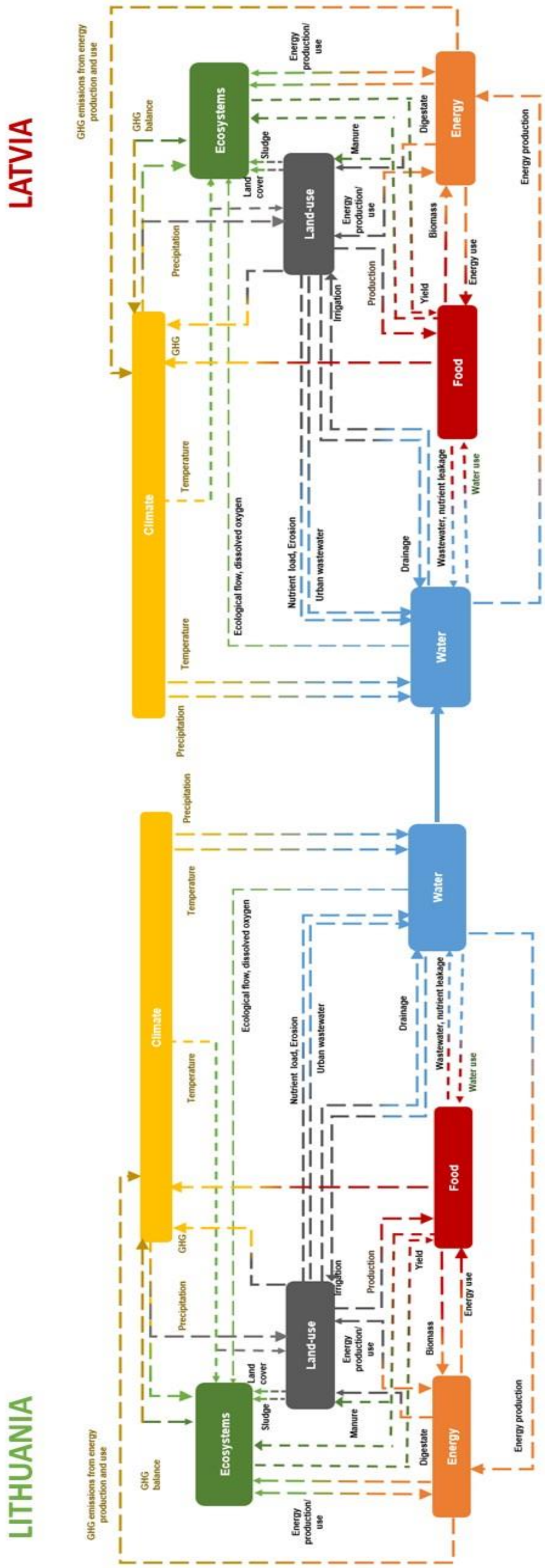

Figure 10: Joint high-level conceptual ap showing how water is the sector that links the two countries.

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4.2.2.2 Water sector map

Figure 11 shows the water sector conceptual map for the Lielupe River Basin. Water use is mediated by hydroelectric production and food production. Water is also used by land (for irrigation) and by ecosystems to support a range of functions and services. Water availability is dictated largely by climatological parameters, and to some extent by drainage from the land to water bodies. Of particular interest is water quality. This is affected by numerous sectors, as follows: Firstly, the climate sector impacts water quality by changes in temperatures. How land is (mis-)managed can contribute to changes in erosion runoff and nutrient leakage to water bodies. Similarly, overuse of fertilisers and pesticides for food production can contribute to nutrient leakage to water bodies. Urban wastewater, if not properly managed can also negatively impact on water quality. In turn, changes to water quality can have impacts to ecosystems.

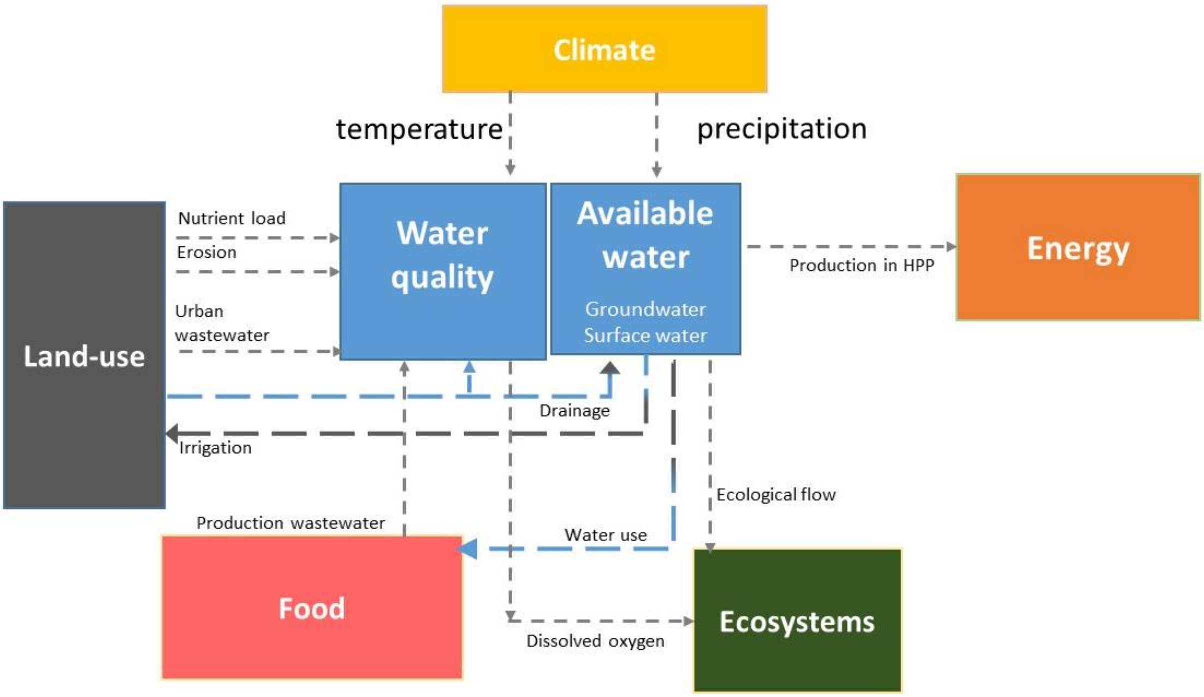

Figure 11: Water sector conceptual map in the Lielupe River Basin.

4.2.2.3 Land-use sector map

Figure 12 shows the land use sector conceptual map. Land uses are split into agricultural uses, forestry, and other land uses (e.g. green energy installations, urban areas). The nature of land use is impacted by precipitation and changes in temperature, and as a feedback, how land is used can contribute to net greenhouse gas (GHG) emissions to the atmosphere. Land uses can contribute nutrients, erosion, and wastewater to water bodies, and in turn, water is used to support irrigation activities on land. Land is used to support to production of food, while food production contributes manure as a waste product. Some quantities of manure of often deemed beneficial, but too much can lead to problems for water quality. How land is used in the Lielupe can support the ecosystems in the river basin, or could also negatively impact

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them. Finally, certain land uses (e.g. bioenergy crops parcels) are used to support energy production (biocrops, solar installations).

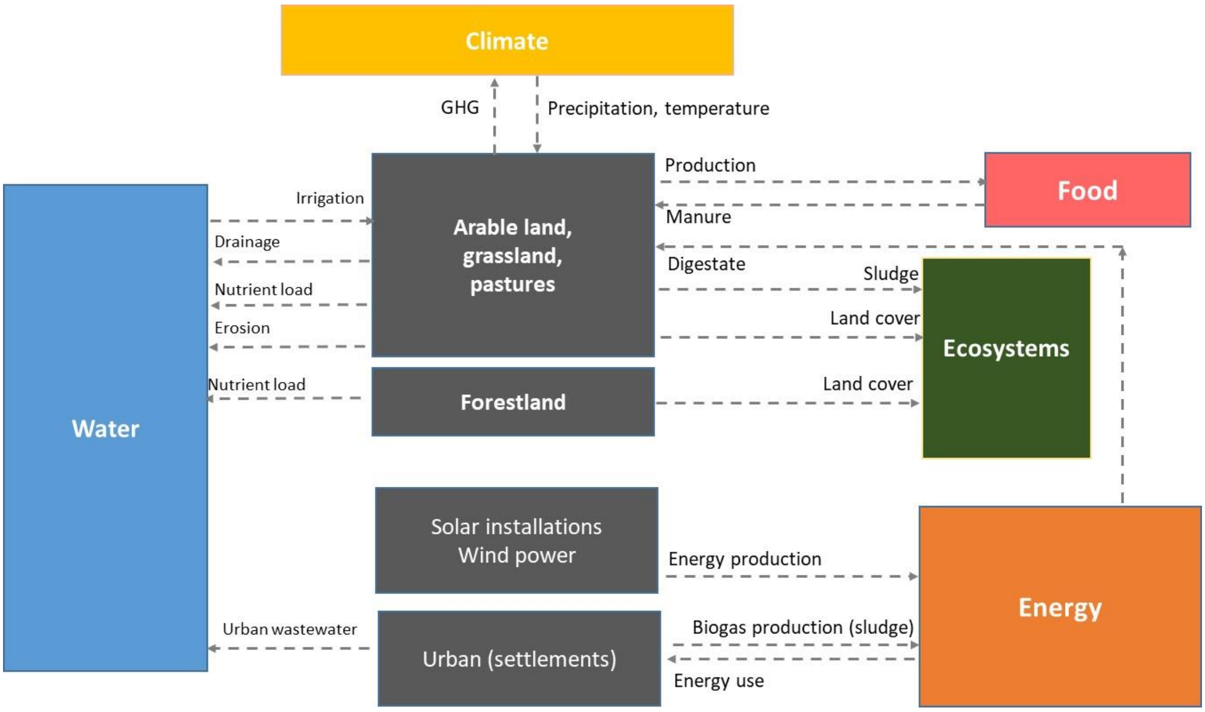

Figure 12: Land-use sector conceptual map in the Lielupe River Basin.

4.2.2.4 Food sector map

Figure 13 shows the food sector conceptual map. The food sector includes both production (rainfed agriculture and irrigated agriculture referring to indoor greenhouses), processing, and demand. Crop production emits GHGs to the atmosphere. Production consumes water resources and nutrient leakage affects water quality. Manure from livestock rearing affects ecosystems, GHG emissions, and water quality, and contributes to energy production through manure production. Food production requires land. Crop and livestock production both may impact on ecosystems. The quality of the land and ecosystems can impact on food yields. Crop residues contribute to bioenergy production. Energy is consumed predominantly in food processing. Processing produced wastewater, which can affect water quality.

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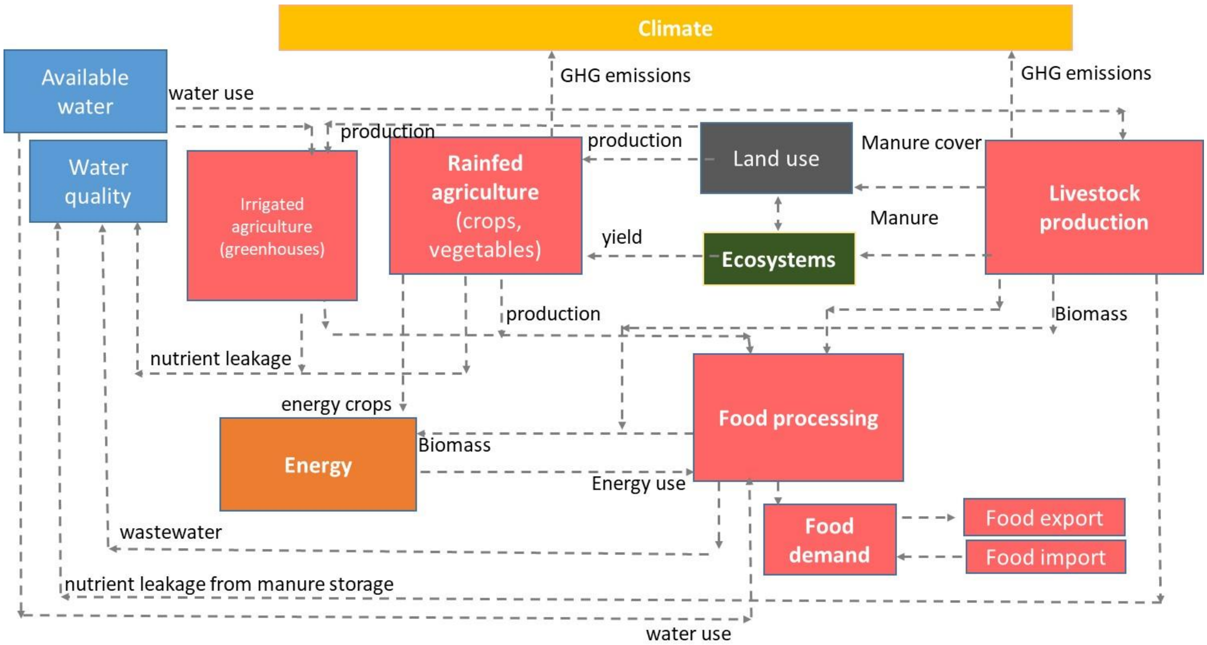

Figure 13: Food sector conceptual map in the Lielupe River Basin.

4.2.2.5 Ecosystems sector map

Figure 14 shows the ecosystem sector conceptual map. Several types of ecosystems are distinguished. Aquatic ecosystems are found in bodies of water – lakes, rivers, ponds. These are primarily affected by water quality parameters, which in turn are affected by other nexus sectors (e.g. land use, food). The terrestrial ecosystems are found on land – grasslands, forests, wetlands, peatland, arable land. Again, these are affected in turn by how the land is used, how food is produced, climatological parameters, etc. To some extent the soil ecosystem characteristics (e.g., moisture, nutrients) is related to crop productivity and yield, with this relationship shown in Figure 14. The link from ecosystems back to the climate sectors indicates that ecosystems contribute to climate modulation.

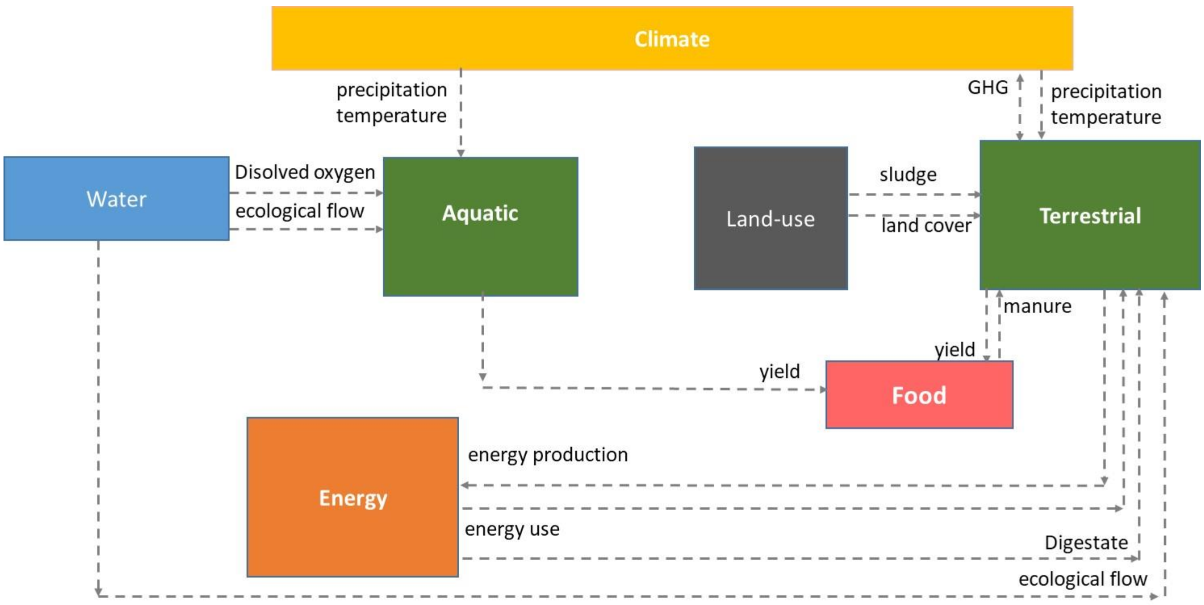

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Figure 14: Ecosystems sector conceptual map in the Lielupe River Basin.

4.2.2.6 Energy sector map

Figure 15 shows the energy sector conceptual map. Energy production from renewable energy sources and fossil sources (mainly imported natural gas) play an important role in the energy balance of the basin. The conceptual model describes the interlinkages with Water (used for hydropower production), Land-use (crops grown for biofuels, land used for energy infrastructure), Ecosystems (impacts by energy generation), and Food (conflict between food production and crops grown for energy fuels) sectors related to primary renewable energy sources, which serves as an input to the energy production with consecutive final energy consumption in different economic sectors. The interrelations between the Energy and Climate sectors are mainly related to GHG emissions.

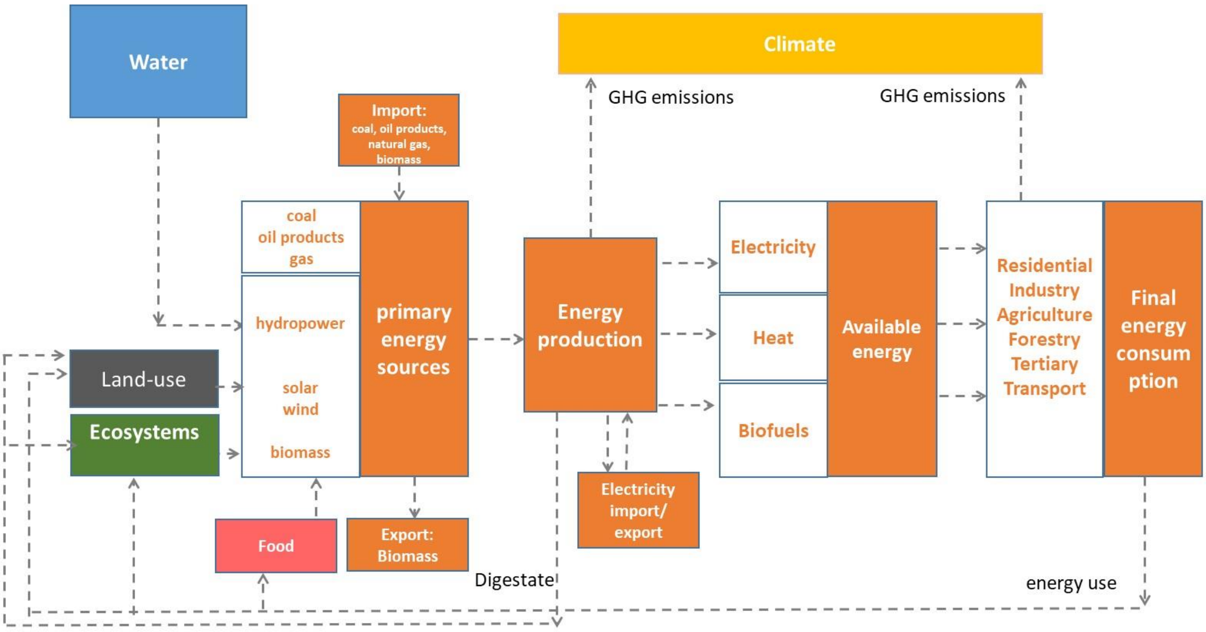

Figure 15: Energy sector conceptual map in the Lielupe River Basin.

As a final analysis in the Lielupe Basin, the critical linkages from one sector to another have been defined. These critical links are shown in Table 3, and act to better define and quantify the nexus in the Lielupe River Basin. They will be used as contribution to the quantitative modelling to be undertaken in NEXOGENESIS (Section 4).

Table 3: Description of interlinkages between nexus sectors in the Lielupe River Basin.

Provider	Recipient	Interlinkage	Description	Units
Climate	Water	Precipitation	Impact on water amount in water bodies	mm
Climate	Water	Temperature	Impact on evaporation from water bodies, water temperature	kg/h
Climate	Land-use	Precipitation	Impact on amount of water precipitated	mm

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Climate	Land-use	Temperature	Impact on amount of water evaporated	kg/h
Climate	Ecosystems	Precipitation	Impact on moisture in soil	m^3/ha, %
Climate	Ecosystems	Temperature	Impact on plant, animal species, cultivars	Number
Water	Ecosystems	Ecological flow, dissolved oxygen	Impact from hydrological regime on habitats and species Impact from obstacles (e.g., dams, incl. beaver dams) Dissolved oxygen in water bodies	m^3/s, mg/l
Water	Land-use	Irrigation	Use of water for irrigation of fields, greenhouses	m^3
Water	Food	Water use	Use of water in processing of food	m^3
Water	Energy	Energy production	Energy produced in hydropower plants	MWh
Food	Water	Wastewater	Wastewater from food processing industry, Nutrient leakage from manure storage	m^3, kg
Food	Climate	GHG	Emissions from food processing industry	tCO_2ekv
Food	Energy	Biomass	Energy produced from food waste for energy (biogas), energy crops	MWh
Food	Ecosystems	Manure	Nutrient supply from life-stock production (organic fertilisers)	kg/t
Food	Land-use	Manure	Are of land covered by organic fertilisers (manure)	ha
Energy	Climate	GHG	Emissions from energy production and consumption	tCO_2ekv
Energy	Food	Energy use	Energy used for food processing industry	MWh
Energy	Ecosystems	Energy use	Energy used for forest cutting, mowing, ploughing, etc.	MWh
Energy	Land use	Energy use	Energy used for residential sector (incl. wastewater treatment)	MWh
Energy	Land use	Digestate	Area of land covered by digestate	ha
Energy	Ecosystems	Digestate	Nutrient supply from digestate (from biogas production) (organic fertiliser)	kg/t
Ecosystems	Climate	GHG	Emissions from soil/ sequestration by plants	tCO_2ekv/ha
Ecosystems	Food	yield	Productivity of crops, vegetables, trees, fish etc.	kg/ha
Ecosystems	Energy	Energy production	Use of biomass (e.g., wood, grass) for energy production	m^3, MWh

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Land-use	Climate	GHG	Area of land use e.g., arable land, pastures producing emissions	ha
Land-use	Water	Nutrient load	Leakage of nitrogen from land-use	ha, kg/ha
Land-use	Water	Erosion	Loss of land along riverbanks	ha, kg/ha
Land-use	Water	Urban wastewater	Waste-water discharge from urban settlements, incl. rainwater	m^3
Land-use	Water	Drainage	Load of nitrogen from the drained land area, incl. various drainage types	ha, kg
Land-use	Food	Production	Agricultural land used for production of e.g., crops, vegetables, cattle	ha
Land-use	Energy	Energy production	Land used for installation of solar and wind turbines Area producing sludge from wastewater treatment plants for biogas production	ha ha
Land-use	Ecosystems	Land cover	Land covered by different terrestrial ecosystems – forests, meadows	ha
Land-use	Ecosystems	Sludge	Nutrient supply from wastewater treatment facilities (organic fertiliser)	kg/t

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4.3 Case Study #3: Jiu River Basin, Lower Danube (Romania)

4.3.1 Description of the Case Study

The Lower Danube case study is focused on the 16 759 km^2 Jiu River Basin in Romania (Figure 16**Error! Reference source not found.**), which is itself a sub-basin of the broader Danube River. The case will explore issues exploring interconnections and will explore the potential for replicability and outscaling of the NEXOGENESIS approach to Serbia and Bulgaria. The Jiu River flows from the Romanian Carpathian Mountains south through several counties in Romania before it discharges into the Danube at Zaval at the Romanian-Bulgarian border near the Bulgarian city of Oryahovo. In addition to the hydrographic network of the Jiu River, more than 640 km of the Danube River are included in the Jiu basin and integrated water management principles are applied for 3 water bodies of utmost importance. The basin is characterised by arable land (48%), forest (30%) and pastures (9%). The population in upstream mountain areas rely on the coal mining industry with lignite-based electricity and heat generation, while the downstream areas are characterized by agricultural activities that depend on water supplies for irrigation and hydropower production. The Lower Danube wetland ecosystem, which includes several EU Natura 2000 sites, is highly sensitive and has already lost nearly 80% of its surface area in the last century due to river dredging, land reclamation and flood control measures. Anthropogenic interventions including dams along the Danube have led to erosion and negatively affected the riverbed, while flood and drought events continue to impact the region.

Figure 16: Location of the Jiu River Basin

Challenges in the Jiu River Basin result from competing interests regarding water availability, both in terms of quantity and quality, and associated risks management across sectors. Hydropower production requires certain amounts of water to maintain electricity production during dry periods, which directly competes with the irrigation water demand in the agricultural sector. Water availability for the population is a top priority in the basin in connection with the

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extension of water supply and sanitation networks under different regional development programs. At the same time, the energy sector with the main Romanian hydropower plant (Iron Gates on the Danube) and lignite-based electricity and heat generation facilities in the north of the basin (currently transitioning to alternative energy sources), has an important presence in the economy of the region. National priorities for energy production impact on local water resources through their water demands and concomitant quality implications, and impact on the surrounding environment. Agricultural activities are playing an important role especially vegetal production (highly dependent on irrigation), horticulture, husbandry and aquaculture. Floodplain restoration projects are initiated in the south of the basin demonstrating nature-based approach to climate change adaptation and socio-economic co-benefits. Such initiatives could prove beneficial across nexus sectors if implemented carefully. Finally, further steps are designed by river management plans aimed at promoting ecological connectivity for enhanced biodiversity and ecosystem services throughout the Jiu River Basin.

4.3.2 Description of the conceptual map

4.3.2.1 Top-level conceptual map

The top-level conceptual map for the CS Jiu is reflecting river basin management priorities and sustainable development goals (SDGs) for the region (monitored indicators are included in the map). Climate change with increasing temperature and variation in frequency and intensity of precipitation strongly influence land use and land cover and vice versa. Flood events have had a long-standing presence in the region while, more recently, desertification is increasingly becoming a concern.

Water availability takes into considertion both quantity and quality. Their good status is essential to ensure drinking water for the population and ecosystems functioning in the Jiu river basin. The availability and accessibility of safe drinking water are expected to increase due to the extension of the water supply and sanitation networks with a positive impact on human health. Water in the basin is mainly used for agricultural (irrigation), energy (production), and industrial (processing) purposes. The main agricultural activities in the basin are horticulture, husbandry, and aquaculture and they consume both water and energy. Energy produced in the basin plays a a major role in the national energy mix and cover water abstraction, distribution, cooling, heating, and treatment in the region. The ecosystems that characterise the basin are important contributors to the system and thus and are supported and controlled by floodplain restoration and flood protection measures, while at the same time are threatened by land use change and agricultural activities. Ensuring good ecological flow is fundamental for maintaining the good status of ecosystems. Specific aquatic plants are currently tested as a nature-based solution to clean water, aiming to contribute to reducing water pollution. A circular approach and ecosystem services are strongly promoted as sustainable alternatives for local development. Details of the top-level conceptual map for the Jiu river basin are shown in Figure 17.

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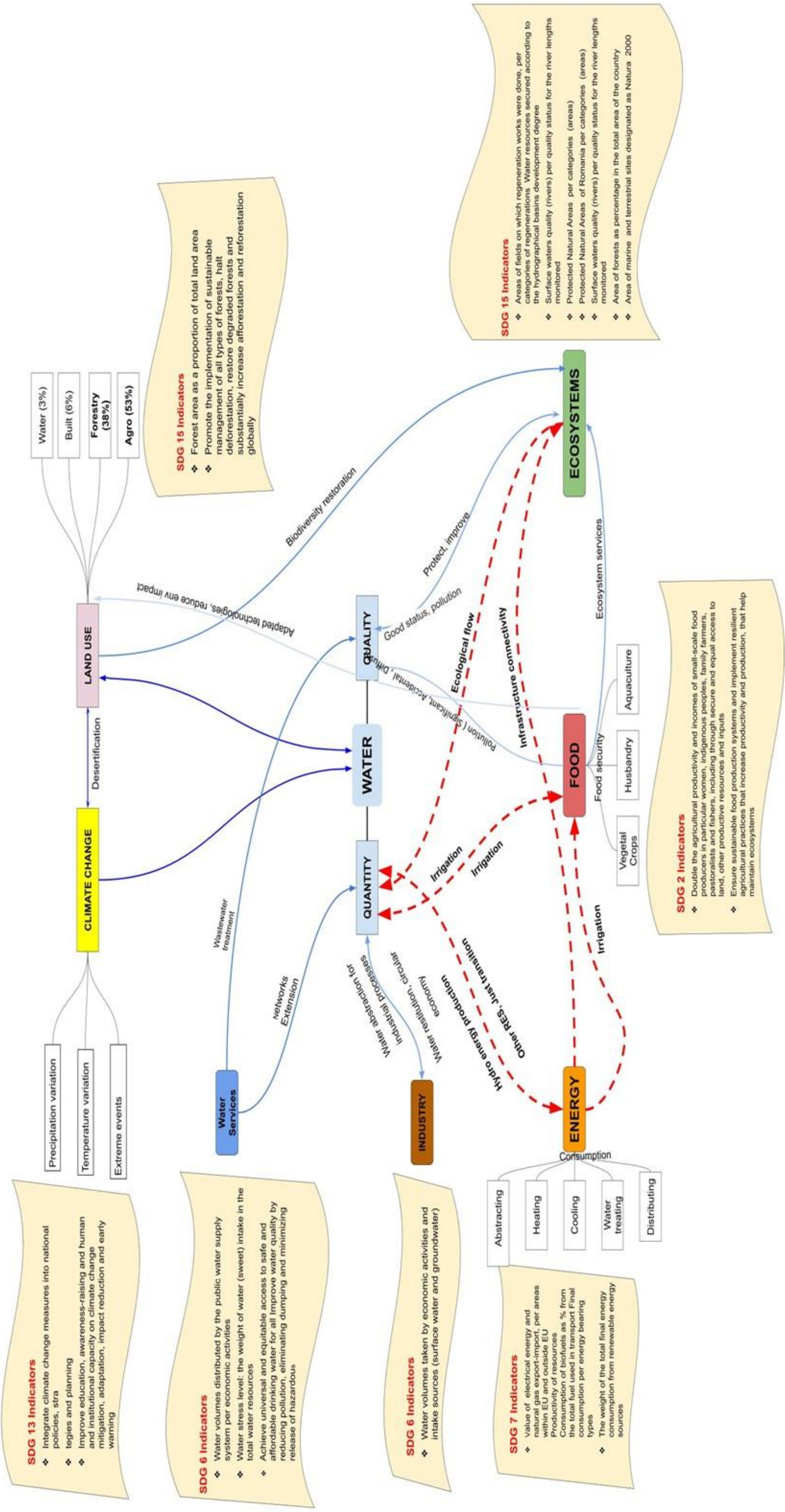

Figure 17: Top-level conceptual map for the Jiu river basin.

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4.3.2.2 Water sub-sector conceptual model

Water availability, considering both water quantity and quality, was identified in the “River Basin Management Plan” of the Jiu river basin as an important component of the system. Directly depending on water quantity, water services have been highlighted as a key entry point to ensure water security in the basin.

Land use change is increasing the impact of climate change on the Jiu river basin where changes in frequency and intensity of precipitation and increasing temperature are threatening the WEFE sectors due to increasing extreme events such as drought and floods.

At the moment there are a large number of people that access water independently because they are not connected to a water network. The country is currently increasing water services thanks to the extension of the water supply network, contributing to achieving SDG 6 with a consequent positive impact on public health and access to clean water and sanitation. Although the agricultural sector is the highest water user, the main priority in the basin is to supply water for domestic and industrial use. Water is often prioritized by national level decisions for energy production and in turn, energy is used locally to increase water availability, especially for water abstraction, distribution, heating, cooling, and treating. Water abstraction is essential for industrial processes (e.g., food processing, packaging, and construction of materials) and agricultural activities, especially for irrigation.

The expansion of the agricultural area, currently up to about 48% of the total available land, is leading to an increased risk for water pollution, due to chemical loads into water bodies, with a significant impact on water quality and ecosystems. Ecosystems are also impacting on water quantity in the basin. The latter are heavily impacted by climate change and land use change. Details of the water sub-sector are shown in Figure 18.

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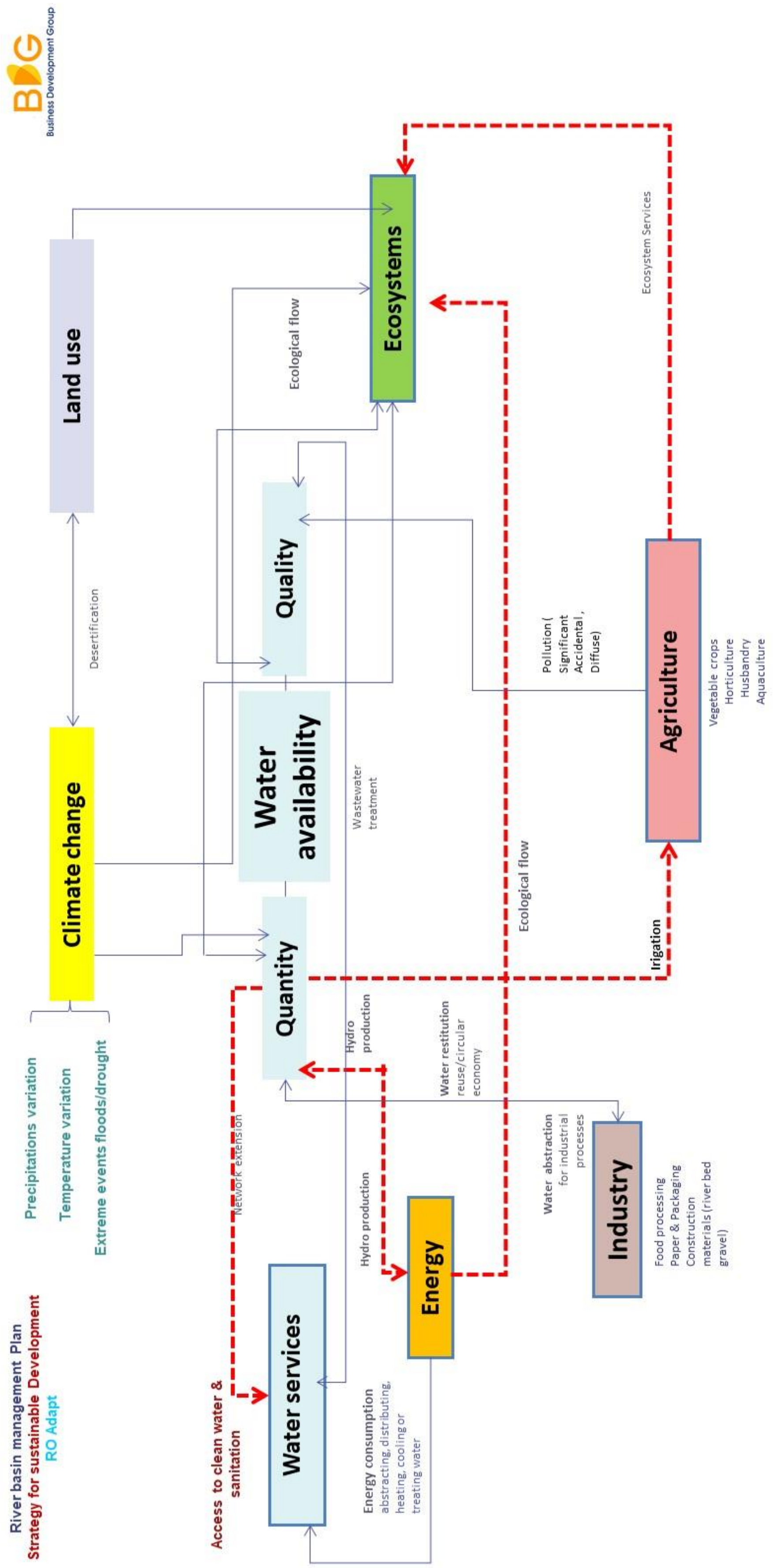

Figure 18: Water sub-sector conceptual map for the Jiu river basin.

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4.3.2.3 Energy sub-sector conceptual model

Climate change influences energy production (e.g. via affecting river flows for hydropower) and vice versa. Infrastructures (e.g. dams) are expected to increase water storage contributing to facing climate change impact in the basin. Changing temperature and precipitation mainly impact on hydropower production and energy crop production. The main energy sources in the Jiu river basin are hydropower, other renewable energy sources (e.g., photovoltaic and biomass), and coal. Energy is mainly used in the domestic, industry, agriculture, and transport sectors. The "National Integrated Plan for Energy and Climate"[1] and the "Just transition mechanism"[2], are framing decarbonization by reducing coal-based energy production in the region. It is expectedthat implemented measures will contribute to reducing GHG emissions and water pollution while adding pressure on the water resource with additional economic activities. The regulation of ecological flow is essential to ensure ecosystem health in the basin, and therefore may have a potential impact on hydropower generation. Hydropower production is expected to contribute to supplying clean energy for agricultural activities, especially for irrigation. An important trade-off in the basin is between land use for energy production (e.g., biomass, solar panels) and for food crops, which might threaten energy and/or food security in the basin. Energy production is expected to impact land use and vice versa. Details of the energy sub-sector are shown in Figure 19.

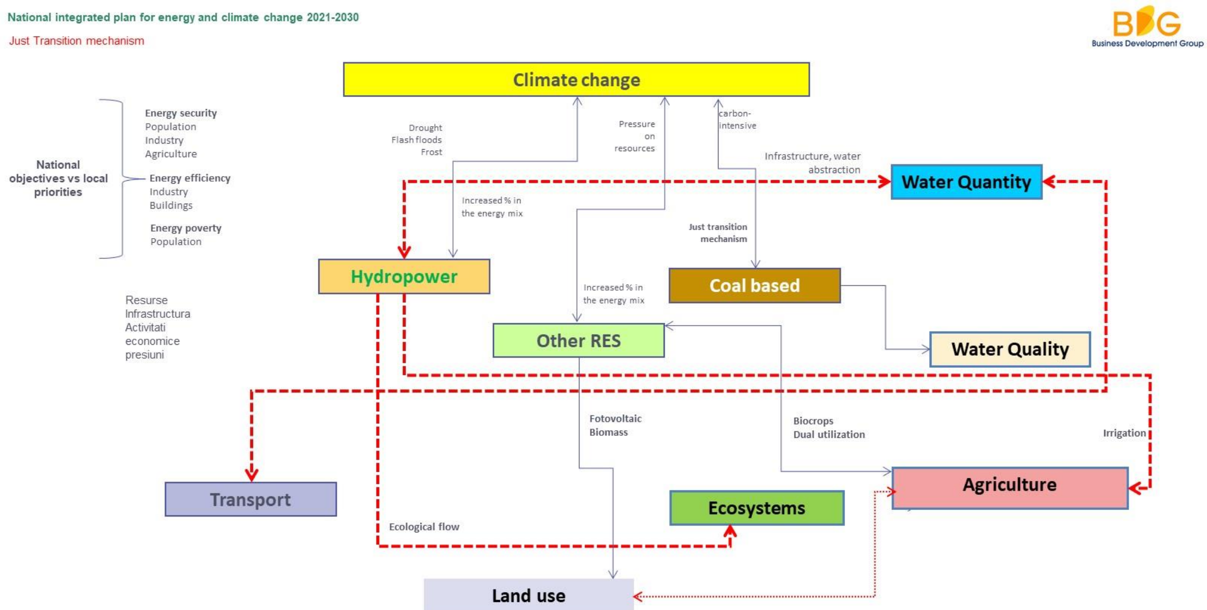

Figure 19: Energy sub-sector conceptual map for the Jiu river basin.

4.3.2.4 Food sub-sector conceptual model

Crops, animal husbandry, aquaculture, and pisciculture are the main sources of food in the Jiu river basin. Food security is threatened by climate change that, due to desertification risk, might have an impact on food production leading to increasing land use changes. Plant genetic

[1] https://energy.ec.europa.eu/system/files/2020-06/ro_final_necp_main_en_0.pdf
[2] https://reform-support.ec.europa.eu/strategy-economic-and-social-development-jiu-valley-coal-region-transition-romania_en

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diversity as well as agriculture adaptation to changing climate and the use of technologies are fundamental to ensuring food security in the Jiu river basin.

Crops, for both food and energy supply, depend on irrigation that in turn depends on water availability (quantity). Likewise, the choice of cropping can impact on overall water quantity available for other uses. Other activities such as aquaculture and pisciculture, largely depend on water quality. Ensuring water quality is therefore essential for reducing biodiversity loss and preserving ecosystem services, as well as maintaining food production in the basin.

Food production activities can contribute to ecosystem restoration, thus maintaining and improving ecosystem services. But at the same time, as mentioned in the energy sector, there might be competition in terms of land use for food and energy (biocrop) production, especially due to the arable land expansion and biomass production (forestry and energy crops). Such activities are exacerbating deforestation which is also a relevant issue in the basin. Energy is consumed in crop production, and crop production (biomass, waste residues) can contribute to local energy generation.

Soil regeneration (SDG 15), a transition to a circular economy (SDG 12), as well as ecological agriculture (SDG2), are expected to be achieved in the basin through the food sector assessment and its interlinkages with other sectors of the nexus. Details of the food sub-sector are shown in Figure 20.

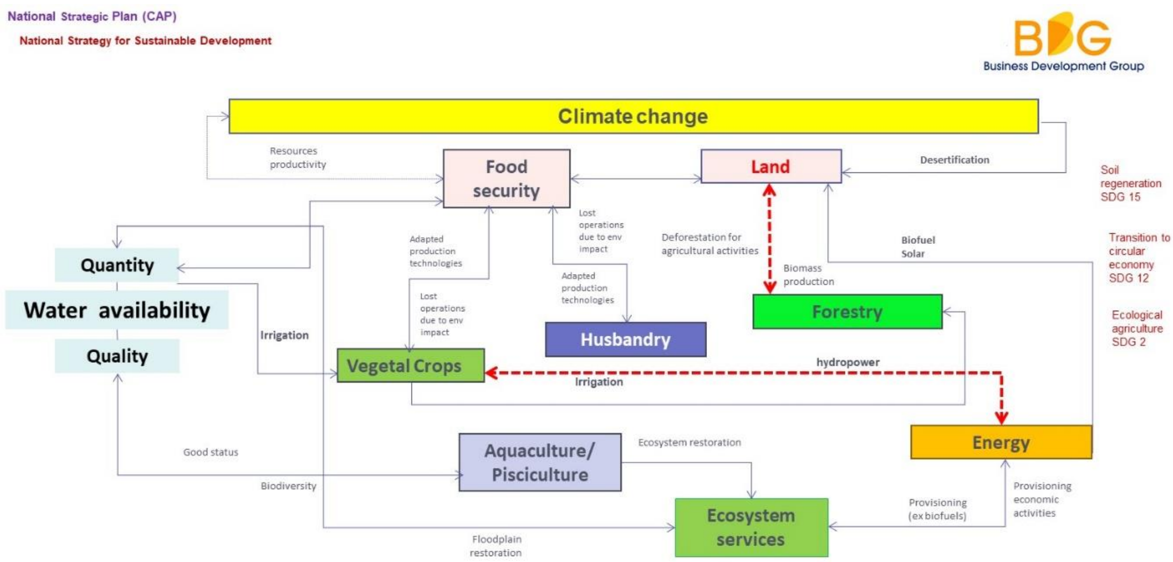

Figure 20: Food sub-sector conceptual map for the Jiu river basin.

4.3.2.5 Ecosystem sub-sector conceptual model

The ecosystems in the Jiu river basin depend on both water quantity and quality, and vice versa. Water quality and quantity are essential to ensure ecosystem services, biodiversity, and the good status of protected areas. As seen in Figure 21, water resources are deeply influenced by changes in climate that in turn is impacted by land use changes, among other sectors. Food and energy production techniques have an impact on ecosystems, but due to implementation of the decarbonization strategies in the basin, and achieving the sustainable

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energy production goals, an improvement in ecosystem health is expected. So food production can negatively impact on biodiversity through ecosystems loss and monocrops, but if well managed, could also lead to the protection and expansion of ecosystems and biodiversity. Aquaculture and pisciculture, as well as good practices such as soil protection and maintining the ecological flow, are expected to contribute to improving the ecosystems' status. These also impact on the diversification of ecosystem services and their increased contribution to adaptation to climate change as well as local development. Interesting links here are those to educaiton. Through NEXOGENESIS activities, a wider stakeholder group is being made incresingly aware of the challenges being faced, opportunities available, the interconnected nature of the WEFE nexus in the basin, and of the potential offerred by the digital instrument that will be developed by the project which will promote new ways to improve policies. These actions may lead to the promotion of new activities, or activities being 'done differently' in order to support more effective integrated resources management in the basin, and improved holistic WEFE nexus functioning. Details of the ecosystem sub-sector are shown in Figure 21.

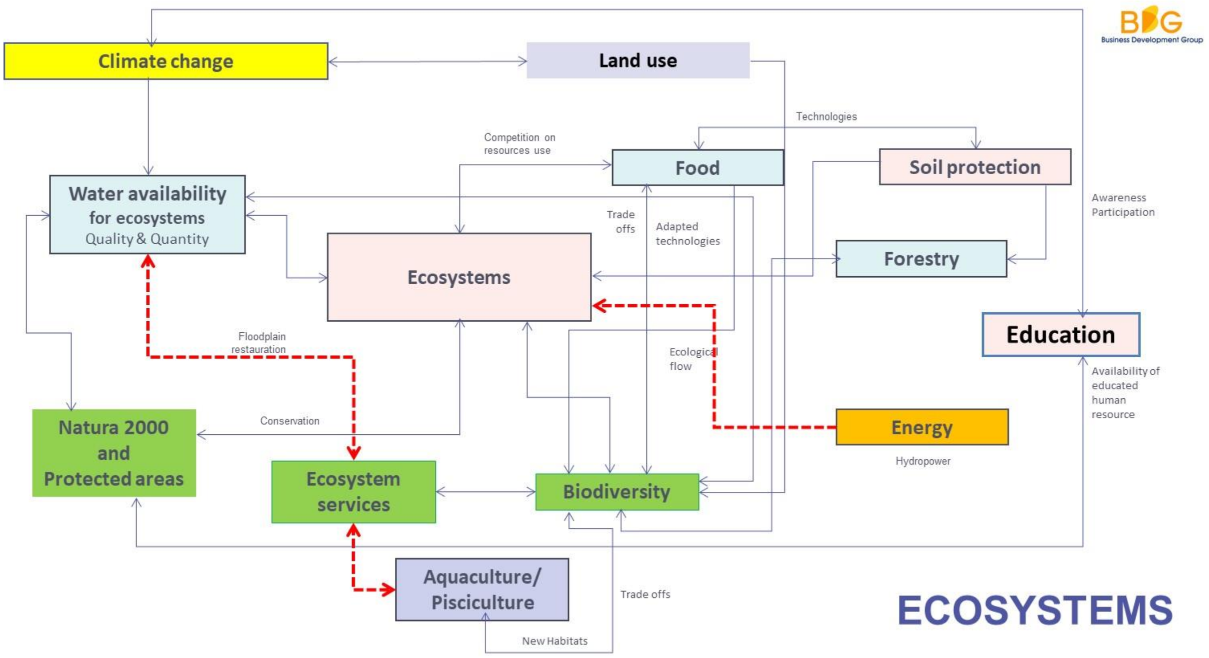

Figure 21. Ecosystem sub-sector conceptual map for the Jiu river basin.

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4.4 Case Study #4: Adige River Basin (Italy)

4.4.1 Description of the Case Study

The Adige case study includes Italy's second-longest river, the 409 km long Adige River. The basin area is 12 100 km^2 (**Error! Reference source not found.**22 and 23). It flows from its source in the Italian Alps at 1550 m through six provinces in northern Italy before it reaches the Venetian Lagoon and flows into the Adriatic Sea. It crosses six provinces, from the Autonomous Provinces of Bolzano-Bozen (62% of the overall basin) and Trento (29%) to the Provinces of Verona, Padova, Rovigo, and Venezia (all of them sum to 9%). The area is characterized by a continental climate, with cold winters and rainfall maxima during the summer upstream, while hot summers and two precipitation peaks in fall and spring in the plain section of the basin. At higher altitudes, significant water resources accumulate during the winter season in the form of snowfall, which are mobilized during spring. This situation determines the main "nival" hydrological regime of the basin area, characterized by a general high availability of water in the warm season and low water availability during winter.

Economic sectors historically developed on abundant water resources. In the upstream areas, ongoing issues related to the WEFE nexus, concern the concurrent impacts of climate change on water availability and a high use of water for hydropower production (reservoirs mostly driven by the energy market) and agricultural needs. A total of 61 hydropower stations in the upper part of the basin produce energy exceeding the provincial energy demands. However, this important renewable energy production strongly influences the amount and timing of the Adige River flow for downstream users. As for the agricultural sector, the valleys in the upstream mountain provinces are characterised by intensive apple orchards, which provide about 15% of European apple production ("Provincia Autonoma di Trento – Servizio Statistica,"; South Tyrol in Figures, 2021; The apple market in the EU: Vol. 1: production, areas and yields, 2022). Moreover, minimum ecological flow is ensured by legislative constraints but often threatened by lobbying hydropower and agriculture sectors with a low perception of potential downstream consequences in case of water availability reductions.

The downstream areas, South of the province of Verona, are characterized by intensive anthropogenic land use. In this area water used for food production and to ensure healthy ecosystems represent the main nexus. Vineyards and cereals are the main cultivations irrigated through water withdrawals, with wine production representing an important economic sector. The intensive agriculture present in the lowlands is often based on low-efficiency sprinklers irrigation systems both competing with the water needed by the ecosystems and depending on the services provided by the healthy delta ecosystems. The regional park and its wetland ecosystem, in the Adige delta, sustains fisheries, aquacultures and provides essential protection against saline intrusion and coastal erosion. Moreover, the delta has a high recreation value being an important touristic destination.

Within the Adige River basin, winter and summer tourism plays an important role; indeed high touristic flows are spread all over the river basin with peak seasons contributing to a population

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increase of 5-6 times the number of inhabitants (Scuttari et al., 2018), leading to an increase water demands for accommodations facilities and snow production.

The diverse and opposed interests in water in the upstream and downstream areas are characterized by different cultural, linguistic (i.e. South Tyrolean, Ladin and Italian), economic and legislative autonomy levels. The complex and diverse water use situation in the Adige basin leads to disputes and tensions for a multi-sector and geographically equitable water management and governance. Although integrated water management systems within the Adige river basin exist (e.g. the Public Water Use General Plan in the Autonomous Province of Bolzano and Trento and the Regional Plan for water protection in the Veneto region), the ongoing combination of: (i) the climate change effects on temperature, rain and snowfall; (ii) an increasing anthropogenic water demand and; (iii) a lack of trust and synergy among the provinces is already now exacerbating water tensions and disputes across sectors and provinces. Furthermore, cultural, geographical and historical peculiarities of the area intersect and are reflected in a unique autonomy governance setting. Finally, recent events of Covid-19 causing sudden changes in water demand patterns (e.g. -20% in tourist flows due to the lockdown) should be considered due to the consequences on water management.

Thus, the ongoing combination of (i) the climate change effects on temperature, rain, and snowfall; (ii) an increasing anthropogenic water demand; and (iii) a lack of trust and synergy among the provinces is already exacerbating water tensions and disputes across sectors and provinces.

Figure 22: Location of the Adige River Basin

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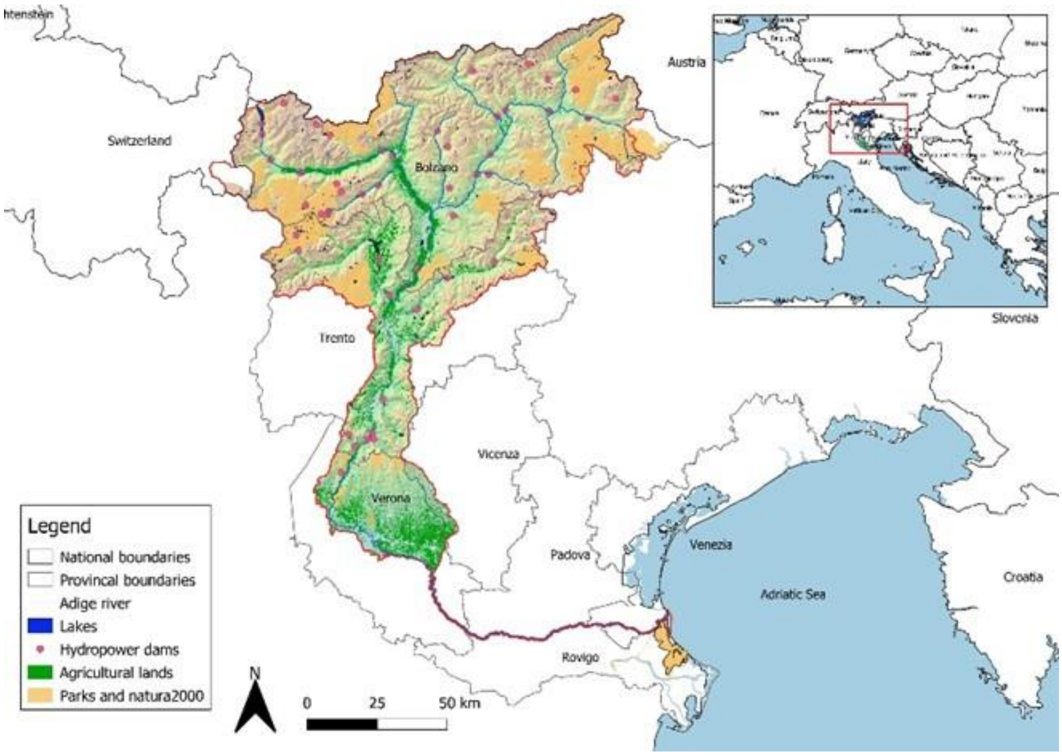

Figure 23: Details of the Adige River case study.

The complex and diverse water use situation in the Adige Basin leads to disputes and tensions for multi-sector and geographically equitable water management and governance. Hydropower production influences the amount and timing of the Adige River flow for downstream users. Climate-change induced shifts in the river flow regime can affect seasonal water availability, and may impact on hydropower generation. Tourism affects water demands, especially for snow production and accommodation facilities, and is strongly seasonal. Diverse and opposed interests for water in the upstream and downstream areas are characterised by different cultural, linguistic, economic, and legislative autonomy levels, adding to the complexity. Thus, the ongoing combination of: (i) climate change effects on temperature, rain, and snowfall; (ii) increasing anthropogenic water demand; and (iii) a lack of trust and synergy among the provinces is exacerbating water tensions and disputes across sectors and provinces in the Case Study.

4.4.2 Description of the conceptual map

4.4.2.1 Evolution of conceptual map development and high-level nexus map description

The understanding of the WEFE Nexus components and their relations within the Adige River basin started with the collection of peer-reviewed, grey literature and newspaper articles dealing with the water management topic. The information gathered in this initial phase were used in combination with expert-based discussions to develop a first conceptualization of the sectors involved in the WEFE nexus for the Adige River basin and the definition of their exchange of material or pressures. Moreover, the conceptual diagram was developed and

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validated through the inputs provided in two workshops held online in May 2022 and in presence in Trento 2022 with the main river basin stakeholders (e.g., from local authorities, academics, decision-makers, environmental associations and hydropower managers). In particular, during the first workshop, stakeholders were asked to provide inputs on the criticalities characterising the WEFE sectors of the Adige River Basin, the causes underlying such challenges, as well as the available and missing tools to address them. This allowed the collection of local knowledge, pinpointing the main WEFE sectors and interconnections to start building the conceptual model. During the second workshop, the conceptualization was used to guide the discussion, collect further information and validate the identified sectoral interactions. Each participant had the possibility to prioritize the existing connections and to add others according to their sectoral and local knowledge.

In the high-level conceptual diagram (Figure 24), the main sectors of the WEFE nexus are illustrated: water, energy, food, ecosystem and ecosystem services, climate, land use and cover changes, and socio-economic. The focus was to identify and qualitatively characterize the relations among the WEFE sectors as well as the pressures by external components on the system (i.e. climate and socio-economic drivers). In this first conceptual map, the main interrelationships among the identified sectors are represented, identifying two different types of interconnections: i) red arrows represent pressures coming from climate conditions, socio-economic components, and land use/cover changes (e.g., changes in temperature and precipitation); ii) blue arrows represent the flows of material going from one sector to the other (e.g., water or energy).

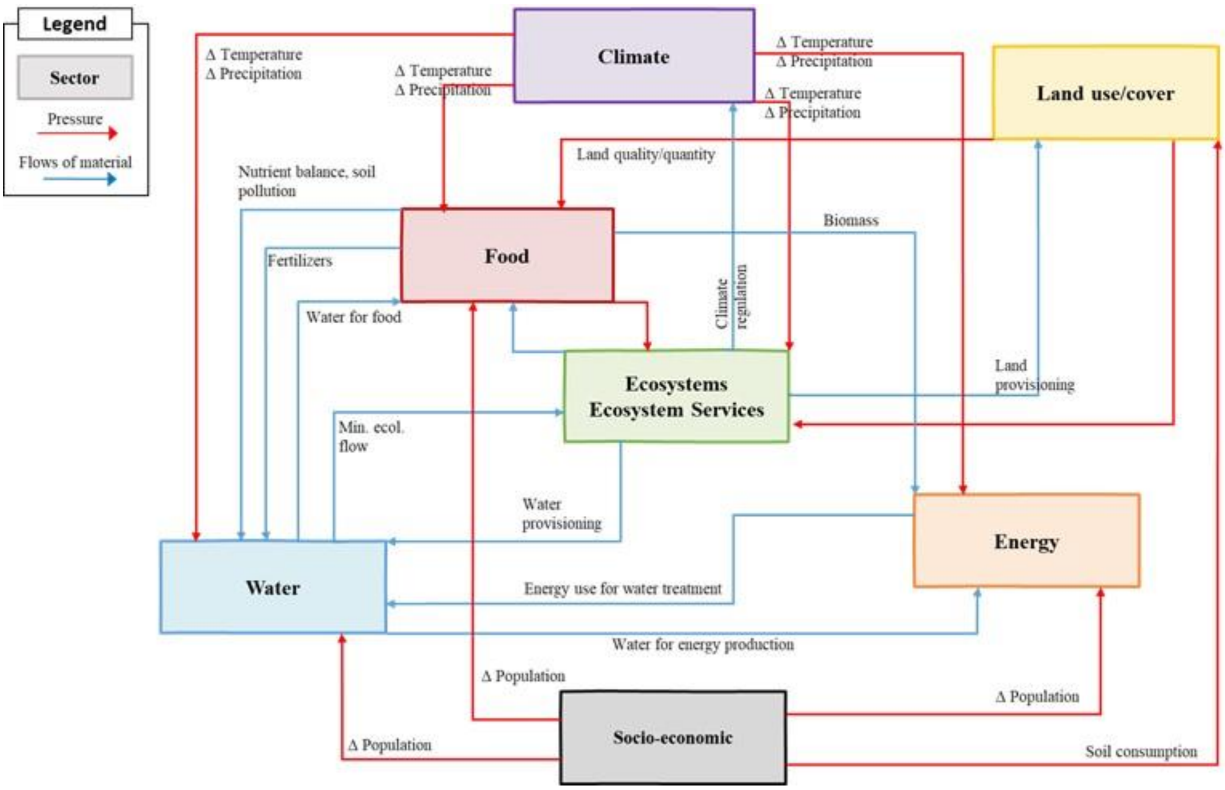

Figure 24: High-level conceptual map for the Adige Case Study.

During the development of the conceptual models, some sectors or processes were not considered or represented given their: (i) limited influence on the overall WEFE nexus over the whole Adige River basin (e.g., minor crop types or water users); (ii) influence over global processes (i.e., GHG emissions on climate); or (iii) effects in international trades which are beyond the scope of this representation (e.g., export/import of goods). Moreover, given the objective of providing a high-level understanding of the WEFE nexus in the Adige River basin, external drivers of socio-economic processes and climate change were here not represented (although these will be represented in the quantitative modelling efforts through data provided by NEXOGENESIS Work Package 2 partners). The developed conceptualizations do not have a spatially explicit representation, but they refer to conditions and processes occurring within the entire Adige River basin. The inter and intra-sectorial relations described by blue and red arrows provide a static snapshot on the type of connection without reference to dynamic changes.

In this top-level conceptual model (Figure 24) some potential cross-sectoral conflicts related to the WEFE nexus were identified and confirmed during the discussions with different stakeholders. Particularly, the Adige River basin is intensively exploited with a high number of large and small withdrawals associated with a variety of water uses from upstream to downstream: hydropower, domestic, ecological, and agriculture (Chiogna et al., 2016). Such a high exploitation of water in the whole basin makes the water users exposed to drought events and their impacts that can exacerbate water management conflicts (Chiogna et al., 2018; Terzi et al., 2021).

Starting from the top-level conceptualization, the water, energy, food and ecosystem sectors were further investigated, conceptualized and described.

4.4.2.2 Water sector map

The water sub-system identifies the interrelationships occurring among the different water components and the effect of external components on these processes (i.e. climate, land use/cover and socio-economic; Figure 25). Three main boxes within the water system were identified:

- Water availability - the biophysical components involved in the provision of water;
- Water demand - the potential water required to meet the real consumption;
- Water consumption – the total consumption of water coming from the main water users;
- Water quality - primary water quality indicators.

In particular, all the hydrological components contribute to determine the “water availability” box and the theoretical water demand from the main water users of the Adige River basin is represented by the “water demand” box. The interaction between “water availability” and “water demand” leads to the characterization of the actual “water consumption”. This schematic representation of the availability, demand and consumption components and their interactions have been also adopted to describe the use of natural resources for the energy and food sub-system.

The principal intra-sectoral processes were identified aiming at characterizing the flows of water between the availability, demand, and consumption: i) the flows of water between water availability and consumption; ii) the requested water quality characteristics by water

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consumption; iii) the effects of socio-economic changes on water demand and consequently on water consumption.

Some cross-sectoral relations within the WEFE nexus have been identified and here reported. Particularly:

i) the water consumption for agriculture and livestock production (water-food);
ii) the water consumption for the maintenance of the minimum ecological flow (water-ecosystems);
iii) the water consumption in hydropower plants for energy production (water-energy);
iv) the role as water regulators of the ecosystems, influencing water quality (water-ecosystem services);
v) the use of energy for water treatment for drinking water (water-energy); and
vi) agriculture and livestock productions affecting water quality by releasing pollutants, nutrients, fertilizers etc (water-food).

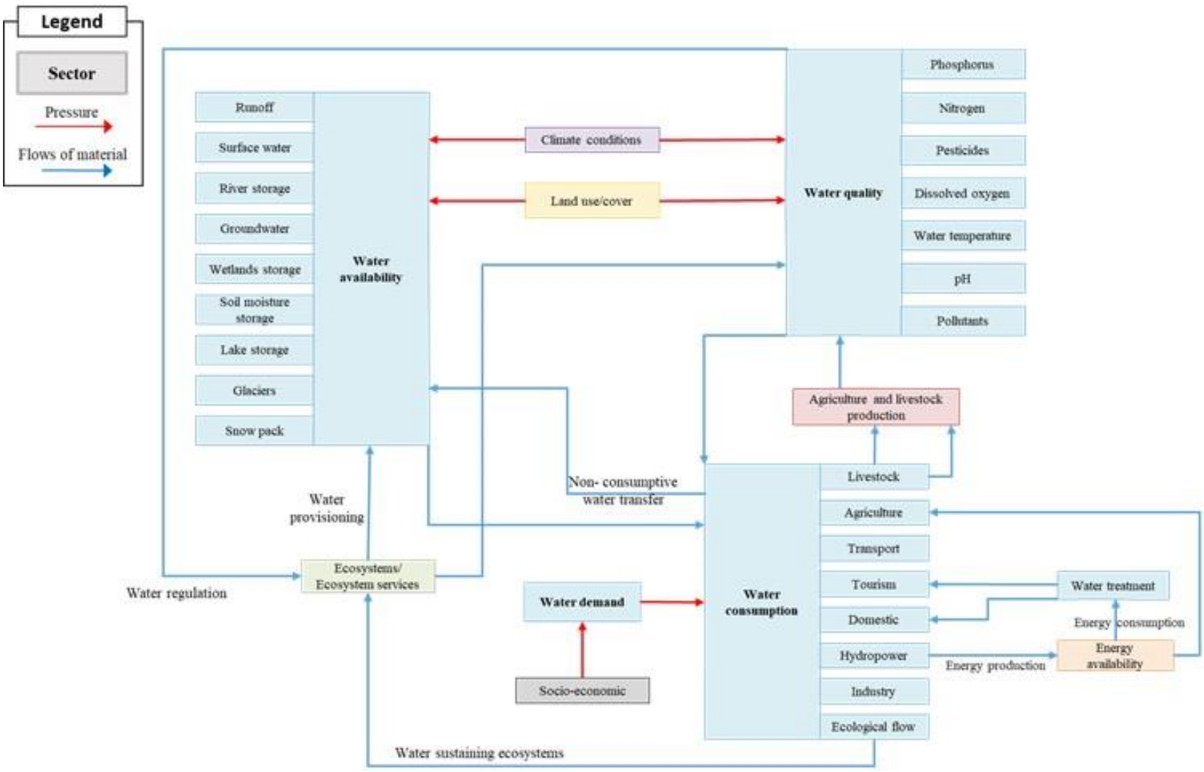

Figure 25: Water sector map for the Adige Case Study.

4.4.2.3 Energy sector map

The energy sources considered in this conceptualization are the most relevant in terms of production and influences on the other sectors (Figure 26). Four types of renewable energy sources due to their relevance in the overall production and belonging to the energy availability component, were here defined: photovoltaic, biogas, wind, and hydropower.
Similar to the water sub-system, the effects of socio-economic changes on the energy demand influence the energy consumption together with energy availability drawing the main intra-sectoral processes.

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Among the interrelationships with other sectors:

i) hydropower contributes to the conflicts for water consumption among the WEFE nexus sector (energy-water);
ii) agricultural products (biomass) are used as energy availability and, on the other hand, energy is employed for food production (energy-food);
iii) food production as energy consumption is interlinked with ecosystem services by food provisioning and water treatment (energy-ecosystem services);
iv) sharing of the same water resource by three main sectors (arrows from water consumption to agriculture, hydropower and ecosystems) highlights one of the above-mentioned potential water management conflicts.

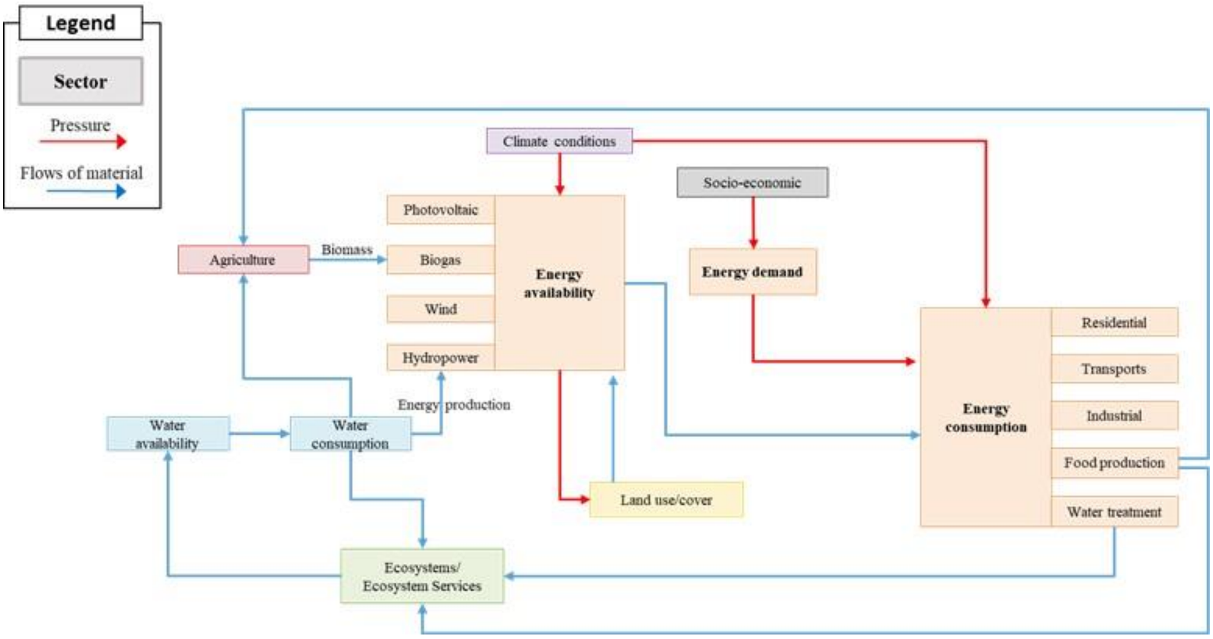

Figure 26: Energy sector map for the Adige Case Study.

4.4.2.4 Food sector map

In the representation of the food sub-system, the food sources considered those belonging to agricultural production, livestock, aquaculture and fisheries (Figure 27). In particular, within agricultural production crops, apples and vineyards are most represented in the case study area, especially in the upstream part of the basin, followed by high livestock production especially in the downstream part of the basin and fishery and aquaculture activities mainly in the Veneto region. Similar to the water and energy sub-system, food availability interacts with food demand (which is influenced by the socio-economic changes) and leading to food consumption.

Food's interlinkages with the other nexus components are related to:

i) water for irrigation and food production, both in terms of availability and quality for fishery and aquaculture (food-water);
ii) energy is needed to irrigate (food-energy);

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iii) ecosystems contribute to the availability of food and food-related activities, and agricultural, livestock and fishing practices have an impact on ecosystems (food-ecosystem/ecosystem services); and

iv) availability and exploitation of land for the development of agricultural and livestock activities in order to produce agri-food and livestock products (food-land).

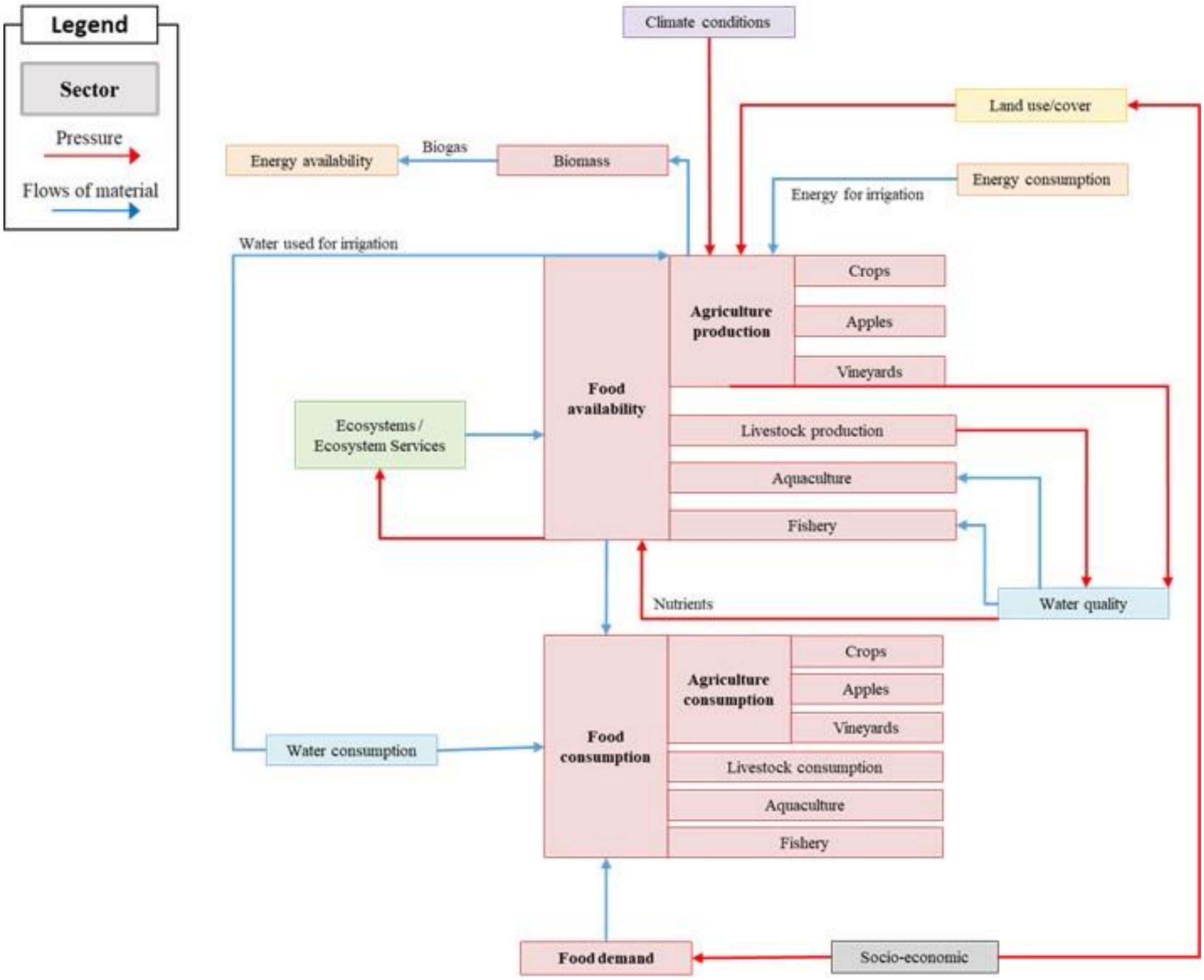

Figure 27: Food sector map for the Adige Case Study.

4.4.2.5 Ecosystems sector map

Ecosystems provide essential services for individuals with specific functions, defined as ecosystem services (ESs) (Egarter Vigl et al., 2017a; Shi et al., 2022). The Adige River basin has a very heterogeneous landscape ranging from the mountainous areas of Trentino-Alto Adige with wide forested areas, to the Veneto region characterized by a flat landscape, with the river delta area gives rise to wetlands. These various landscapes and ecosystems were here considered in four types of their ecosystem services, namely regulating, supporting, provisioning and cultural (Figure 28).

Within regulating service, two ecosystem services were considered: climate and water regulation. Climate and ecosystems/ESs have a dual interaction taking into account the climate regulation, indeed ecosystems are affected by the variations of climate conditions and are, on the other hand, contributing in regulating the climate. Water quality is influenced by the water

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regulation ES. In turn it contributes to the maintenance of ecological characteristics of the ecosystems (ESs- water).

For the supporting services, biodiversity degradation is interconnected with water quality (ESs-quality), since the support of the biodiversity needs specific water quality parameters.
Dealing with the provisioning service, for the Adige River basin three provisioning ESs were considered: i) ecosystems as such provide water that represent the water available for consequent different uses, as mentioned in the water sub-system (ESs-water); ii) in the same way the energy availability is dually connected with the energy provisioning (ESs-energy); iii) food availability is both providing food and provided by ecosystems as such (e.g. animals, plants) (ESs-food).

Finally, within cultural services, the most relevant ESs related to summer and winter touristic activities and the natural parks were here considered. Water availability is interconnected with these services by providing water needed for summer and winter activities (ESs-water).

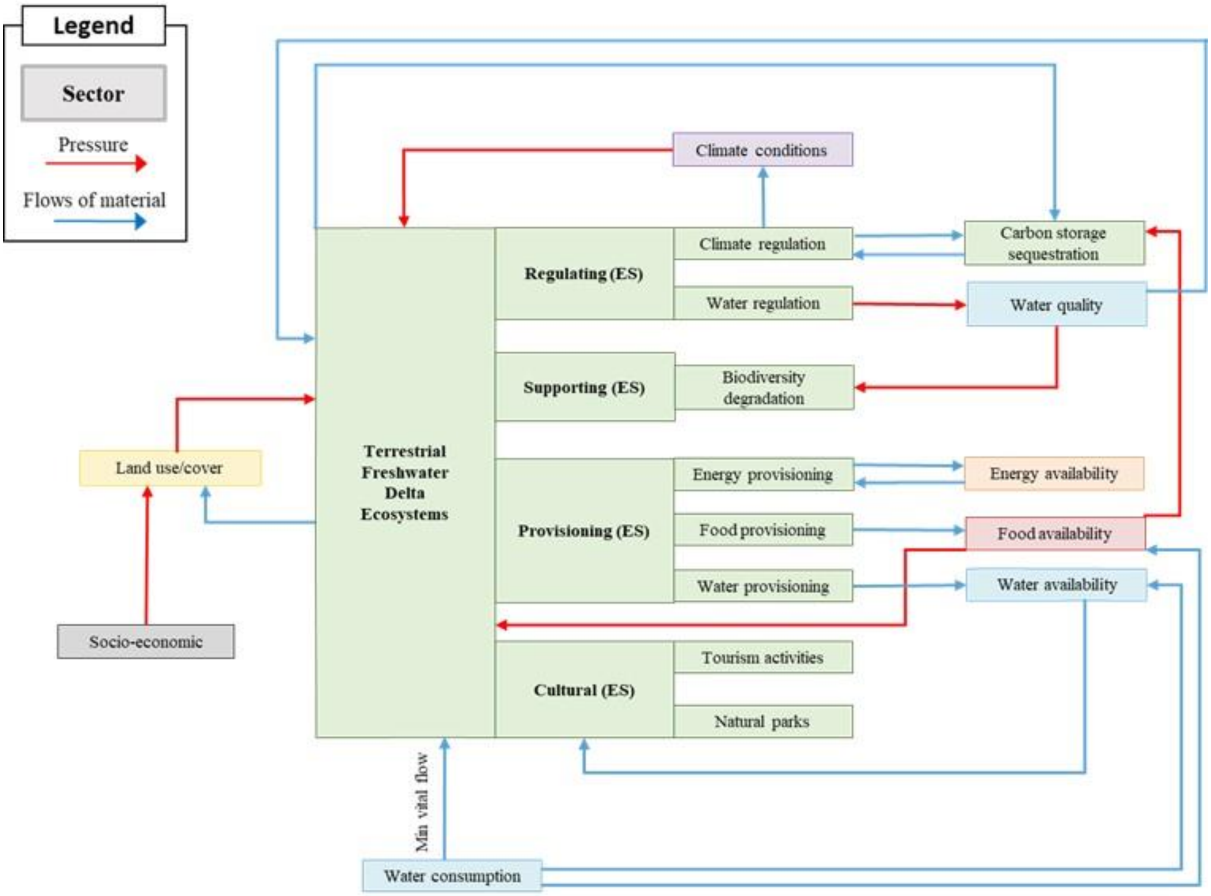

Figure 28: Ecosystems sector map for the Adige Case Study.

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4.5 Case Study #5: Inkomati-Usuthu (South Africa)

4.5.1 Description of the Case Study

The Inkomati-Usuthu Water Management Area (IUWMA), located in South Africa, includes several adjacent river catchments and borders on the countries of Mozambique and Eswatini. These catchments drain in an easterly direction and later converge to form the Inkomati and Usuthu rivers in Mozambique and Eswatini, respectively. The Usuthu river subsequently becomes the Maputo river in Mozambique (**Error! Reference source not found.**29).

The dominant economic activities within this river basin are agriculture, eco-tourism, forestry and mining, which are critical for ensuring energy security, food security, and livelihoods. Several of these activities, however, pose a threat to water quality and water availability. This water management area also contains critical conservation areas, such as the southern portion of the Kruger National Park. Irrigated agriculture and forestry provide about 60% of the jobs in this region, and use most of the water, with 31% and 21% being utilised for irrigation and forestry, respectively (IUCMA APP 2020).

Based on the spatial data associated with the 2011 Census (StatsSA 2011) together with the 2021 Mid-year population estimates (StatsSA 2021), the population in the IUWMA was estimated to be 2.3 million in 2021, consisting of an urban, semi-urban and rural areas. In 2012 it was estimated that the Gross Geographic Product (GGP) of the IUWMA was approximately 9 billion Rand yr^{-1}, contributing to about 0.3% of South Africa's Gross Domestic Product (GDP) (DWAF, 2012). The manufacturing and mining sectors were the most significant contributors.

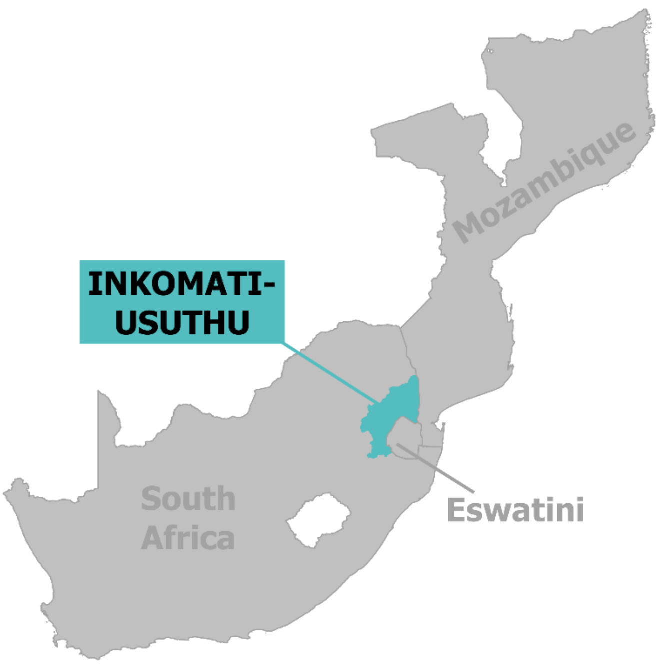

Figure 29: Location of the Inkomati-Usuthu case study

The main challenge relates to the close links between energy, food and water security. Coal mining and agriculture in the basin are critical for ensuring to ensure energy and food security, respectively, but jeopardize water quality and water availability for all users. Climate change is expected to exacerbate resource sector challenges and threatens economic development, making it more difficult for the three neighbouring countries to meet sustainable development objectives. As the river flows through three countries, its management requires transboundary considerations. Furthermore, inequalities still exist in South African society, and livelihoods (equal access to resources) must be incorporated into the nexus assessment of this case study whereever possible.

4.5.2 Description of the conceptual map

4.5.2.1 High-level map

The high-level conceptual WEFE nexus map for the Inkomati-Usuthu case study is shown in Figure 30. As with the other high-level maps, only the major connections between nexus sectors are shown, with the details appearing in the sectoral sub-maps. Population drives water, energy and food demand. The energy, ecosystems, and food production sectors affect the climate sector, which in turn impacts back on all sectors. There are bi-directional (i.e. feedback) links between energy and water, energy and food, and food and water, to name a few. For example, energy is used in the food-producing sector, and biomass contributes to the generation of energy. The details of the linkage mechanisms are outlined in the following sections.

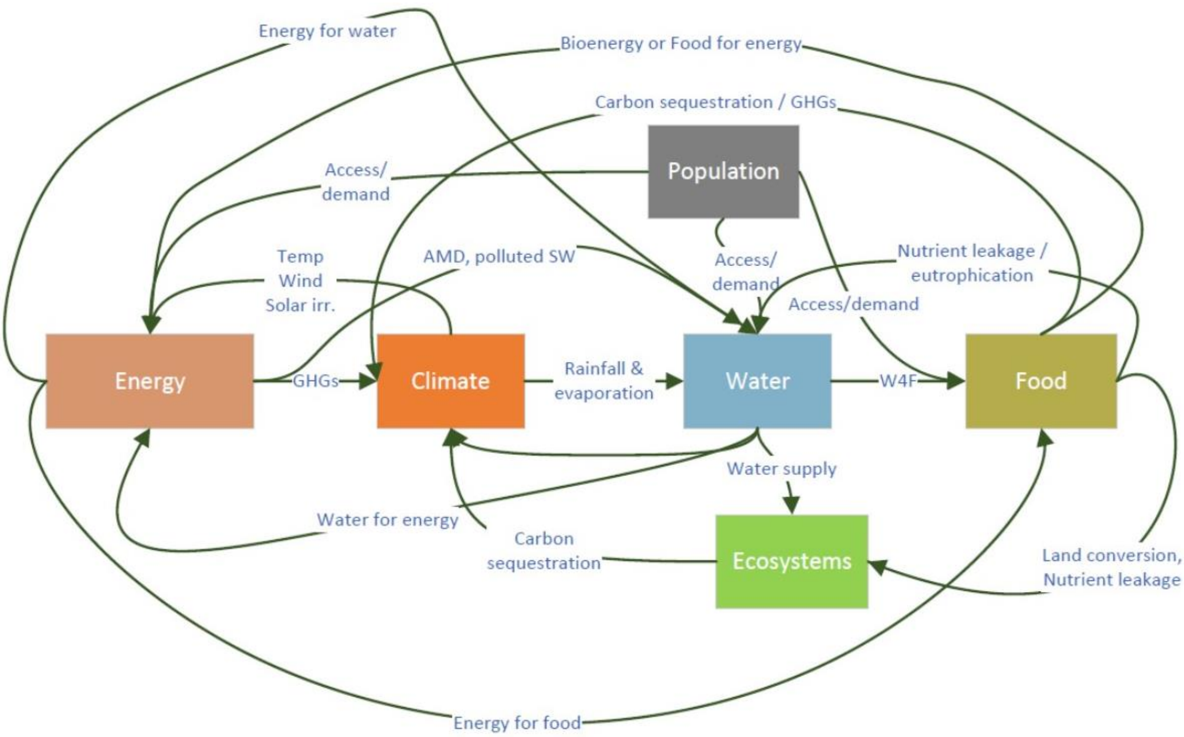

Figure 30: High-level conceptual map for the Inkomati-Usuthu case study.

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4.5.2.2 Water sector map

Figure 31 shows the water sector map for the Inkomati-Usuthu case study. Quantity and quality are emphasised, and water resources are overallocated in the basin. Water is sourced primarily from groundwater and surface water resources (via accumulation in reservoirs behind dams), and is thus modulated by climate changes. Some of this water is required for transboundary flow requirements. Water is consumed by a wide range of economic sectors, with irrigated agriculture and, uniquely in NEXOGENESIS, mining activities featuring prominently as large water users. Food production and mining alter land use and ecosystems, which then impact on water quality characteristics and the climate. There is also the issue of diffuse pollution of untreated wastewater from informal settlements and poorly functioning wastewater treatment plants. The mechanisms forming the interconnections are detailed in the arrows in Figure 31.

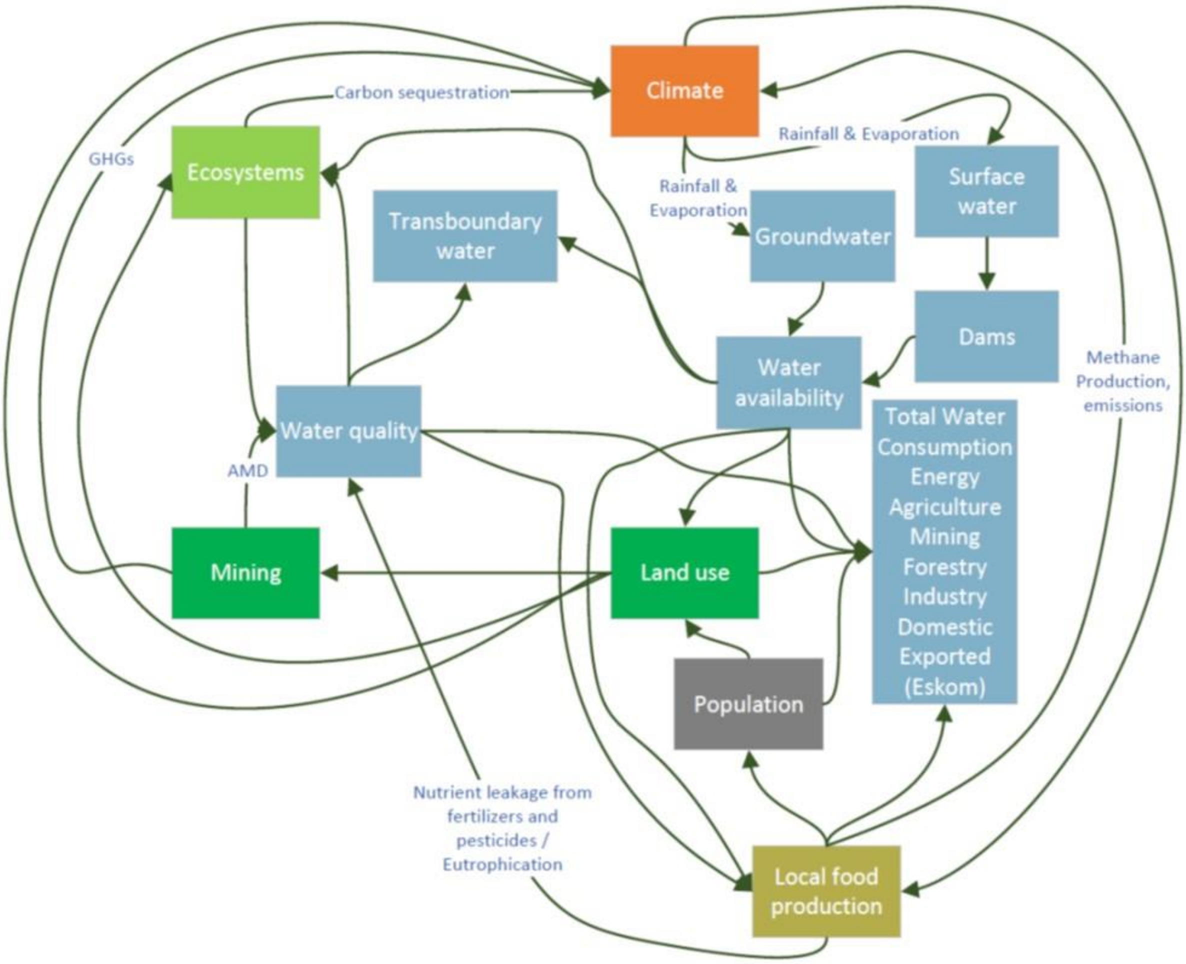

Figure 31: Water sector map of the Inkomati-Usuthu case study.

4.5.2.3 Food sector map

The Inkomati-Usuthu food sector conceptual map is shown in Figure 32. Food is produced from rainfed and irrigated agriculture, and there is also livestock rearing in the basin. Water

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quantity and quality affect food production. Food production itself alters the use of land, hence the connection to the land use component of the conceptual map. The amount of local food demand, and thus of land needed to satisfy local demand, is driven by the local population in the basin. Changes in food production affect the amount of energy consumed in the agricultural sector, and also the amount of direct emissions from livestock. This energy demand and emissions from livestock impact on the climate through the generation of GHG emissions. Interestingly, many larger farmers are energy-independent through the development of solar power on their farms. Finally, nutrient and pesticide applications, energy demand, and changes in land use characteristics can all have impacts on the local ecosystems, especially the fragile Kruger National Park. There are clear trade-offs between land used for food production, energy sourcing (i.e. mining), and ecosystems. The mechanisms forming the interconnections are detailed in the arrows in Figure 32.

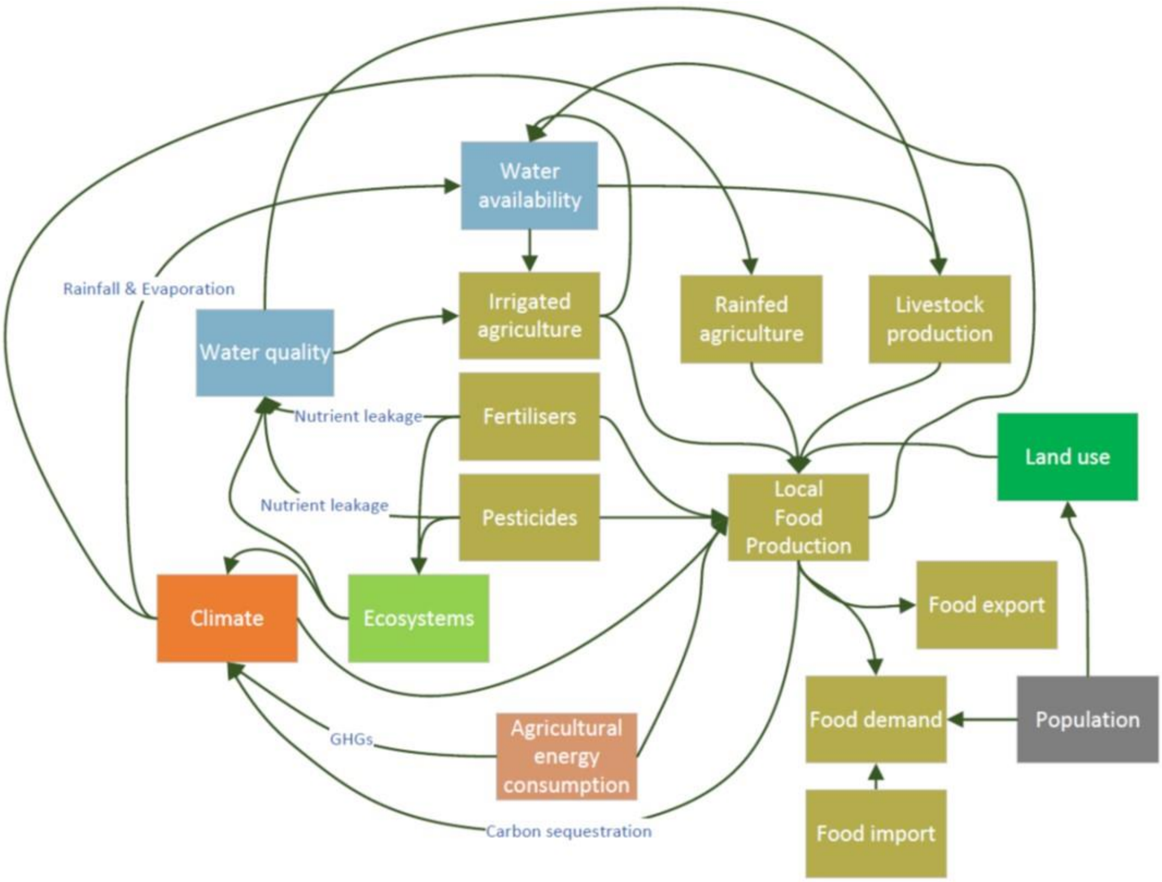

Figure 32: Food sector map of the Inkomati-Usuthu case study.

4.5.2.4 Energy sector map

The Inkomati-Usuthu energy sector map is shown in Figure 33. Here, recognition is made of the fact that most energy is sourced from outside the study area, but used within the study area, thereby contributing to climate impacts. There is no grid-based energy generation within the IUWMA. Population changes drive energy demand. Energy is produced from both renewable sources, which tend to be off-grid, and non-renewable sources (e.g. from coal-fired power stations, with considerable climate, land, and ecosystems impacts). Energy is shown to

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be consumed by many economic sectors. Challenges relate to boosting renewable sources, and creating energy storage solutions for more reliable supply.

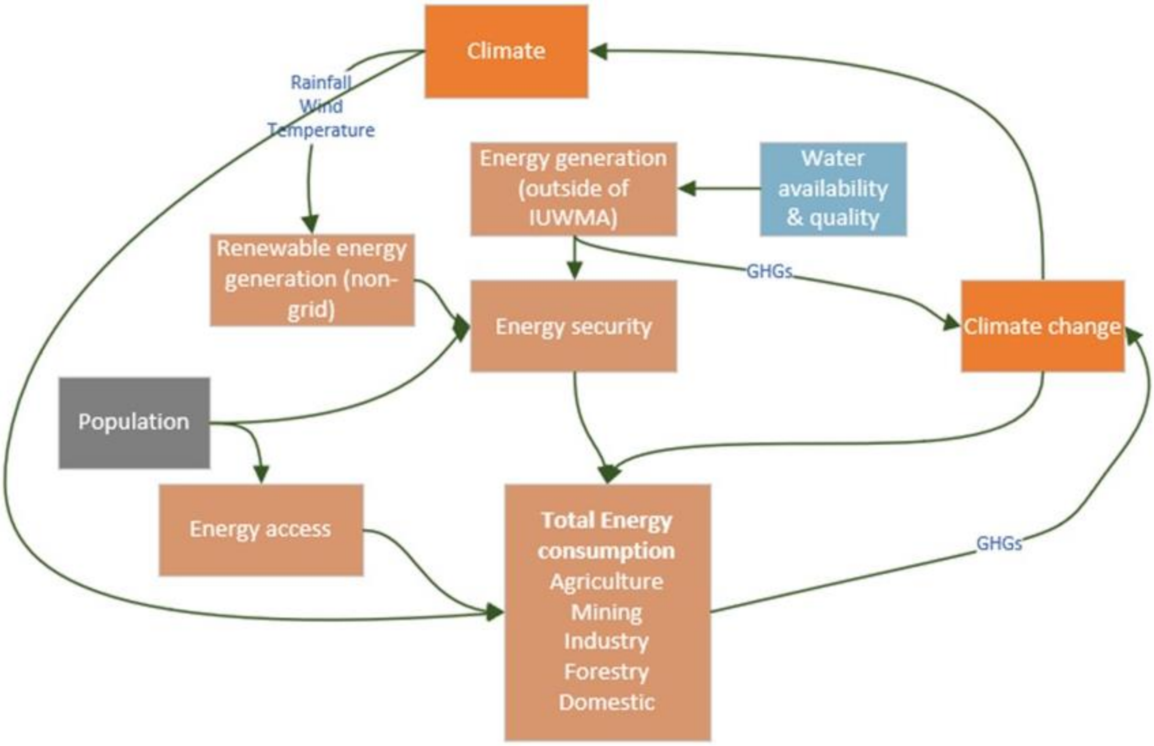

Figure 33: Energy sector map of the Inkomati-Usuthu case study.

4.5.2.5 Ecosystems map

The final sectoral conceptual map for the Inkomati-Usuthu case study is for ecosystems (Figure 34), which are critically important in the case study. They are impacted by, and impact upon, several nexus sectors. Biodiversity, biomass, wetland water storage, forestry, and food production all impact to some degree on ecosystems, either directly, or indirectly by altering land use patterns and patterns of nutrient and pollutant loads to ecosystems (via water bodies). Ecosystems are impacted by climate change, but can also meditate climate impacts by sequestering GHGs for example. Changes in water quality characteristics (e.g. by changes in agricultural management practices and leakage from mining sites) also affect ecosystems and their services, and this is indeed critical within this case study. Finally, the coal mining sector, important economically and for power generation, plays a significant local role in affecting fragile ecosystems, thus representing a substantial trade-off in the study area. Figure 34 also hints at some of the indices which may be used to track ecosystems in the Inkomati-Usuthu NEXOGENESIS case study.

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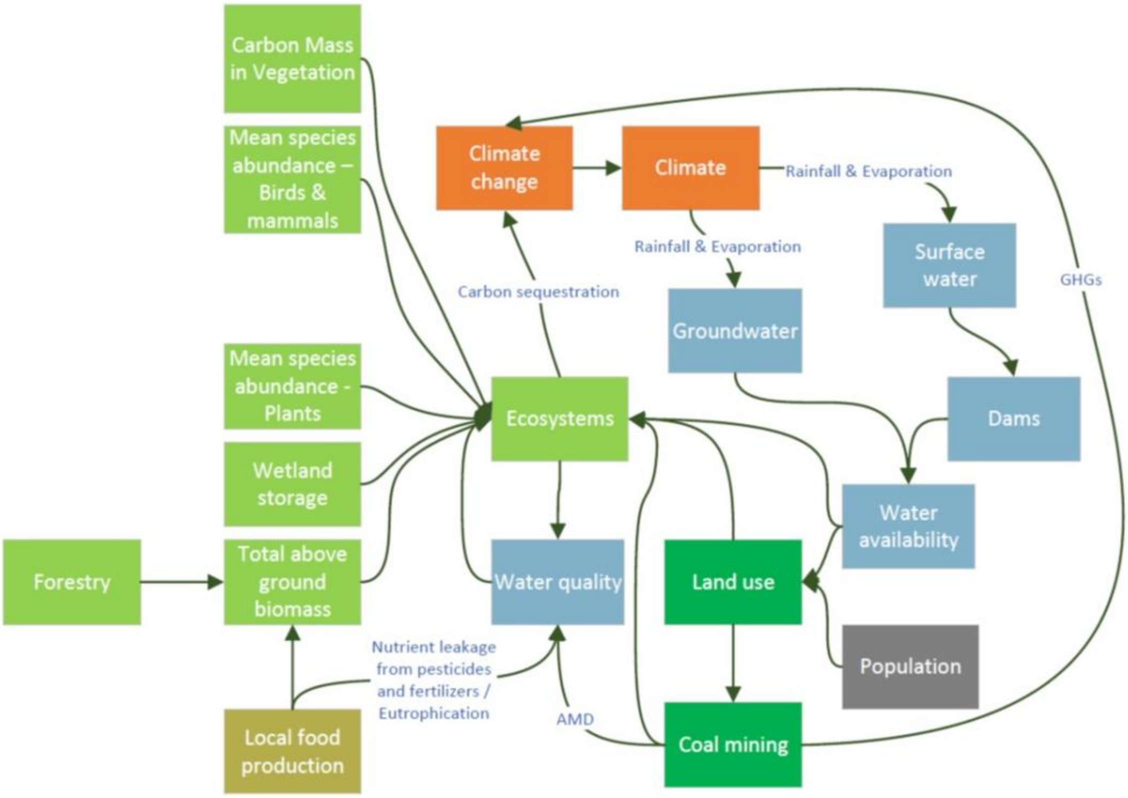

Figure 34: Ecosystems sector map of the Inkomati-Usuthu case study.

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5. Contribution to the next steps in the NEXOGENESIS modelling chain

The conceptual maps in NEXOGENESIS form an early part of the whole complexity science modelling process, and are critical to the success of the rest of the modelling in NEXOGENESIS. As they are developed in close cooperation with local stakeholder groups (via the work of the Case Study leads and through the local stakeholder workshops in which the conceptual maps have been presented, discussed, and revised), the intention is that the quantitative models and the results from the SLNAE will have more relevance for these stakeholder groups. Stakeholders have been involved in conceptual map design and the integration of suitable policies for consideration into the maps. Therefore, results and recommendations are hoped to be of greater practical relevance, promoting uptake of NEXOGENESIS findings, as well as the development and implementation of national and EU environmental policies.

The next stage in the modelling process is to develop causal loop diagrams (CLDs; Ford, 2009), which are extensions of conceptual maps. CLDs seek to add information to the conceptual maps, and are to be seen as a simple one-to-one translation. Firstly, they simplify the conceptual maps to indicate the main causal relationships in the systems. As such, when developing the CLDs, extraneous details, and very specific details relevant to the case studies, can be removed without loss of essential causal information. What this means, is that the CLDs to be developed will not necessarily have as many 'components' as the conceptual maps presented in this deliverable. As a simple example, in this Deliverable, in some case studies, energy demand may be broken down by energy type and/or economic sector (i.e. who is using the energy). In a CLD, a simplified causal relationship between, for example, population, socio-economics, and energy demand per-capita, would suffice to capture the relevant causal information – the detailed breakdown is unnecessary.

CLDs give more explicit detail about causal connections between system elements, including the polarity of individual connections and the polarity of whole feedback loops. For individual loops, connections are indicated with a "+" sign if a variable B changes in the same direction as the change in variable A. negative polarity is indicated with a "-" sign, and indicates that variable B changes in the *opposite* direction as variable A. Elements can be linked to form closed feedback loops. If in a loop there are no "-" connections, or an even number of "-" connections, the feedback loop is positive ("+"), which may result in runaway behaviour (e.g. exponential growth). If a loop has one or any number odd number of "-" connections, then the loop is negative ("-"), which results in dampened or goal-seeking behaviour (e.g. oscillation around a mean or target value). CLDs, including a full explanation, and their development for all NEXOGENESIS case studies, are given in NEXOGENESIS Milestone 11 (M17).

The following stage in which the conceptual maps are important in NEXOGENESIS is in the guidance of the development of quantitative system dynamics models (SDMs; Sterman, 2000; Ford, 2009). The case study SDMs will be developed to mimic, as closely as possible, the conceptual maps in order to account for all relevant nexus connections and integration of policies identified. This work will be carried out in close cooperation with WP2 to identify data

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availability. Connections and/or variables for which no data exist, or which cannot be quantitatively represented may be omitted or amended from the conceptual map representation. This will be done on a case-by-case basis. It will be crucial to integrate as many identified policies as possible to assess their nexus-wide impacts upon potential implementation. The SDM prototypes will be reported in Deliverable 3.4 (M23). The SDMs form the basis for the development of the SLNAE to be implemented by WP4.

It is obvious that the conceptual maps are a key part of the whole NEXOGENESIS modelling process. It is important therefore that considerable effort was put into this stage in the project, and the wide stakeholder groups were involved in their development so as to capture pertinent issues, relevant policies to include, and to promote the eventual uptake of NEXOGENESIS policy recommendations emanating from the models (as stakeholders have played in role in conceptual nexus map development, policy selection, and will also discuss and validate modelling results later in the project, with opportunity for feedback and correction of modelling efforts as required. This Deliverable therefore serves to demonstrate the development of the conceptual maps, which will be taken forward through the rest of NEXOGENESIS, and aim to contribute to the successful implementation of the SLNAE and the development of sound policy recommendations in all the project Case Studies.

In conclusion, these maps show the added value in qualitatively assessing resource nexus connections. This is a similar conclusion to that drawn by Purwanto et al. (2019). By engaging case study leaders and stakeholders in these conceptual mapping exercises, they are encouraged to adopt a systems-thinking approach to resource management and policy design, going beyond traditional sectoral siloes. Inter-departmental discussions can be promoted. Stakeholders often become more aware of the wider impacts of sectorally-developed policies/objectives. By adopting a systems-thinking attitude, and by engaging in dialogue with other resource sectors, potential trade-offs and bottlenecks can be more easily identified and mapped, and solutions discussed. Likewise, synergies (where policies support each other's' ambitions) can also be identified and leveraged. This process means that significant progress can be made without recourse to quantitative modelling. At the same time, this process supports the quantitative modelling in NEXOGENESIS. As stakeholders are already invested at this stage, and have offered input and advice, future model and assessment-engine outcomes are more likely to be engaged with and proposed solutions considered for real-world implementation. This approach is replicable to many other locations, and is not context dependant.

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