NEXOGENESIS
STREAMLINING WATER RELATED POLICIES

D1.5 Consolidated nexus governance framework & guidance for co-creation of nexus governance

Lead: UFZ

Due Date: 31/08/2025

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Project Deliverable

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

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D1.5 Consolidated nexus governance framework and guidance for co-creation of nexus governance

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Abstract

The purpose of Deliverable 1.5 is to present a revised (improved) version of the original stakeholders´ co-creation approach for water-energy-food-ecosystem (WEFE) nexus governance, which was developed in 2021 and reported in D1.1. The approach was conceptualized to move stakeholders through a structured process of defining nexus resource management and governance challenges, developing advanced (state-of-the-art) complexity science and AI tools to understand nexus system dynamics and explore the complexity of the policy solution space, and developing 'whole-of-society' pathways towards improved nexus governance arrangements. The version of the approach presented now directly incorporates the lessons learned from the implementation of the co-creation approach over the 4-years of the project, in 5-case studies. This is presented as a 'guidance' which codifies, step-by-step, the implementation of the approach – thereby facilitating the replication of the approach. Accompanying this are guidelines for outscaling the approach – which captures high-level advice on strategic implementation issues. The target audience of this report is any organisation at all scales in the WEFE nexus domains that would like to initiate a bottom-up stakeholders' co-creation process for improving policy integration and foster transition towards WEFE nexus governance, with a particular focus on water management organisations such as river basin organisations, including transboundary ones, water and environment ministries and water utilities.

Keywords

Water-Energy-Food-Ecosystems (WEFE), nexus governance, stakeholder co-creation, transdisciplinarity, artificial intelligence, policy optimization, system dynamics modelling, biophysical and socio-economic projections, governance roadmaps, stakeholder agreement,

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ACRONYMS & ABBREVIATIONS

AI	Artificial Intelligence
CFNG	Co-creation Framework for Nexus Governance
Cf	Conflict (relationship)
CGE	Computable General Equilibrium (model)
CLD	Causal Loop Diagrams
Cm	Complementary (relationship)
CMIP	Coupled Model Intercomparison Project
CORDEX	COordinated Regional climate Downscaling EXperiment
CORINE	CORINE (Coordination of Information on the Environment) Land Cover
Cp	Cooperation (relationship)
CS3	Copernicus Climate Change Service
D1.1, D1.2, etc.	Deliverable 1.1, Deliverable 1.2, etc.
DSS	Decision support system
EC	European Commission
EU	European Union
FAO	Food & Agriculture Organisation of the United Nations
FPIC	Free, Prior & Informed Consent
GAT	Governance Assessment Tool
GCM	Global Circulation Models
GDP	Gross Domestic Product
G-RDEM	Global Recursive Dynamic Model
GRDC	Global Runoff Data Centre
GTAP	Global Trade Analysis Project
GLOBIO	Global biodiversity model for policy support
ILK	Indigenous and Local Knowledge
IPCC	Intergovernmental Panel on Climate Change
IPLC	Indigenous Peoples and Local Communities
IIASA	International Institute for Applied Systems Analysis
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
KERs	Key Exploitable Deliverables
LUH2	Land-Use Harmonization (project)
LPJmL	Lund-Potsdam-Jena managed Land model
MAGNET	Modular Applied GeNeral Equilibrium Tool
ML	Machine Learning
NE	Non-existent (relationship)
NEPAT	NExus Policy Assessment Tool
NXG	NEXOGENESIS (project)
NXGAT	Nexus Governance Assessment Tool
PI	Power-Interest
PCAT	Policy Coherence Assessment Tool
RCP	Representative Concentration Pathway

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REST API	REpresentational State Transfer Application Protocol Interface
RL	Reinforcement Learning
SAM	Global Social Accounting Matrix
SD	Systems Dynamics
SDM	System Dynamic Modelling / Models
SHE	Stakeholder Engagement
SIMETAW-GIS	Simulation of Evapotranspiration of Applied Water – GIS (platform)
SDGs	Sustainable Development Goals
SFD	Stock-and-Flow (diagram)
SHE	Stakeholder Engagement
SPF	Simulation Policy Framework
SSP	Shared Socioeconomic Pathways
SVPP	Stakeholder Validated Policy Packages
T1.1, T1.2, etc.	Task 1.1, Task 1.2, etc.
ToC	Theory of Change
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
WEFE	Water-energy-food-ecosystem
WP	Work Package

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Part 1. Executive Summary

The NEXOGENESIS (NXG) project strengthened governance across the Water-Energy-Food-Ecosystems (WEFE) nexus by developing and testing three solutions: an AI-driven Nexus Policy Assessment Tool (NEPAT), a WEFE Nexus Footprint for sustainability monitoring, and a cross-sectoral policy-making framework. Implemented over four years in five river basins across Europe and Africa (Adige, Inkomati-Usuthu, Jiu, Lielupe, and Nestos/Mesta), the project applied a structured stakeholder co-creation approach that integrated scientific and experiential knowledge and complexity science and artificial intelligence tools, to disentangle complex nexus dynamics, explore optimized policy solutions, and design actionable governance pathways.

This Deliverable presents the revised Co-Creation Framework for Nexus Governance (CFNG), which consolidates the original five "Building Blocks" into three coherent and progressive phases—Co-Explore, Co-Design, and Co-Develop—making the framework more accessible for practitioners. These phases guide understanding of local governance challenges, engagement of stakeholders in shaping technical outputs and policy options, and joint development of solutions that promote ownership and long-term integrated governance. Co-Explore focuses on building shared understanding of the nexus, mapping stakeholders to engage, and identifying governance gaps. Co-Design focuses on developing complexity science tools to analyse nexus dynamics and is the phase in which stakeholders actively shape technical content and outputs. Co-Develop involves deliberating on optimal policy solutions with the assistance of AI and plotting implementation pathways. This participatory approach ensures that solutions are rigorous, relevant, and actionable.

Across diverse contexts, the CFNG has proven replicable and adaptable. Successful scaling requires transdisciplinary capacity, robust stakeholder engagement, open data practices, and deliberate case-study design. Capacity-building is central to sustaining collaborative governance, equipping stakeholders with the skills needed for negotiation, facilitation, and evidence-informed decision-making beyond the project lifecycle. Multi-case applications highlight the potential for cross-learning while also underlining the importance of careful coordination and resource planning. The CFNG's modular design, which supports selective adoption of methods to meet local contextual needs and priorities, helps to manage these requirements effectively.

Overall, the CFNG is a tested, evolving approach that fosters systemic nexus thinking and inclusive decision-making for integrated resource management in varied socio-ecological contexts. This deliverable codifies the CFNG, step-by-step, as it was implemented in NXG. It directly integrates the lessons learned at the finer-grained methodological scale and the consortium's recommendations for improved strategic implementation at the broader level. It is presented in a guidebook format aimed at organizations—particularly water management bodies, ministries, and transboundary authorities—seeking to initiate stakeholder-driven processes for integrated WEFE nexus governance and sustainable resource management.

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Part 2. Introduction

2.1 Project Summary

Water, energy, food, and ecosystems (WEFE) are interconnected components of a coherent and complex system (nexus). Changes in biophysical conditions (e.g. climate, land cover) and socio-economic drivers (e.g. economic development, agriculture, urban growth) continuously reshape the WEFE resource nexus. These shifts influence actor behavior and, in turn, policy decisions on how to manage resources. Currently, resource consumption is outpacing ecological limits, leading to deepening resource and ecological deficits. Because resources are interdependent, constraints in one area can ripple through others and ultimately limit economic and social development. As an example, expanding hydropower in a transboundary river basin alters river flows, reduces irrigation water availability, drives groundwater overuse and higher energy demand, and degrades wetlands and fisheries. The resulting trade-offs affect food security, ecosystem integrity, and cross-border relations, and are further amplified by climate variability.

Yet, the prevailing practice of developing sector policies in isolation overlooks these linkages. The result is inefficient resource use, uncertainty over future effectiveness, greater risk of counterproductive results, and, at times, conflict among stakeholders — as trade-offs and synergies are not adequately addressed in decision-making.

Managing the WEFE nexus is challenging due to both its inherent complexity, limited understanding of how policies interact across sectors and the extremely wide policy space that should be explored to find the best solutions. Recent advances in complexity science and artificial intelligence tools now provide opportunities to better assess multiple policy interactions and impacts and design more integrated, intelligent policies across sectors and scales.

The NEXOGENESIS (NXG) project aimed to improve governance across the WEFE nexus by developing and testing three key solutions:

- **Coherent cross-sectoral policy-making framework:** An analytical framework for addressing climate and socio-economic change, stakeholder behaviour, and transboundary issues
- **NExus Policy Assessment Tool (NEPAT):** An artificial intelligence-driven tool that identifies policy combinations to maximize nexus performance
- **WEFE Nexus Footprint:** A composite indicator, accompanying NEPAT, designed to monitor the sustainability of resource management.

These solutions were developed and tested over four years across five diverse case studies: Adige River basin (Italy), Inkomati-Usuthu River basin (South Africa), Jiu River basin (Romania), Lielupe River basin (Latvia & Lithuania), and Nestos/Mesta River basin (Greece & Bulgaria).

The project applied a structured stakeholder co-creation approach in which researchers and case-study leads worked alongside local stakeholders to address tasks such as understanding nexus interlinkages, developing models to describe the nexus, evaluating policy impacts, and exploring possible integrated governance mechanisms. The initial stakeholder co-creation framework was designed to be revised based on lessons learned from its testing in local contexts and to support the out-scaling of methodologies and tools to other settings. Accordingly, this deliverable presents the

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improved co-creation framework for nexus governance, consolidated with insights from four years of implementation across the five case studies.

The purpose of this deliverable is to present the revised Co-Creation Framework for Nexus Governance (CFNG), codifying the approach step-by-step and embedding lessons learned from its operationalization. The framework is intended as a guideline, adaptable to local contexts, consolidating all NXG activities and processes, and providing recommendations for replication and outscaling.

This deliverable is organized as follows:

- **Chapter 1: Introduction** – Overview of the case studies and the original co-creation framework for nexus governance, previously presented in Hüesker et al., 2022 (NXG D1.1).

- **Chapter 2: Conceptual and Analytical Framework** – Outline the approach applied to codifying the CFNG and integrating lessons learned;

- **Chapter 3: Co-Creation Framework for Nexus Governance** – The revised CFNG, codified step-by-step with improvements integrated, presented in a guidebook format for policymakers, NGOs, practitioners and researchers seeking to initiate and test bottom-up stakeholder co-creation processes for integrated WEFE nexus governance.

- **Chapter 4: Guidelines for Replication and Outscaling the CFNG** – Synthesized strategic advice for replication and broader application, with emphasis on water management organizations, river basin authorities, transboundary bodies, ministries, and utilities.

Therefore, this deliverable provides practitioners with a tested, adaptable roadmap for implementing stakeholder-driven processes to achieve integrated governance across the WEFE nexus.

2.2 Case Studies

The five NXG case-studies are located in different geographical areas (Figure 1) and each of them addressed different nexus issues. The case studies have diverse spatial, social, political, cultural, and history of development challenges. They also feature strong WEFE nexus relations, with the potential for disruption from policy implementation. Accordingly, they allowed for an assessment of how WEFE-related policy can be streamlined into the nexus.

Two of the case-studies, Nestos and Lielupe, were “frontrunners,” which means that they conducted case study activities slightly earlier (ca. 2 months) than the other three case-studies (Adige, Jiu, Inkomati-Usuthu). This was to identify potential problems, redundancy or shortcuts in the applied methodology so these could then be adjusted accordingly.

Application of coherent approaches throughout the project enabled synthesis and comparison of the experiences and lessons learned in the cases. The use of a similar approach in each case-study aimed to foster the exchange of ideas and experiences among them, to allow for broader comparative conclusions and recommendations. The piloting of this coherent co-creation framework in the diversity of cases has demonstrated suitability for its wider out-scaling to other regions globally.

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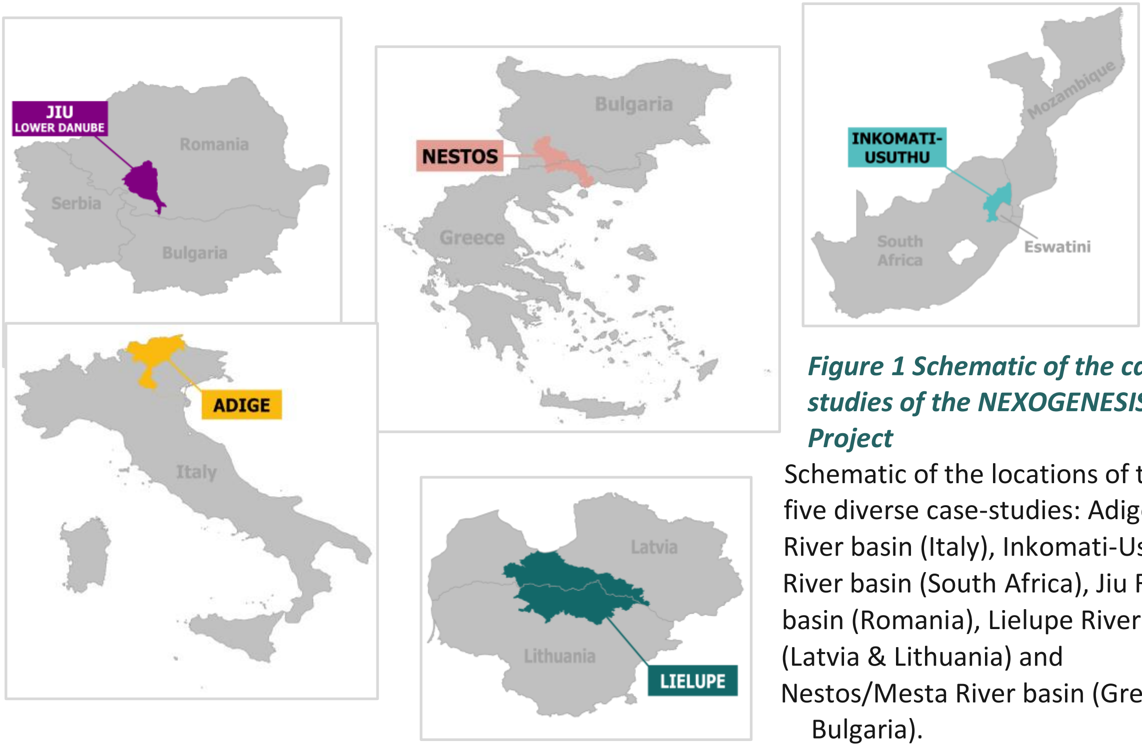

Figure 1 Schematic of the case-studies of the NEXOGENESIS Project
Schematic of the locations of the five diverse case-studies: Adige River basin (Italy), Inkomati-Usuthu River basin (South Africa), Jiu River basin (Romania), Lielupe River basin (Latvia & Lithuania) and Nestos/Mesta River basin (Greece & Bulgaria).

The Nestos/Mesta River Basin comprises the Nestos/Mesta River basin shared between Greece and Bulgaria. The Nestos/Mesta River springs from the Rila Mountains (BG) and discharges in the Thracian Sea (GR). Its basin area is approximately equal to 5,479 km2 and its length is about 243 km. The river forms a significant ecosystem throughout its course and its delta is a unique ecosystem protected by the Ramsar Convention and considered as a first priority site under EU Natura 2000. Two dams operate in the Greek part of the basin (downstream) which are mainly used for electricity production purposes, covering also irrigation needs. The main activities supporting local income are agriculture and livestock. ***More information about the Nestos/Mesta Case-Study***

The Lielupe River Basin is in North-Eastern Europe and includes the 17,788 km2 Lielupe river basin shared between Latvia and Lithuania and is situated in the lowland part of the countries. Around 12% of Latvian population and around 11% of Lithuanian population live in this territory (altogether around 800 000 inhabitants). The basin is predominantly used for agriculture (ca. 60%) but also includes large areas of forests (ca. 30%) and some 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 significantly contributing to the economy of the region. Other economic activities in Lielupe CS relate to trade and transport services, as well as the processing industry and public services. Agriculture has intensified over the past decades at the cost of natural grassland habitats. During the last decade the area of croplands has increased while meadows and pastures have been reduced. The development prognosis indicate that these trends will be maintained and coupled with increased volumes of fertilisers utilised in line with intensification of agriculture. ***More information about the Lielupe River Basin case-study.***

The Lower Danube CS is focused on the 16,759 km2 **Jiu River Basin** in Romania, a sub-basin of the Danube River, aiming to explore interconnection and replicability crossborder in Serbia and Bulgaria. The Jiu River flows from the Romanian Carpathian Mountains southwards through several counties before it discharges into the Danube at Zaval, the Romanian- Bulgarian border near the Bulgarian city of Oryahovo. The basin is mainly characterised by arable land (48%), forest (30%) and pastures (9%). Population in the upstream mountain areas of the basin rely on the coal mining industry with lignite-

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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 (e.g. dams) along the Danube stimulated erosion and negatively affected the riverbed, while floods and drought events continue to impact the region. ***More information about the Jiu River Basin Case-Study***

The **Inkomati-Usuthu River Basin** comprises the Inkomati-Usuthu Water Management Area, which in turn includes several parallel river catchments in South Africa and Swaziland (now known as Eswatini), which later converge to form the Inkomati river at the border with (or within) Mozambique and later flow into the Indian Ocean. The river basin is located downstream of mining activities and contains high potential agricultural land as well as conservation areas, including the southern portion of the Kruger National Park. Thus, the basin is vital to South Africa's development, in particular relating to energy security (coal-fired power stations), food security (almost half of the country's high potential agricultural land) and water security (numerous competing water users). *More information about the Inkomati-Usuthu Case-Study*

The **Adige River Basin** spans over Italy's second-longest river: the 409 km long Adige River that comprises a river basin area of 12,100 km2. It flows from its source in the Italian Alps through six provinces in northern Italy before it reaches the Venetian Lagoon and flows into the Adriatic Sea. Within the Adige River basin, economic sectors historically developed on abundant water resources: e.g., 61 hydropower stations in the upper part of the basin produce energy exceeding the provincial energy demands, while the valleys in the upstream mountain provinces are characterised by the intensive apple orchards, which represent more than 15% of European apple production. In addition, winter and summer tourism play an important role in the mountain economy, with an annual population increase of 5-6 times the number of permanent residents. The lowlands, downstream of the province of Verona, are characterized by intensive cultivation, mainly including vineyards and cereals irrigated through water withdrawals. The regional park and its wetland ecosystems sustain fisheries, aquaculture and provide essential protection against saline intrusion and coastal erosion. Moreover, the delta has a high recreation value, being an important touristic destination. ***More information about the Adige Case-Study.***

2.3 Co-Creation Framework

The Co-Creation Framework for WEFE Nexus Governance (CFNG) supports stakeholders in a certain region (e.g. a river basin), or gathered around a commonly acknowledged challenge, to collaborate and commit to improved nexus governance. The originally designed CFNG (as presented in *NXG D1.1 - Stakeholders' co-creation approach for WEFE nexus governance*) included two steps:

1. **Nexus governance problem identification** via assessment of the performance of the existing governance system to identify barriers, leverages and entry points for governance and policy change, and assessment of policy coherence to identify policy gaps related to nexus interlinkages;

2. **Stakeholders' co-creation of WEFE goals and policies** and commitment to implementation through a stakeholder agreement -- operationalised in **five building blocks**:

    - **Preparing the stakeholders' co-creation process**: stakeholder identification and analysis;

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- **Initiating the stakeholders' co-creation process**: interaction between the stakeholders of different sectors, awareness raising, setting the stage and data collection;

- **Facilitating the stakeholders' co-creation process**: stakeholder engagement, management and sustainment for trust building and social learning throughout the project;

- **Developing the stakeholders' co-creation content**: designing an action plan and ensuring coordination with existing policies;

- I**mplementing the stakeholders´ agreement**: fostering stakeholders´ ownership of the action plan, and monitoring of the planned implementation.

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Part 3. Conceptual & Analytical Co-Creation Framework

3.1 Methodology of consolidating the co-creation framework for nexus governance

The overarching methodological steps that were used to produce this deliverable align with the requirements of Task 1.5 in the NXG Grant Agreement "*Consolidation of co-creation framework for the nexus governance: guidelines for design and implementation.*" The steps were:

1. Compare the implementation of the initial co-creation framework for nexus governance (CFNG) (proposed in D1.1) in the case-studies and extract lessons learned;
2. Compare the implementation of the initial CFNG amongst the NXG work packages and extract lessons learned in implementing a transdisciplinary project;
3. Review of the initial CFNG in light of lessons learned that were extracted from step #1 and step # 2 above. Revise the initial framework accordingly;
4. Based on the results of step #3 above, deliver a guidance that codifies the revised and improved CNFG in detail, so as to be reproducible in other contexts;
5. Extract specific lessons learned for the benefit of water organisations such as river basin authorities, ministries of water and environment, transboundary river organizations, water utilities – thereby providing the water sector with an approach to foster a holistic WEFE nexus resources management.

To this end, we reviewed an extensive repository of data, listed below in Sub-section 2.2.1 (Data Sources) to collect information on step #1, step #2 and step #5 (listed above). In **Part 4**, we present the **revised and improved CFNG as a "guidance"** (responding to step # 3 and step #4 - listed above) that can be adopted for implementation in future case-studies (i.e., for replication).

Part 5 responds to step #5 – providing overarching, synthesized, **high-level advice** to the target audience, derived from cumulative insights, providing strategic guidance intended to inform practice broadly.

Part 4 and **Part 5** are presented as a **'guidance' for implementation of the CFNG** - for any organisation at all scales in the WEFE nexus domains that would like to initiate a bottom-up stakeholders' co-creation process for improved integrated management of WEFE resources. The target audience is water management organisations such as river basin organisations, including transboundary ones, water and environment ministries and water utilities. However, it should be noted that the CFNG can be adopted and led by stakeholders in other domains of the WEFE nexus (see Part 5 on Guidance for Outscaling).

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3.2 Steps for the consolidation of the CFNG

3.2.1 Approach

UFZ systematically reviewed deliverables and milestones for each work package (WP) (see 3.2.2 Data Sources – below) and documented:

- Overarching steps and operationalisation of tasks (as specified in the Grant Agreement)
- Challenges in implementing the tasks and learning lessons

Based on this review, UFZ codified the step-by-step process of how tasks were implemented in each WP, in a clear manner that allows for replication by an external audience. Learning lessons specific to the implementation of a method were integrated directly into the step-by-step instructions. Therefore, each chapter in Part 4 of this deliverable captures the overarching workflow and methodologies applied within a WP (see table below), that were necessary to realise the CFNG.

Chapter in Section 4 of D1.5	WP Methods and workflow
Chapter 1: Understanding the stakeholder landscape	WP5: Case study coordination WP6: Impact maximisation: communication, dissemination and exploitation of project results
Chapter 2: Understanding the governance landscape	WP1: Co-creation of WEFE nexus governance and water policy streamlining
Chapter 3: Biophysical and Socio-economic Future Scenarios	WP2: Biophysical-human modelling
Chapter 4: System Dynamics Modelling	WP3: Nexus System Thinking and Integration
Chapter 5: Nexus Policy Assessment & Stakeholder Validated Policy Packages	WP4: Nexus self-learning assessment engine development
Chapter 6: Governance Roadmaps and Stakeholder Agreements	WP1: Co-creation of WEFE nexus governance and water policy streamlining

At the final Consortium General Assembly in Latvia in July 2025, a reflection session was hosted by WP1 and WP5 on the co-creation process. The topic focused on the quality of the process and how this influenced the achievement of outcomes and stated NXG objectives, as per the grant agreement. There were 4 World Café tables, with representatives from all WPs, and discussions on:

- Policies identification, assessment and integration complexity science tools and the NEPAT
- Development of SDMs
- Integration of (forecast) data into the SDMs and the NEPAT
- NEPAT and WEFE Footprint development

The following questions structured the discussions:

- What went well? What was missing? What needs to be improved?
- What was achieved? To what degree did you achieve the objectives? What concrete results (outputs/outcomes) have you accomplished that support the objectives?

These discussions created a space for domain experts to explain complex concepts underlying their work, challenges encountered in implementing methods and the overarching co-creation approach, and propose improvements. Feedback specific to each WP was incorporated into the respective chapters for this deliverable.

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Also at the General Assembly, UFZ presented the NXG workflow (**Figure 2**) to validate the interlinkages of knowledge, inputs and outputs across WPs and the adoption of the phases - co-explore, co-design, co-explore – for the revised CFNG.

Post-General Assembly, consortium partners in each WP subsequently reviewed the representation of their work in their respective chapters, making adjustments as needed and desired. They also commented on intersections of their work with those of other WPs, as detailed in other chapters.

Broader lessons and reflections highlighting common, recurring themes from the implementation of the CFNG were extracted from selected deliverables, milestones, and other sources (see 3.2.2 Data Sources). These overarching, non-domain-specific lessons provide guidance for strategically designing and executing the CFNG to maximise impact and are summarized in Part 5 – Guidelines for Outscaling, with feedback from all WPs integrated.

3.2.2 Data Sources

The step-by-step implementation of the CFNG and accompanying lessons learned have been documented in project deliverables, project reports, internal consortium meetings and exploitation activities. These sources of data are used to construct the revised CFNG and are presented in the tables below, which indicate the type of information that was extracted from those sources:

- NXG project reports (milestones, deliverables): Tasks and methods implemented in the CFNG and consolidate the step-by-step codification (Table 1)
- NXG inter- and intra-work package meeting notes: Challenges faced, adaptive management strategies implemented and lessons learned (Table 2)
- NXG exploitation activities & outputs: Feedback from more science, policy, practice communities on CFNG & associated methods & tools (Table 3)

Table 1: NXG project reports reviewed for consolidation of CFNG. These deliverables and milestones of the NXG project were directly reviewed by UFZ to consolidate, step-by-step, the revised CFNG.*document is not (yet) publicly available*

Document	Topic	Information & insights gathered
WP1: Co-creation of WEFE nexus governance and water policy streamlining		
D1.1	Co-creation framework for nexus governance	Original co-creation framework proposed and implemented
D1.2	Governance & policy assessment in CSs	Method for conducting the nexus governance assessment and policy coherence assessment
D1.3*	Policies for the SLNAE (NEPAT)	Process for selection of policies to include in the SLNAE (NEPAT)
D1.4*	Governance roadmap & building blocks of a river contract in CSs	Method for creating governance roadmaps

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WP2: Biophysical-human modelling		
D2.1	Document information & consolidated data available according to specific nexus dimensions from large repository & Inter- Comparison projects	Explanation of global models and biophysical & socio-economic datasets
D2.2	Nexus data vector of biophysical data for each case study	Downscaling methods and data used for case-studies
D2.4	Socioeconomic data at grid level	
D2.5	Future Trends and Validation of biophysical data for uncertainty assessment	Method for retrospective analysis & uncertainty assessment
M7*	Delivery of documentation reporting data and information available to specific Nexus dimension	Explanation of global models and biophysical & socio-economic datasets
M16*	Interface of MagnetGrid with G-RDEM and DEMETRA	Method for downscaling of simulations
WP3: Nexus System Thinking and Integration		
D3.1	Conceptual models completed for all the case studies.	Conceptual model methodology
D3.2	Final report on the complexity science & integration methodologies	Explanation of systems dynamic modelling, chosen approach for SDMs
D3.3	Final report on application of biophysical models & stakeholder recommendations	
D3.4	Complexity science models implemented for all CSs: Prototypes & explanatory report/manual for each CS methodology	Method for developing causal loop diagrams and stock-and-flow diagrams
D3.5	Sensitivity & uncertainty analysis methodology	Methods for uncertainty and sensitivity analysis
D3.6	Sensitivity/Uncertainty Analysis Report.	
D3.7	Final report on the WEFE Nexus Index methodology & visualisation	Conceptualisation & methodology
WP4: Nexus self-learning assessment engine development		

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D4.1	Self-learning nexus engine specifications & technical design	• Theoretical background on using AI-agents for multi-objective problems • Design process for the NEPAT • Functionalities and capabilities of the NExus Policy Assessment Tool (NEPAT)
D4.3	Simulation policy framework	
D4.4	Core module of self-learning nexus engine	
D4.5	Final version of the self-assessment nexus engine with corresponding validation (NEPAT)	
WP5: Case study coordination		
M2 *	Roadmap for CS work/activities	Coordination activities across co-creation steps & methods which allow for smooth implementation of the framework and interaction across the WPs
M5 *	Internal communication strategy	Case-study preparations for workshops
M15, M23	First & second intermediate reports on co-creation activities across all five CSs	• Lessons learned from the implementation of stakeholder engagement strategy in CSs • “Stories of change” from case-study leads.
D 5.1 *	Report on stakeholder engagement	Stakeholder engagement methods and lessons learned from application in case-studies
D 5.7 *	Recommendations, experience, lessons learned from all CSs	Recommendations for future projects seeking to engage stakeholders in co-creation activities
WP6: Impact maximisation: communication, dissemination and exploitation of project results		
D 6.1 *	Communication strategy	Strategies & tools for supporting stakeholder engagement, raising awareness of nexus issues, maximizing project impact
D6.8	Internal and external exploitation workshop (first report).	Challenges and strategies in improving the uptake of project outputs by stakeholders during and post-project and therefore, amplifying project impact
D6.9	Internal and external exploitation workshop (second report).	

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D 6.11	Policy Impact strategy	• Tactics for local policy impact • Stories of change from case-studies • Adaptive management of stakeholder engagement strategies
D6.12	Policy Brief 1: Mainstreaming the WEFE Nexus into Policy Making.	Recommendations on implementation and outscaling a (WEFE) nexus-based governance approach in the EU policy landscape
D6.13 *	Policy Brief 2: Contribution to the EU Water Resilience Strategy	
D6.14*	Policy Brief 3: Lessons from 5 case studies to scale-up Smart WEFE Nexus Policies for a green & digital world	
WP7: Project Management and Coordination		
D7.4 *	First project periodic report to the EC + review comments	Internal reflection of accomplishments & challenges across different domain expertise and evolving recommendations for increasing policy impact through the CFNG External feedback on areas of strengths and improvements in methodologies and ideas of avenues for increasing policy impact
D7.5 *	Second project periodic report to the EC + review comments	

Table 2: NXG internal project meeting notes reviewed for consolidation of CFNG. *These are internal WP and consortium-wide meeting notes which captured challenges faced, adaptive management strategies implemented and lessons learned throughout the project.*

Meeting	WPs involved	Information & insights gathered
Consortium co-creation meetings (55 online meetings)	All WPs	Reflections on coordination of workflow, interdisciplinary knowledge exchange, adaptive management in response to evolving challenges, lessons learned
Coordination workshops (3 in-person workshops hosted by KWR, UFZ, NTUA)	WP1 & WP5	
General Assemblies (4 in-person meetings hosted by BEF, UNT, BDG, BEF)	All WPs	

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Official Interim Reporting Review Meetings with EU Project Officer	All WPs	Internal reflection of accomplishments & challenges across domain expertise and evolving recommendations for increasing policy impact through the CFNG External feedback on areas of strengths and improvements in methodologies and ideas of avenues for increasing policy impact
WP5 internal (online) meetings	Internal WP5	Challenges & lessons learned on case-study activities
WP3 internal (online) meetings	WP3 + WP1, WP5	Challenges & lessons learned on method development & implementation
WP4 internal (online) meetings	WP4 + WP1, WP5	

Table 3: NXG exploitation activities and outputs informing the consolidation of CFNG. *These are events, publications and media from which project activities were documented and feedback about project work was gathered from an external audience.*

Activity / Output	WPs involved	Information & insights gathered
External events: Dresden Nexus Conference (2025), Water Europe BlueDeal 2025 Conference (2025), GoNexus Final Conference (2025)	All WPs	Feedback from science, policy, practice communities on CFNG and its associated methods & tools
NXG Videos	All WPs	Reflections from consortium on CFNG implementation
Selected publications (scientific and grey)	All WPs	Methodologies applied in CFNG

3.3 Results & Reflections

Two overarching conclusions emerged from our reflections, regarding the structure of the CFNG:

Conclusion 1: The original conception of the **NXG workflow**, which is the backbone of the CFNG, was **methodologically sound**. There was coherence in the interdisciplinary interlinkages of the methods, inputs and outputs. Because of this, the workflow also delivered on stated objectives. Therefore, **no 'structural' changes are required; only some process improvements for efficiency and impact**. Accordingly, we have presented the workflow as was originally described in the CFNG of D1.1 (and therefore also aligned with the grant agreement).

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Conclusion 2: The CFNG was named and communicated in two different ways in WP1 and WP5, which led to bouts of miscommunications when planning the next stages of activities. In WP1, the CFNG is documented as in **D1.1 as** "**Building Blocks**" with a governance focus and in WP5, the CFNG is documented in **D5.1 as** "**Co-Creation**" and is stakeholder engagement focused. From this, some additional observations came to light:

- Both approaches structured the implementation of the CFNG in phases
- The approaches complemented each other, with the same steps for the implementation of the CFNG; however, they partitioned the steps into the implementation phases differently

To try to reconcile the approaches, we conducted an exercise of listing all steps in the Building Blocks approach, as documented in D1.1, according to their phase. We then mapped these steps to their corresponding in the Co-creation approach as document in D5.1. Table 4 below shows the results of the mapping exercise.

Table 4: Mapping of building blocks and co-creation approaches.

Five "Building Blocks" framework (methods & tools)	Equivalent phase of "Co-creation" framework
1: Preparing the stakeholders´ co-creation process: stakeholder identification and analysis;	
Stakeholder identification	Co-explore
Stakeholder analysis	Co-explore
Stakeholder engagement plan	Co-explore
2: Initiating the stakeholders' co-creation process: awareness raising, setting the stage and data collection;	
Raise awareness of project	Co-explore
Set stage for collaboration (project team & stakeholders)	Co-explore
Policy Coherence Assessment	Co-explore
Policy Inventory	Co-explore
Conceptual maps for SDMs	Co-design
Biophysical & socioeconomic data inventory	Co-explore
Nexus Governance Assessment	Co-explore
3: Facilitating the stakeholders´ co-creation process: stakeholder engagement plan, management and sustainment for trust building and social learning throughout the project;	
Stakeholder engagement plan (adaptions)	Co-design, Co-develop
4: Developing the stakeholders´ co-creation content: designing an action plan and ensuring coordination with existing policies;	
Validated policy inventory	Co-explore
Validated policy coherence assessment	Co-explore
Validated Nexus Governance Assessment	Co-explore
Preliminary & validated "policy packages" to input into NEPAT	Co-design
Validated SDM conceptual maps & causal loop diagrams	Co-design
Validated datasets for SDMs	Co-explore
Vision of common goals for project & river basin	Co-explore, co-design

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Governance roadmap (preliminary & validated)	Co-develop
Stakeholder validated policy packages	Co-develop
Stakeholder agreement (stakeholder validated policy packages, governance roadmaps, action plan)	Co-develop
Indicators for SDMs & WEFE Footprint (preliminary & validated)	Co-explore
Customisation of NEPAT user interface	Co-design
5: Implementing the stakeholders´ agreement: fostering stakeholders´ ownership of the action plan, and monitoring of the planned implementation.	
Stakeholder Agreement (action plan, roadmaps)	Co-develop

From this mapping exercise, the following observations

- The Building Blocks frame had a bit of redundancy in steps within the NXG workflow, thereby making it difficult to follow and communicate (for an external audience)

- The Co-Creation frame had a slightly clearer partitioning of steps within the NXG workflow, with some (expected) overlap during transition between the phases.

We decided to **apply the 'co-creation' approach** for communicating the revised CFNG for the following reasons:

- It is divided into only three phases (vs. 5 phases of the building blocks approach) - which makes it easier to understand. This reduces potential for confusion in project coordination and communication activities.

- The terminology (co-explore, co-design, co-develop) aligns with the co-creation theme, thereby creating coherency in communication to stakeholders and to the science-policy-practice community.

Accordingly, **Figure 2** below presents the validated NXG workflow and how it is framed within the Co-Creation phases.

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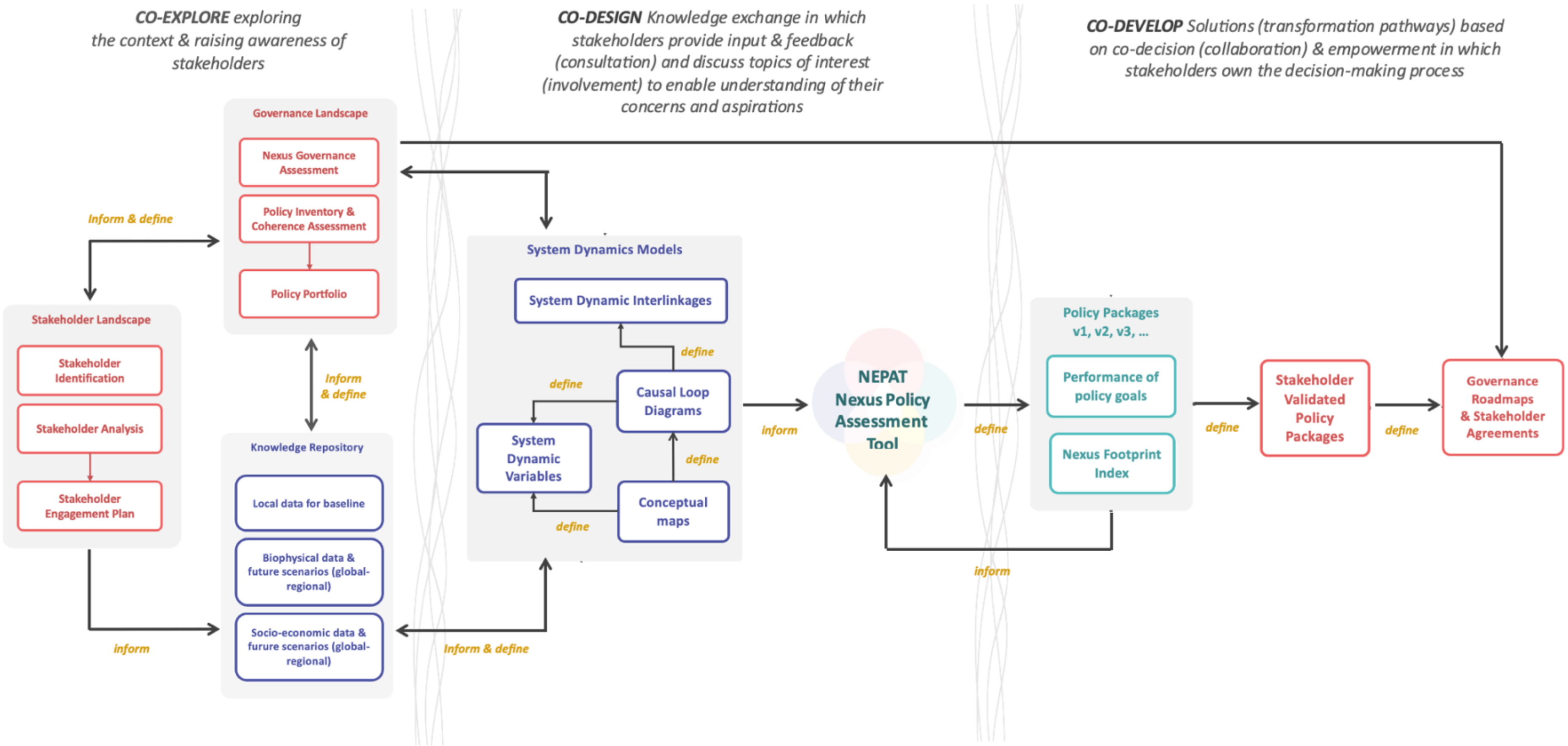
Figure 2: Co-Creation Framework for Nexus Governance

The workflow of the CFNG, illustrating how the interdisciplinary work and outputs were interlinked to produce stakeholder validated tools for improved nexus governance. [Figure: Sabina J. Khan (Helmholtz Centre for Environmental Research UFZ), Blaine Haupt (Jones & Wagener Consulting) and the NEXOGENESIS project team, 2025]



Summary guide on how to read the revised CFNG presented in Part 4 of this document:

- 'Building blocks' terminology is not used (as it would have been in D1.1)
- Co-creation (**co-explore, co-design, co-develop**) terminology is now exclusively used
- Overarching content and workflow of the initial CFNG (as per D1.1) remains the same, but is now partitioned / organised according to the phases of co-explore, co-design, co-develop
- The original **NXG pipeline workflow** of linkages between interdependent methods, inputs and outputs (as proposed in the Grant Agreement) remains the same
- It provides a condensed version of the steps implemented in the CFNG, with differing levels of explanation and detail as required depending on the complexity of the topic.
- Methodological aspects of the CFNG which are highly complex and extensive (e.g., downscaling of global datasets) are not fully described step-by-step; instead, in certain instances, the respective NXG Deliverable is referred
- The step-by-step development of the NEPAT and WEFE Footprint Index are not included:
    - Such details fall under protection of intellectual property rights; and
    - The guidance is developed under the assumption that the use of the CFNG in future projects will be accompanied with the use of the NEPAT and the WEFE Footprint Index. Therefore, this would not entail building of a new AI engine or nexus index.
- Some case-study examples are provided, though not in great detail; the focus is on presenting the revised framework. Case-study results are presented in greater detail in all previous deliverables.
- The **content is written in the style and tone of a 'guidebook'** - prioritising clarity, practicality, and accessibility for practitioners and policymakers to support real-world application. It assumes a **target audience** with 'medium level' (not laymen, not expert) familiarity with each of the topic (data, models, artificial intelligence, policy, communications, stakeholder engagement). Part 4 and Part 5 will be used to produce a forthcoming professional guidebook for dissemination by case-studies and partners.
- The following terms in the NXG grant agreement have been slightly (and in some cases, unofficially) modified only for the purposes of improving simplicity and clarity for the target audience, based on our learning lessons (Table 5 below).

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Table 5: Terminology in NEXOGENESIS grant agreement modified in Deliverable 1.5

Grant Agreement	Term in Part 4	Notes
SLNAE	NExus Policy Assessment Tool (NEPAT)	This was a change officially approved for the project in 2024 and therefore continued use in this deliverable.
River Contracts	Stakeholder Agreements	This was a change officially approved for the project in 2024 and therefore continued use in this deliverable.
User-Validated Policy Packages (UVPP)	Stakeholder Validated Policy Packages (SVPP)	SVPP aligns more closely with the concept of stakeholder co-creation, and thus avoids introducing a new term such as “user.” The term “user” is more appropriately applied to those who utilize the validated policies, regardless of whether they participated in the co-creation process partially or fully. In contrast, “stakeholder” specifically refers to the actors who actively participated in the co-creation process, making it a more precise and accurate descriptor.
Validated Policy Package	Policy Portfolio	These refer to the comprehensive set of policies that are first selected as inputs for NEPAT to conduct the policy assessments. Although these policies were also validated by stakeholders, it is important to distinguish this initial validated set from the SVPP. Using similar terminology for both has caused confusion, as experienced within our consortium. The term “Policy Portfolio” was therefore adopted to designate this master set, as it aligns well with the concept of a “Policy Package,” where specific policy packages can be drawn from the broader policy portfolio.

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Part 4. Guidance for a consolidated co-creation framework for nexus governance

**NB: A reminder that Part 4 is written in the style of a guidebook. It will be extracted as is, and slightly modified (improved upon), to be published as a professional guidebook forthcoming in 2025.*

4.1 Introduction to the co-creation framework for nexus governance

Interdisciplinarity & Transdisciplinarity

The CFNG embeds an inter- and transdisciplinary approach, aligned with sustainability science's core aim to engage beyond traditional scientific boundaries. Transdisciplinary research is understood as *"a facilitated process of mutual learning between science and society"* (Scholz & Steiner, 2015). It links interdisciplinary research with multi-stakeholder dialogue focused on real-world problems, through participatory processes.

Following Scholz and Steiner (2015), interdisciplinarity combines knowledge across scientific disciplines, while transdisciplinarity goes further by integrating scientific and experiential knowledge. In practice, this involves close collaboration with stakeholders to foster "vertical learning" between researchers and local actors, as well as "horizontal learning" across multiple locations and groups. Participatory processes range from top-down methods—such as information sharing and consultation—to bottom-up collaboration, including deliberation, co-design, co-production, and joint decision-making (Reed et al., 2018).

Co-Creation Approach

Transdisciplinary co-production of knowledge is an essential modus operandi for generating rigorous, relevant, legitimate and actionable policy solutions. To this end, the CFNG applies a structured co-creation logic, unfolding across three phases: Co-Exploration, Co-Design, and Co-Development (IAP2 2018; Bojovic et al. 2021).

1st Phase – Co-exploration: Building understanding & foundations for collaboration

This phase begins by building mutual understanding across sectoral stakeholder groups. Relevant stakeholders are identified, their relationships mapped, and their diverse expectations, needs, and capacities related to the WEFE nexus are surfaced. Consultative activities combine context mapping with exploratory dialogue to understand the socio-environmental and policy landscape, uncover perceived challenges and opportunities, and clarify stakeholder concerns and aspirations regarding specific technical or governance issues.

Information- and awareness-raising activities align local perspectives with the project's goals and create conditions for meaningful cross-sectoral dialogue. Key objectives include introducing stakeholders to the project, gathering early insights, and establishing a shared understanding of WEFE system dynamics. This phase also involves identifying relevant problems, socio-economic and environmental risks, existing policies and governance structures along with their gaps, and collecting

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critical socio-economic, biophysical, and policy data. The resulting project roadmap and stakeholder engagement strategy will guide subsequent activities.

The technical work focuses on collecting and harmonizing nexus data to characterize physical, environmental, and socio-economic components under current and future climate scenarios. Data will support model design and stakeholder engagement, enabling analysis of biophysical-human interactions. Common reference scenarios and standardized data structures facilitate comparability across case studies, while spatial and temporal resolution is tailored to local needs. Biophysical data is validated and calibrated against retrospective analyses and local statistics to ensure relevance for each case study.

2nd Phase – Co-design: stakeholders shaping the scope & content of co-creation process

This phase shifts toward consultation and active involvement, where stakeholders help shape the development of technical content—such as data, models, indicators, and scenarios—by co-framing the problem space, validating assumptions, and providing feedback. It emphasises joint learning, ensuring stakeholder knowledge, perspectives, and values are reflected in final outputs. Feedback loops between technical teams and local actors enhance the relevance and legitimacy of outcomes.

Stakeholder input is tangibly integrated into early project outputs, including indicator frameworks, modelling assumptions, and policy packages. Engagement expands to include both grassroots actors and institutional decision-makers, ensuring outputs are informed by a broad range of expertise and perspectives.

The technical work focuses on developing qualitative and quantitative complexity science models, based on expert and stakeholder input and using nexus data characterising current and future projections. Models are applied to simulate multiple scenarios, with outputs informing the WEFE nexus footprint as a comprehensive methodology for evaluating case study baselines and policy interventions. These models also provide essential data for AI-driven assessment tools.

3rd Phase – Co-Development: Validating Outputs & Implementation Pathways

This phase represents the most intensive stage of stakeholder engagement, focusing on collaboration and, where possible, empowerment. It centers on the joint development and evaluation of solutions—such as policy packages, institutional pathways, and transformation roadmaps—with the goal of enabling long-term, whole-of-society shifts in WEFE nexus governance.

Stakeholders use the NExus Policy Assessment Tool, an artificial intelligence engine that combines agent-based modeling with reinforcement learning to evaluate policies and identify optimal policy combinations to meet multiple WEFE goals under different scenarios. Stakeholders participate in collaborative decision-making to identify preferred options, co-design innovative approaches, and define implementation strategies. In some contexts, this process evolves into stakeholder empowerment, where participants assume ownership over decisions and actions, particularly when they have both the capacity and legitimacy to do so (Mauser et al., 2013).

This approach supports immediate action while laying the groundwork for institutionalization beyond the project's duration. Clear, post-project roadmaps foster continuity, and stakeholders can lead or co-lead implementation efforts wherever feasible. Key elements of this phase include collaborative decision-making on technical and policy alternatives, stakeholder-led innovation in designing and refining solutions, and shared ownership of outputs such as tools and roadmaps.

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*Together, the three stages form a structured pathway for co-creation, allowing stakeholder engagement to evolve from awareness and problem understanding, through design and testing, to action and transformation. **Figures 3 and 4** illustrate how CFNG methods and tools are framed within the co-creation process and how interactions between project team members and stakeholders are implemented throughout the project.*

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Figure 3. Co-Creation Framework for Nexus Governance

The workflow of the CFNG, illustrating how the interdisciplinary work and outputs were interlinked to produce stakeholder validated tools for improved nexus governance – within a co-creation approach (co-explore, co-design, co-develop) [Figure: Sabina J. Khan (Helmholtz Centre for Environmental Research UFZ), Blaine Haupt (Jones & Wagener Consulting) and the NEXOGENESIS project team, 2025]

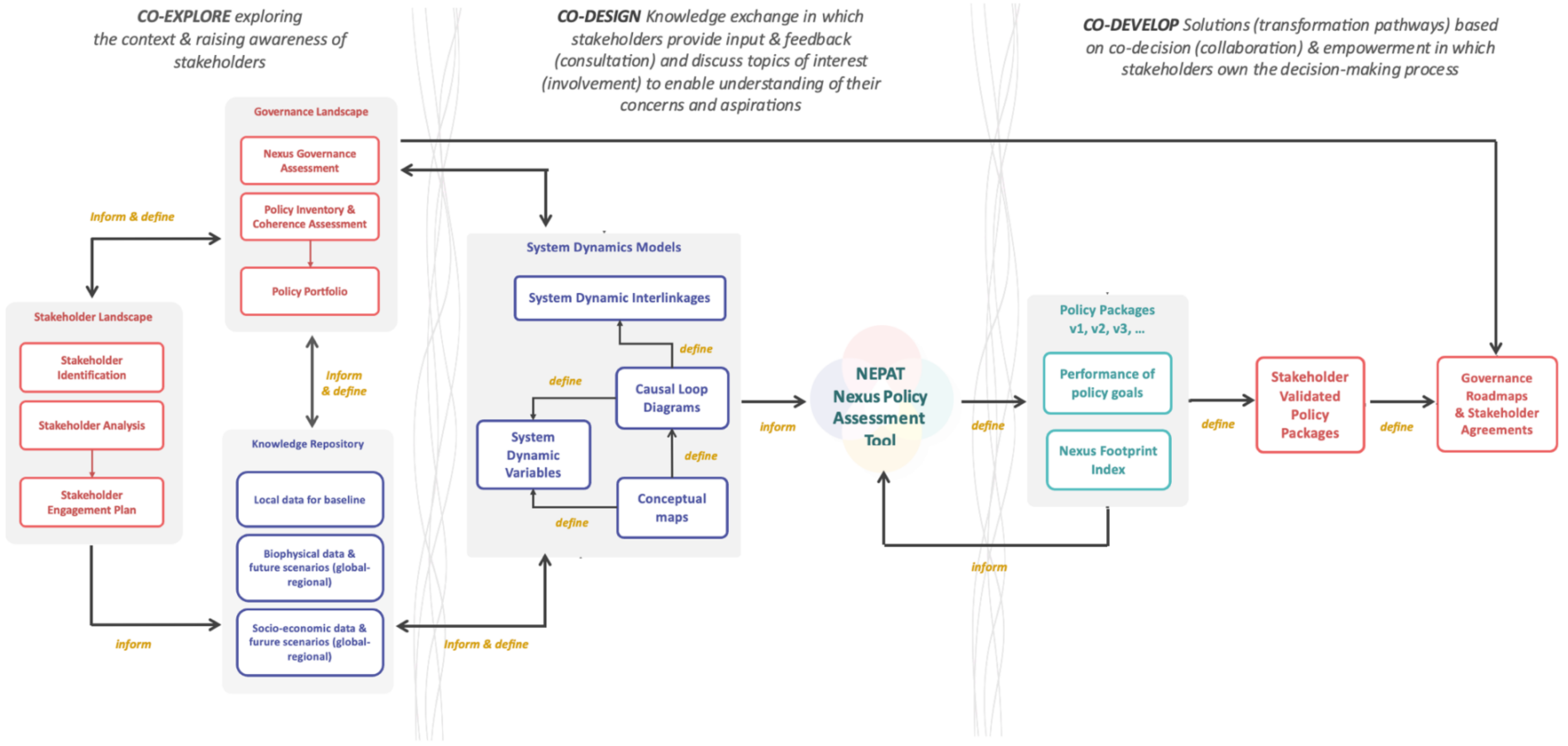

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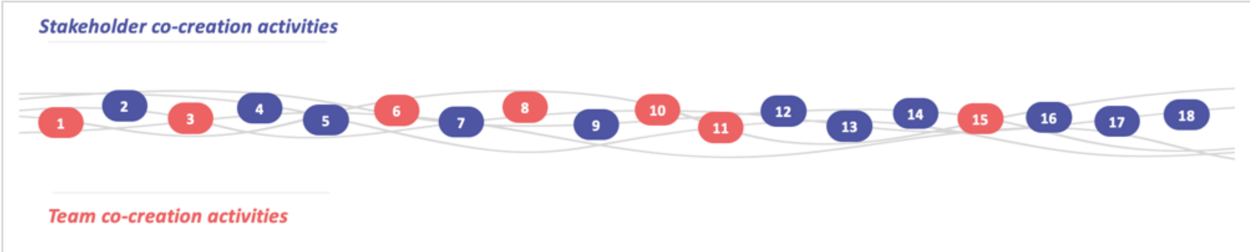
Figure 4: Implementation sequence for co-creation activities. *The overarching sequence of activities to be implemented in the CFNG. 'Project team co-creation activities' are those interdisciplinary exchanges required between the domain experts on the team. Stakeholder co-creation activities are transdisciplinary exchanges between the project team and stakeholders. [Figure: Sabina J. Khan (Helmholtz Centre for Environmental Research UFZ, 2025)]*



CO-EXPLORE

1. Preliminary project design, scoping of nexus context & stakeholder analysis
2. ca. 2 workshops - orientation to project concept, refining project design, exploring nexus issues, exploring stakeholder landscape
3. 1st draft conceptual models, 1st repository of preliminary global climate, biophysical & socio-economic data sets, 1st stakeholder engagement plan
4. Interviews & focus groups - nexus governance assessment, policy coherence assessment & policy inventory
5. ca. 3 workshops – validate policy coherence assessment & nexus governance assessment results

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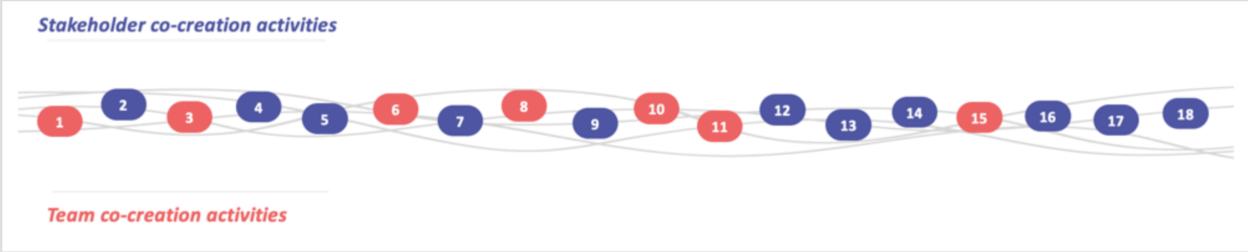

CO-DESIGN

6 Integrate policy preferences into conceptual models, source local datasets to reflect modeling needs for policy preferences, develop preliminary WEFE nexus indicators, 2nd phase stakeholder engagement plan

7 ca. 4-6 workshops – validate conceptual models, validate data sets, validate WEFE nexus indicators

8 Convert conceptual maps to causal loop diagrams, convert causal loop diagrams to stock & flow diagrams (systems dynamic models), populate SDMs with data, calculate WEFE indicators, validate SDMs (retrospective analysis & uncertainty analysis)

9 ca. 4-6 workshops validating SDMs with local experts, explore design needs for user interface of the NExus Policy Assessment Tool

10 Transate SDMs into NEPAT, validate NEPAT results

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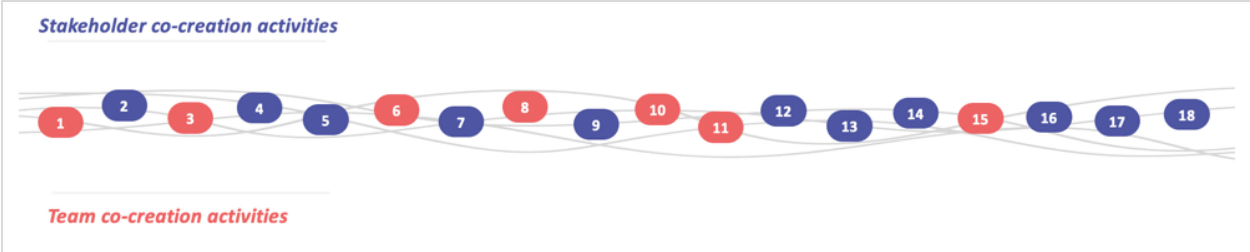

CO-DEVELOP

11 3rd phase stakeholder engagement plan

12 ca. 10-12 workshops – in-depth training on using the NExus Policy Assessment Tool and subsequent exporation of optimization of policy packages

13 Focus groups & bilateral meetings - in-depth training on using the NExus Policy Assessment Tool and exporation of optimization of policy packages

14 ca. 4-8 workshops validating final policy packages (output: stakeholder validated policy packages)

15 Drafting governance roadmaps of policies in each stakeholder validated policy package

16 ca. 8-12 workshops on developing goverance roadmaps and exploring stakeholder agreement options

17 Focus groups & bilateral meetings - developing governance roadmaps and exploring stakeholder agreement options

18 ca. 4-6 workshops validating governance roadmaps & stakeholder agreements

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4.2 Section 1: Co-explore phase

This phase builds mutual understanding between stakeholders and the project team, generates early insights, and establishes a shared view of system dynamics while mapping knowledge gaps. It explores the socio-environmental and policy landscape, identifies nexus interlinkages, collects critical data, and develops a stakeholder engagement strategy to support cross-sectoral dialogue and collaboration. It also clarifies stakeholders' expectations, their interest in the tools, their capacity to contribute – and transforms this into a stakeholder engagement plan.

4.2.1 Chapter 1 - Understanding the Stakeholder Landscape

This chapter provides an overview of how to design, implement and evaluate a stakeholder engagement (SHE) process for the CFNG as described in detail in D5.1: Report of Stakeholder Engagement. The section here is a short summary of how the SHE process was carried out in NXG.

SHE is ideally aimed at enabling full systemic empowerment, nurturing the capacities, networks, and governance pathways that can carry forward the nexus vision over the long-term. In the NXG framework, SHE processes supports co-developing and leveraging complexity science tools and artificial intelligence for decision-making by promoting ongoing dialogue between stakeholders across science, policy, practice and society.

Stakeholders are defined here as "*individuals, groups and organizations who are affected by or can affect those parts of the phenomenon (this may include non-human and non-living entities and future generations)*" (Reed et al. 2009). Therefore, within the CFNG, the local project (case-study) team are also considered stakeholders.

The SHE process explores the stakeholder landscape to identify who should be engaged how, when, and in which activities. This analysis is consolidated into a SHE plan, which is evaluated at regular intervals (i.e., at the transition points between the three co-creation phases: co-exploration, co-design, co-development) and revised to reflect changes to the engagement aims and strategies due to changing realities, contextual challenges and stakeholder expectations. The SHE process is iterative and is divided into five cohesive steps, as illustrated in Figure 5 and Table 6.

Stakeholder engagement offers significant added value to the project by addressing multiple key aims. It helps cover existing knowledge gaps by incorporating diverse perspectives and local expertise. Engagement raises critical issues, particularly regarding synergies and trade-offs in the implementation of policies and actions related to nexus sector management and resource allocation. It also supports the assessment of current practices and policies to evaluate their effectiveness in real-world contexts. Finally, stakeholder input is essential for proposing future policy measures and actions that reinforce resilience, especially by factoring in the anticipated impacts of climate change.

The CFNG apply some principles of stakeholder engagement from sustainability science, participatory research and international best practices, as follows (*Adapted from: de Vente et al., 2016; Reed et al., 2014; 'Stakeholder Engagement: A Good Practice Handbook for Companies Doing B' n.d.):*

- **Commitment:** Demonstrated when the need to understand, engage and identify the community is recognised and acted upon early in the process;

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- **Integrity:** Occurs when engagement is conducted in a manner that fosters mutual respect and trust;
- **Respect:** Created when the rights, cultural beliefs, values and interests of stakeholders and neighbouring communities are recognised;
- **Transparency:** Demonstrated when community concerns are responded to in a timely, open and effective manner;
- **Inclusiveness:** Achieved when broad participation is encouraged and supported by appropriate participation opportunities; and
- **Trust-building:** Achieved through open and meaningful dialogue that respects and upholds a community's beliefs, values and opinions.

Figure 5: Steps in the stakeholder engagement process. *The SHE process explores the stakeholder landscape to identify who should be engaged how, when, and in which activities. The SHE process is iterative and is divided into five cohesive steps. (Figure: (Avellán et al. 2025 - Deliverable 5.1 - Report on Stakeholder Engagement – link available in October 2025)*

Table 6: Steps in the stakeholder engagement process. *(Avellán et al. 2025 – NXG D5.1 - Report on Stakeholder Engagement – link available in October 2025)*

Stakeholder engagement aims	Defining expectations and communicating to the stakeholders their role in the co-creation process
Stakeholder analysis	Identification of who should be involved when, where and how
Stakeholder engagement plan	Assesses the SH's interest to identify incentives and benefits that can drive their engagement
Stakeholder management & sustainment	How to maintain this interest and engagement of the SH throughout the duration of the project and how to sustain the SH's engagement beyond the lifetime of the project

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Stakeholder process evaluation	Evaluating the participatory process and its effects on the project and achievement of objectives

STEPS IN THE STAKEHOLDER ENGAGEMENT PROCESS

Step 1: Define stakeholder engagement aims

Clear aims for engagement give a frame and a sense of clarity for the co-creation process (**Table 7**). Before setting aims, it is important to differentiate between the aims and points of views of the project (top-down) and the stakeholders (bottom-up). This distinction is important for clear communication, as there are two types of messages to be delivered: (a) general message delivered from the project's point of view (top-down); and (b) case-study specific messages related to the on-ground realities of stakeholders (bottom-up).

Table 7: Aim of stakeholder engagement per co-creation phase. General aims of stakeholder engagement across the co-creation phases. *(Source: Avellán et al. 2025 - D5.1 - Report on Stakeholder Engagement - link available in October 2025)*

Co-Creation Phase	Aim of stakeholder engagement activities
Co-explore	• Establish a strong foundation of mutual understanding • Identify key actors, relationship dynamics and varying stakeholder expectations across the nexus • Initiate trust-building and alignment of local perspectives with project goals
Co-design	• Diversify engagement formats, strengthen communication, expand reach to grassroots & institutional actors • Clarify the policy relevance of tools & integrate SH input into technical outputs
Co-develop	• Deepen trust and (social) learning • Empower certain stakeholder groups through tailored outreach and engagement formats • Participatory development & improvement of tools and results

Both the project team and the stakeholders must define these aims in line with the three types of knowledge (system, target, transformation) (**Table 8**) that are co-produced within the CFNG. This acts as a benchmark for evaluating the effectiveness of SHE in the co-creation process and supports adaptative management. **Table 9** shows the mapping of the stakeholder engagement aims per type of co-created knowledge, that was identified by the case-studies in the NXG project.

Table 8: Types of co-created knowledge (ProClim 1997)

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System	Knowledge about the current state of the real-world situation (natural and human systems) and its context; helps assess causes of change, evaluate the extent of problems, and determine the effects of interventions.
Target	Knowledge about desirable future states of the real-world situation (i.e., goals, visions, etc.); helps guide decision-making by articulating what society wants to achieve in terms of sustainability.
Transformation	Knowledge about the pathways to get from the current to the desired target state; supports implementation of political and socio-economic strategies for change, innovation, and decision-making towards target.

Table 9. Examples of aims for co-creation per type of co-produced knowledge. *These are examples of the aims for co-creation per type of co-produced knowledge that were identified by the case-study leads and stakeholders in the NEXOGENESIS project; similar or different, and more or less aims may be identified for other projects. (Source: Avellán et al. 2025 - D5.1 - Report on Stakeholder Engagement – link available in October 2025)*

System knowledge	Deepen understanding of WEFE nexus problems (e.g., water scarcity) and identify pressures and critical WEFE nexus interlinkages
	Characterise (social, economic, ecological, and institutional) context
	Understand the institutional, organisational and political context and river basin management plans (incl. neighbouring countries)
	Identify conflicts/synergies between Stakeholders as well as actions and strategies
	Get data for model development
Target knowledge	Know about future expectations/perspectives (in general and for assessment tools)
	Determine solutions/systems (and their drivers) that balance sectors
	Diffuse conflicts between sectors (e.g., through the use of a common language)
	Raise awareness of water as a depleting resource
	Gain knowledge on required infrastructural improvements
Transformation knowledge	Develop and implement formal agreements and aligned policies for a coordinated river basin management
	Design of pathways to enhance awareness of (water) resources management

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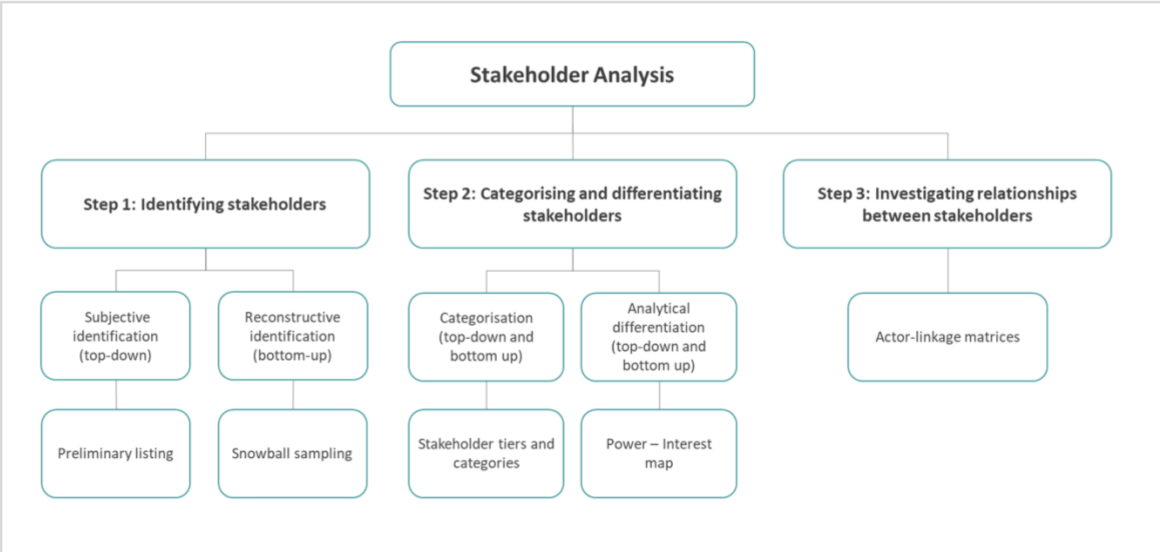
	Co-design and co-validate NXG tools and build capacity to use the NXG tools
	Identify relevant WEFE Nexus components and indicators
	Improve communication between stakeholders and break silos
	Determine the requirements to invest in infrastructure

Step 2: Conduct a stakeholder analysis

A stakeholder analysis includes three steps (Reed et al. 2009): (1) Stakeholder identification; (2) Stakeholder categorisation and differentiation; and (3) Defining stakeholder relationships. Figure 6 provides an overview of the analysis and its substeps.

Figure 6: Stakeholder analysis sub-steps. Based on Reed et al. (2009), these are the sub-steps to conducting a stakeholder analysis, indicating the methods chosen in the NXG project. *(Figure: Avellán et al. 2025 - D5.1 - Report on Stakeholder Engagement – link available in October 2025)*



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Stakeholder identification

In this step, a Stakeholder Registers created, in which there is a listing, collecting, and storing basic information about people, entities or organisations that are affected by or affect the project. This enables identifying the aim and type of connection with the stakeholders, i.e., who should be involved when, where and how.

Stakeholder mapping usually entails applying the following criteria: position, importance and reach across the governance landscape, influence and impact on the project outcomes, legitimacy across different constituencies and stakeholder groups, priority for engagement and interest in project work. A desk assessment (from public sources) can provide a preliminary list based of 'obvious' stakeholders and based on the subjective perception of the project team, their categorization relationships (see step 2 below). From there, using a snowball sampling technique, the identified stakeholders would be asked to suggest new stakeholders who could or should be involved. Field work allows identifying less obvious stakeholders and their relationship to the project (e.g., stakeholders with expertise in modelling, data, policy, etc.). A final SH register and categorisation is compiled by comparing and combining the results of the three techniques. The register should be regularly revised and updated to include changes in the number and categorisation of Stakeholders. This revision process could coincide with scheduled reviews of the SHE plans. **Appendix 1** provides some **stakeholder categorisation**.

There can be an interdependent relation between defining the aim of stakeholder engagement and identifying relevant stakeholders: as stakeholders are identified according to the aim, they also help (re-)define the aim. Hence, the importance of a regular update of the register for this iterative process. Strong iteration is possible at the beginning of an initiative, but the aim should be set at the earliest stage possible with as little few changes throughout the duration of the work. Nonetheless, if changes to the aim changes need to occur, because the context has shifted or new needs arise, this needs to be accounted for and made transparent.

Consent to be placed included in the SH register should be actively sought. A Privacy Policy Consent Form should be created to explicitly record consent and stakeholders should receive the contact of a person in the project who is responsible for data management, should they wish to see, change or retract the information collected.

Stakeholder categorisation and differentiation

The categorisation and differentiation of stakeholders help characterising the stakeholder landscape to prioritise which stakeholders will be engaged in the engagement phases and how they will be engaged.

a. Stakeholders are categorized in **tiers** (also recorded in the register), which specifies the type of engagement to be applied.

Tier 1: Stakeholders who are relevant to steering and managing the nexus issues at hand, and therefore, should be directly engaged in the development of the project outputs (e.g. models, analysis and validation of policy packages, etc.). There should be representation of all WEFE domains for a robust nexus approach.

Tier 2: A wider constellation of stakeholders with an interest or influence in the application of project results and products.

Tier 3: A wide group of stakeholders with a general interest in the project.

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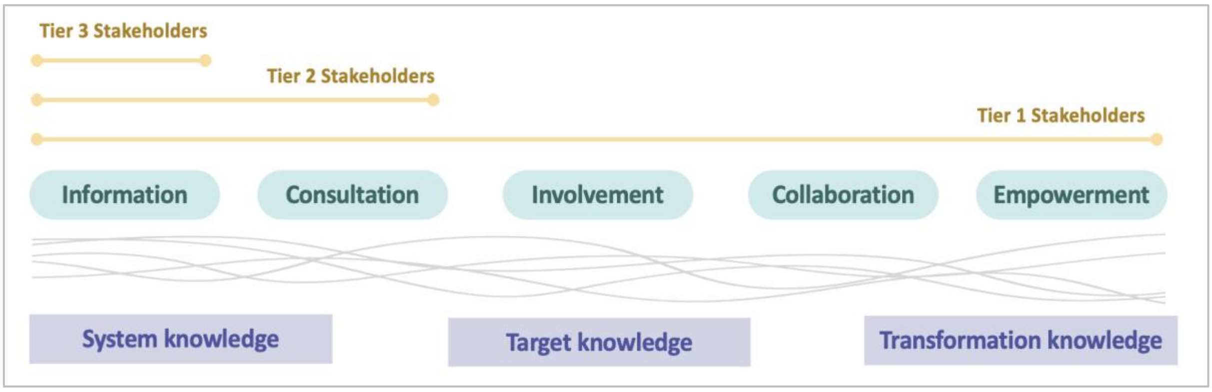
They can be further categorised to help the project team 'think outside the box' or beyond the 'usual suspects', thereby expanding the preliminary list of stakeholders identified. For an initial stakeholder identification, the focus can be on Stakeholders in Tier 1, with some hints on stakeholders in Tier 2 and Tier 3, but in principle, stakeholders across all Tiers are identified. **Appendix 1** presents categories that may be used, a brief description of each, and examples. Other categories may be added to the list as determined by the project team.

b. Relate the tiers to different **levels of engagement: information, consultation, involvement, collaboration, empowerment.** See **Figure 7** below.

Figure 7. Relation of stakeholder tiers to engagement levels to knowledge co-produced.
(Figure: adapted from Avellán et al. 2025 – NXG D 5.1 - Report on Stakeholder Engagement – link available in October 2025)



c. Create a **power – interest map** (also known as **influence – interest map**) (Reed et al. 2009) to help prioritise stakeholders for engagement. **Power** is understood as the ability of the stakeholder to change or stop the achievement of the project's aim. **Interest** is the amount of involvement the stakeholder has in the project, namely the size of the overlap between the stakeholder's and the needs of the project. In a power-interest map, stakeholders are classified into four categories (Figure 8):
- Low interest – High power
- Low interest – Low power
- High interest – High power
- High interest – Low power

To develop a power – interest map, the following steps should be taken:

- The project lead provides their own (preliminary) assessment of the level of interest and power of each stakeholder on a scale from 0 to +10 based on their own perception (with 0 representing low and +10 high power or interest)

- Stakeholders themselves are asked to place themselves in a category when completing their Privacy Policy Consent form.

The exercise identifies key players (e.g., High interest – High power) that may play a leading role in delivering the anticipated outcomes of the project. It also informs the development of tailored communication and engagement strategies, targeting efforts where most impactful.

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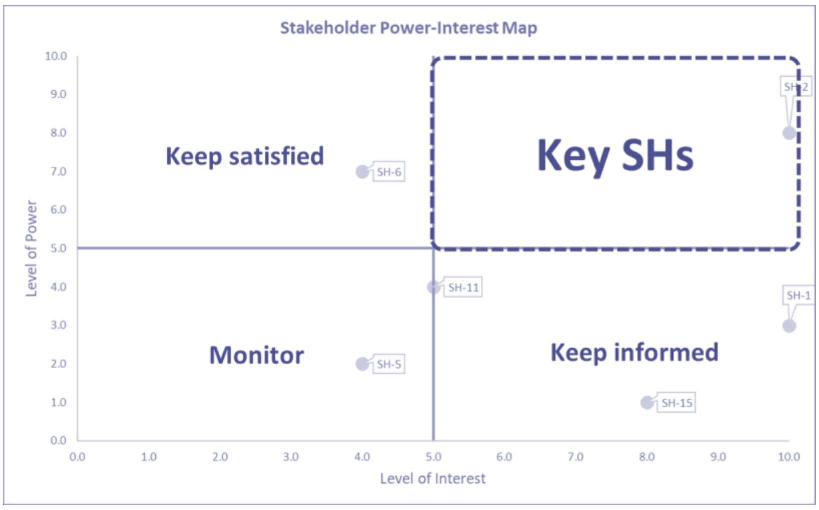

Figure 8. Stakeholder Power-Interest Map. *This is also known as a also known as influence – interest map, which helps to prioritise stakeholders for engagement. Power is the ability of the stakeholder to change or stop the achievement of the project's aim. Interest is the amount of involvement the stakeholder has in the project, namely the size of the overlap between the stakeholder's and the needs of the project. (Reed et al. 2009)*

Stakeholder relationships (actor-linkage matrix)

A practical method to identify relationships among Stakeholders is an actor-linkage matrix (Reed et al., 2009). Here, the categorisation of relationships revolves around *the capacity of stakeholders to develop or achieve aligned policies and agreements* – which is one of the aims of co-producing transformation knowledge.

The actor-linkage matrix requires identifying the relationships between pairs of stakeholders. For the exercise, **Table 10** should be used to guide the characterization of the types of relationships

- Create a matrix in an Excel document in which stakeholders which consented to participation in the project are listed in the first column of a table. Configure the table so that it generates additional columns automatically.

- Starting with the first row of the first column, indicate the project team's collective perceptions of a pair of stakeholders' relationship, in the development or achievement of aligned policies and agreements. The relationships are: conflict (CF), complementarity (CM), or cooperation (CP), or even non-existing (NE). See **Table 10.**

- There is no directionality is considered in the relationships. This means that the relationship from Stakeholder 1 with Stakeholder 2 is assumed to be the same as the relationship from Stakeholder 2 with Stakeholder 1. Accordingly, it is only necessary to complete only the bottom-right half of the matrix.

The results help identify a focus for the SHE plan. As an example, a focus may be on creating connections if there was a majority of non-existing (NE) relationships, reducing conflicts (CF) by building or increasing trust, or enhancing cooperation (CP) by connecting stakeholders with each other.

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Table 10: Type of relationships identified in the actor-linkage matrix. *The categorisation of relationships revolves around the capacity of stakeholders to develop or achieve aligned policies and agreements – which is one of the aims of co-producing transformation knowledge. (Reed et al., 2009)*

Relationship	Description	Illustrative example
Conflict (Cf)	There is a trade-off in the fulfilment of the interests/aims of these stakeholders.	Interest of energy authority on water allocation is in conflict with the environmental protection authority - hampering an agreement.
Complementary (Cm)	The fulfilment of one SH's interests/aims enables or enhances the fulfilment of the second stakeholder's interests/aims.	An agricultural private sector company requires that the water management authority considers their water supply needs in the water allocation plans. While it is the aim of the authority to map all the needs.
Cooperation (Cp)	These Stakeholders work together for the fulfilment of common interests/aims.	A civil society organisation works with the river basin authority in gathering water quality data.
Non-existent (NE)	These Stakeholders have no relationship.	A civil society organisation that belongs to one country (administrative area) and whose work/interests/aims do not connect/relate to a stakeholder in another country.

Step 3: Develop a stakeholder engagement plan

The SHE plan outlines activities and outputs that help achieve the desired outcomes and impact of the project. It sets the strategies for which stakeholders to involve in which activities, and why, with the aim of maintaining inclusiveness, enhancing commitment, while also not overburdening stakeholders. Key objectives:

- Map and profile relevant stakeholders (science, policy, practice, societal impact) and gather key information about them.
- Establish a strategic and reliable engagement process that enables stakeholders to shape outputs, policy outcomes, and overall impact.
- Maintain regular, transparent, and inclusive consultation and co-decision with stakeholders.
- Implement a targeted communication strategy that uses appropriate tools to support awareness and behaviour change.
- Clarify roles and responsibilities for stakeholder engagement within the project team.
- Set up systems for monitoring, reporting, evaluation, and adaptive management of stakeholder engagement activities.

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Based on the stakeholder analysis, activities of engagement are developed. An overview table of who should be involved in which phase of the engagement process, to foster what type of engagement, and how, should be developed (see Table 11 below). These activities are reviewed and refined regularly based on the insights gained from the **stakeholder engagement process evaluation** (see step 5 below). The plan is adapted to the needs, aims and co-creation mode of the project.

Engagement Activities

In the CFNG, a (progressive) series of **workshops are the anchoring co-creation moments** with stakeholders, moving the project team and stakeholders through the pipeline workflow and co-explore, co-design and co-develop phases.

An overarching workshop schedule and workshop aims should be developed early in the project to set milestones. However, these should be adjusted to respond to evolving contextual developments; therefore, closer to the timing of a (cluster of) workshops, define the purpose based on the needs of the co-creation process (e.g., inform, consult, co-create, validate, etc.). The workshops are complemented with focus groups and one-to-one meetings including interviews, which can serve the same purposes, but provide “deep engagement” interaction.

Three **workshop modalities** can be applied: in-person, online, hybrid. For broad outreach or information-sharing purposes, online or hybrid workshops engage larger and diverse group of stakeholders. For workshops focused on co-designing and co-developing outputs, in-person or hybrid settings are usually more suitable. **Appendix 2** provides an overview of the three workshop modalities and considerations regarding their advantages and limitations.

Within the workshops, focus groups and one-to-one meetings, stakeholders can be engaged in:

- **Surveys:** to capture views on governance, WEFE linkages, policy priorities
- **Semi-Structured Interviews:** to explore governance settings, power dynamics, barriers to coherence, capacities
- **Real-time interaction with tools:** Interactive interpretation of conceptual models, system dynamics structure and outputs, modelling results, policy assessment evaluations from the NEPAT and WEFE Nexus Footprint
- **Facilitated groupwork and negotiations:** Collaborative and participatory processes to design of integrated policy mixes, governance roadmaps (implementation pathways), drawing on multiple knowledge systems, trade-off discussions, design of stakeholder agreements.

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Table 11: Example of main components in the stakeholder engagement process. Overview table of who should be involved in which phase of the engagement process, to foster what type of engagement, and how. *(Source: Avellán et al. 2025 – NXG D 5.1 - Report on Stakeholder Engagement – link available in October 2025)*

	Co-exploration	Co-design		Co-development	
	Information	**Consultation**	**Involvement**	**Collaboration**	**Empowerment**
Who?	All SH categories should be properly informed	E.g., civil society, public initiatives, businesses, authorities, media	E.g., civil society, public initiatives, authorities	E.g., authorities, policymakers, businesses	E.g., authorities, civil society, small enterprises
Why?	E.g., Low power-interest	E.g., Low to medium power-interest	E.g., Medium power-interest	E.g., Medium to high power-interest	E.g., High power-interest and medium to low power with high interest
What?	E.g., Inform about results from meetings and workshops	E.g., Consult about perception of trust context	E.g., Involve in framing nexus problems	E.g., Engage in framing and finding solution pathways together	E.g., Engage in framing and finding solution pathways by themselves
How?	E.g., emails, newsletter, website, workshops	E.g., surveys, workshops	E.g., surveys, focus groups, interviews	E.g., focus groups, interviews, workshops, signing commitment documents	E.g., focus groups, workshops, training/capacity building

Step 4: Stakeholder management and sustainment

Stakeholder management

Management pursues the main purpose of reducing the risk of stakeholder fatigue and maximising the gains of SHE for the project outcomes. It relies strongly on making use of the understanding of the stakeholders' interests and their perceived need to be engaged. Two sources of information support this work:

- On the privacy and consent form, stakeholders are asked to provide their expectations of the project;
- The Power-Interest analysis gives an indication of which key stakeholders to take particular care of.

In this stage, SHE activities suggested and executed in the previous year are compared against those suggested in current year or in the next year. This gives insight into the changes in stakeholder management strategies or activities that are due (or required) because of, for example:

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- Changes in context (e.g., geo-political events changing policy directions or extreme events bringing select WEFE issues to the agenda or disrupting engagement activities);
- Aspects of stakeholder engagement that arose over time (e.g., participation of new stakeholders with high power-interest, e.g., high-level policy-makers).

At this stage, there is usually a diversification of engagement and **communications** formats, visible integration of stakeholder input into technical outputs and personalised communication to certain stakeholders showing increasing interest in adopting project outputs in their initiatives. The communication plan is revised to support the newly planned / adjusted management and sustainment activities**. Table 12** provides an overview of common challenges in the stakeholder engagement process and possible solutions.

Stakeholder Sustainment

Throughout the course of a particularly long and intensive co-creation initiative, and towards its concluding phase, stakeholder interactions and collaborative actions may wither. Often this is because it is unclear to stakeholders how future engagement with either the project team or with stakeholders might be possible. Sustainment strategies should be proactively and continually reflected upon throughout the co-creation process (rather than only towards the last phase). This includes also, directly asking stakeholders to provide ideas for moving forward together and then nurturing these seeds through deliberate efforts and opportunities. Some strategies include:

- Finding existing platforms and networks which could benefit from nexus thinking
- Identifying ongoing or upcoming policy processes that could make use of the co-creation outputs and results
- Inviting stakeholders to be part of further development of scientific outputs (e.g., as co-authors of scientific articles for which they contributed knowledge)
- Continuing the development of the governance roadmaps (see Section 3, Chapter 6) to uncover new opportunities and pursuing opportunities
- Expanding the stakeholder agreements (see Section 3, Chapter 6) to include new actors interested in being part of the committed local action
- Continuing the refinement of the usability of the project outputs: datasets (Section 1, Chapter 3) and system dynamic models (Section 2, Chapter 4) – which may be used for other initiatives beyond the CFNG project
- Identifying and pursuing opportunities for innovations (in outputs) to be taken up for commercialisation (e.g., by external companies)

Step 5: Stakeholder engagement process evaluation

The SHE plan includes mechanisms for continuous feedback between the project team and stakeholders, enabling activities to be adapted to the evolving needs and capacities of stakeholders while maximising co-creation of knowledge. Although evaluating SHE can be complex and cumbersome, it provides insight into stakeholder perceptions of the quality of knowledge co-production and the effects of carrying out a participatory approach. The impact of working in a participatory manner can be evaluated through regular surveys to the stakeholders.

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An effective way to evaluate stakeholder engagement is to combine targeted survey questions with interactive workshop activities that elicit deeper insights. Surveys may focus on stakeholders perceived degree of co-creation and the knowledge gained from each workshop, enabling assessment of both process quality and output quality (see **Appendix 3**). Complex topics, such as preferred approaches to co-creation, can be explored through facilitated plenary or breakout discussions during key workshops, with results compared to the project team's experiences to identify alignment or divergence in expectations. This should be complemented by ongoing feedback loops, including structured interviews, multi-day reflection workshops, and annual assemblies, to capture evolving priorities and adapt engagement strategies accordingly—ensuring alignment between stakeholder needs and project outputs over time.

In NXG, a survey was designed to assess the stakeholder's perception throughout the project implementation of: (1) The quality of the stakeholder engagement process (phases of engagement; expectations); and (2) The quality of the outcomes of the stakeholder engagement process (for knowledge generation – see **Appendix 3**).

A workshop activity can also be designed focused on the approaches to co-creation, which make up a central component of the Chambers et al. (2021) framework. This framework assesses 66 dimensions of co-creation—covering how processes are approached, designed, implemented, supported, pursued, and what they produce—scored on a 1–7 Likert scale. In NXG, the framework was operationalised in a simplified manner using a reduced number of dimensions. Central to the framework are eight approaches to co-creation, which determine **six "typical" modes: researching solutions, empowering voices, brokering power, reframing power, navigating differences, and reframing agency**. These modes reflect **different balances of purpose, power, politics, and pathways** in co-creation, and provide a structured way to interpret and compare engagement strategies - especially across diverse case studies. (for more information on this methodology, see *Avellán et al. 2025 – NXG D 5.1 - Report on Stakeholder Engagement – link available in October 2025).*

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Table 12: Common challenges and possible solutions in the stakeholder engagement process. *These challenges were all faced within the NXG project and some of solutions were proactively and reactively implemented. Other solutions are those that the NXG team have reflected upon as recommendations to consider for future projects. The nuance of the challenges and the suitability of the solutions should be evaluated against the backdrop of the local project context and stakeholder landscape. (Source: Avellán et al. 2025 – NXG D 5.1 - Report on Stakeholder Engagement – link available in October 2025)*

Common Challenges	Possible Solutions
Managing diverse stakeholder expectations and their preferred and evolving roles in the co-creation process: co-producing solutions, observing, influencing, etc.	Flexibility in engagement formats (e.g., technical workshops vs. deliberative sessions) Ensure the project team has the capacity, visibility and authority/mandate to lead and shape multi-actor processes Clear communication on project limits helps prevent unrealistic SH expectations.
Balancing depth vs. breadth of engagement: Deep engagement with local and marginalized stakeholders (to build trust & empowerment) coupled with broad engagement targeting decision-makers (to ensure policy relevance)	Clarify and address stakeholder expectations from the onset Do not use a 'one-size-fits-all' approach to designing engagement activities, plan for engagement formats that are suited for different needs and purposes
Building trust: for participation, dialogue and sustained collaboration towards policy impact	Regularly share co-produced knowledge after engagement activities and show how input was/will be used Use external (neutral) facilitators for workshops and focus groups who are credible and legitimate within the local context Ensure language needs are met (e.g., verbal and written translation services for workshops, documents, etc.)

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	For Indigenous Peoples and Local Communities (IPLCs), use methodologies that apply the Free, Prior and Informed Consent (FPIC) principles and the highest standards when working with *Local and Indigenous Knowledge Systems (LINKS).* (UNESCO 2018) Clearer framing of project goals and co-creation process for transparency Surface and discuss myths or fears, especially on contentious issues Brief but meaningful in-person dialogue with stakeholders requiring more attention, e.g., in mastering scientific content Document dissent, synthesize perspectives, and clarify trade-offs Facilitate conflict resolution and consensus-building Cultural norms, internal community conflicts, and power dynamics may hinder participation; local liaison officers can help navigate these nuances
Recruitment & Representation unbalanced representation, difficulty engaging highly influential stakeholders	Partner with other initiatives for expanded outreach Enter nexus conversations through energy, agriculture and ecosystem platforms rather than only water (also, platforms on spatial planning, development planning, finance, etc.) Consider how engagement formats limit or facilitate participation across gender, age, interest groups
Stakeholder fatigue Repeated requests (consultation overload) without tangible outcomes leads to disillusionment	Dovetail engagement activities with other similarly-themed initiatives Tailor communications: concise updates and value-focused feedback loops Regularly and explicitly acknowledge and integrate stakeholder feedback into outputs

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Methodological and practical difficulties: Limited workshop time & uneven survey responses Dwindling attendance at events due to stakeholder fatigue Measuring effectiveness of engagement activities Managing contradictory inputs from diverse stakeholders	Combine participatory formats with qualitative reflection to yield valuable insights Offer a variety of engagement formats to accommodate stakeholder needs, demonstrating commitment to meaningful engagement Extensive pre-workshop briefings in which technical content is thoroughly reviewed by the domain specialists on the project team to pick up areas of improvement in science communication Bring together domain specialists with stakeholders to co-interpret complex data Prioritize engagement activities based on project leverage Seek external funding or collaborators Capacity-building workshops help tackle both fatigue and expertise gaps, and can enhance trust by showing respect for stakeholder needs.
Ensuring sustainability during and after the initiative	Dovetail with other projects to continue relationships with stakeholders engaged on those platforms Find institutions within which the initiative could be anchored (and funded) within, preferably also with a mandate, over a longer term Foster exchange about post-project engagement early in the project phase Continue to develop the governance roadmaps to uncover existing or develop new local actions that can continue project work Start early in connecting project outputs with policy processes, including through tailored policy briefs, modelling demonstrations, etc.

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COMMUNICATION & EXPLOITATION STRATEGY

A communication and exploitation strategy should complement the implementation of the SHE plans. It should outline how the communication tools and channels will be creatively applied to reach important stakeholders, nudge behaviour changes and ensure that a project creates lasting impact well beyond its formal completion.

Communication plays a vital role in raising awareness, fostering stakeholder engagement, and facilitating the transfer of knowledge across diverse audiences - including policymakers, researchers, practitioners, and the general public. It ensures that a project's innovations and insights are widely understood and accessible.

Exploitation is focused on ensuring that a project's results are not only disseminated but also actively used. This includes transforming technical outputs - such as tools, methodologies, and policy recommendations - into real-world applications that inform decision-making, influence policy processes, and support education and capacity building.

Before launching the project, it would be useful to create a unified visual identity across materials, while still with flexibility for local adaptations (if it is a project with multiple case-studies). This 'brand' presence will make it easier for stakeholders to identify and remember the project work and project team.

The communication and exploitation approach for a project should be purpose-driven – every communication activity and output / product should be thoughtfully crafted to achieve the aims of the co-creation process, towards long-term policy impact aims.

This begins by understanding the stakeholder engagement aims (e.g., raise awareness, enable knowledge exchange, uptake of project results) for the stakeholder groups identified (Tier 1, Tier 2, Tier 3), assessing stakeholders' interests with respect to project's aim and identifying incentives and benefits that drive engagement. From this base, communication touchpoints, outreach channels and customised content can be designed and decided upon.

To reach broad and varied audiences, multiple communication channels can be considered:

- A project website with regularly updated news, resources, and tools
- Active social media engagement across platforms like LinkedIn and YouTube
- A project newsletter to provide concise, periodic updates
- Scientific articles and policy briefs to target academic and institutional readers
- Factsheets, videos, infographics, and storytelling formats to convey complex information in accessible ways
- Radio spots, podcasts and opinion letters in newspapers (letters to the editor) for deep-dives into complex issues
- Press releases to announce achievement of particularly important milestones
- Conferences which target the science, policy, practice and private sector stakeholders

In addition to general dissemination, ad hoc tailored communication materials should be developed to meet the specific needs. For example, for workshops, materials may be needed in the local languages and be polished in wording to be sensitive to the political or cultural context.

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Exploitation activities run in parallel to communications. They ensure that project outcomes are not only shared but also adopted by stakeholders and the wider science-policy-society arenas for long-term use. This requires the definition of Key Exploitable Results (KERs). Examples include:

- Training materials and curricula that can be adopted by universities, NGOs, or development agencies
- An open-access, high-resolution land-use dataset – useful for local governments, NGOs, or impact modelers.

Each KER is supported with a distinct strategy to enhance its long-term usability and impact. To develop such a strategy, co-creation workshops with stakeholders can explore practical 'use cases' for these KERs. These sessions can include scenario role-playing, hands-on demonstrations, and structured feedback exercises. The aim is for stakeholders to share their needs and constraints and then use this feedback to consider refinements to the project's tools and methodologies to add value by removing pain points and creating value.

Finally, to support future uptake, exploitation plans for the different KERs can be developed. Some exploitation options include:

- Open access publication and sharing of tools and methods developed
- Commercialisation pathways for high-value tools, including licensing models
- Continued availability of user-friendly interfaces and instructional content

A calendar should be established to manage and track the communication and exploitation activities. This is because the activities have a layered approach: multiple activities will run in parallel, or must be regularly implemented (e.g., bi-weekly social media posts), or must be timed sequentially (e.g., policy briefs which progressively inform development of new EU strategies), or must support particular project activities (e.g., factsheets for conference booths). In addition, the strategy and calendar should be flexible to respond to windows of opportunities that may arise to engage particularly influential stakeholders or raise attention to a WEFE nexus issue. For example, during a period of drought, communication messages and touchpoints could be briefly increased and reoriented to raising attention to policy solutions.

A well-designed and executed communication and exploitation strategy should ideally move beyond awareness-raising to supporting meaningful and lasting behaviour change and policy impact. **Table 13** provides an overview of some challenges that may be faced in this quest and possible solutions. By adopting a co-creation approach that is sensitive to the needs of stakeholders (user-centered), implementation challenges can be turned into opportunities for improvement and innovation.

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Table 13: *Challenges and possible solutions in designing and executing a communication and exploitation strategy. Sample of challenges and solutions for designing and executing a communication and exploitation strategy. Some of these were encountered and deployed in the NXG project; similar or different, or more or less, challenges and solutions may arise with other projects. (Source: Lisa Pourcher & Nina Oliver, GAC Consulting Group, NEXOGENESIS Project, 2025).*

Common Challenges	Possible Solutions
Raising awareness and building understanding of the WEFE nexus concept among non-specialist stakeholders	Develop clear, visually engaging, and storytelling-style communication materials (e.g., factsheets, infographics, animated videos) to demystify technical content and convey complex concepts in relatable ways.
Diversity of stakeholders' communication needs (particularly in projects with multiple case-studies)	Create adaptable templates and customize content for specific workshops and community engagement events (e.g., translation to local languages, modifying the level of technical content, visuals that relate to the local context).
Readiness level of tools to be exploited post-project (addressing issues of long-term maintenance, data availability, integration into decision-making workflows)	Host stakeholder co-creation sessions to explore different 'use cases' of the KERs and how these could be refined, adopted, financed and supported post-project Develop value proposition canvases and business model canvases for each KER to properly articulate the direction needed to meet a particular readiness level Reduce 'barriers to entry' by developing training materials, demo videos, and user-friendly interfaces (e.g., thoughtful customization of the NEPAT user interface to meet language needs, etc.)
Sustaining interest & engagement beyond the project's duration	Encourage partnering institutions on the project to develop individual exploitation plans using their institutions communication channels & resources Foster collaborations with 'sister projects' and broader (long-term) international initiatives which can amplify project results through their network

Concluding remarks on stakeholder engagement

The NXG experience indicates that stakeholders hold diverse, and at times conflicting expectations, for their involvement in a co-creation project. These expectations are not static; they evolve over

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time. Managing this pluralism deliberately is critical to maintaining relevance and trust throughout the engagement process. Such management and sustainment of stakeholder engagement rely on having a solid understanding of the stakeholder landscape, the motivations of their participation and their preferred modes of co-creation.

Ultimately, the most enduring impact of a stakeholder engagement process may lie not in the technical tools developed, but in the capacities, relationships, and mutual understandings built along the way. This underscores the need for adaptability, clarity, and sustained relationship-building in multi-stakeholder co-creation projects. A flexible and context-sensitive approach, responsive to evolving contextual developments, stakeholder needs, power dynamics, helps ensure that stakeholder processes are meaningful and impactful, both strategically and relationally.

4.2.2 Chapter 2 - Understanding the Governance Landscape

INTRODUCTION

This stage focuses on identifying key governance challenges, uncovering cross-sectoral interdependencies, and prioritizing issues that influence resource management across the WEFE nexus. The Nexus Governance Assessment Tool (NXGAT) and the Policy Coherence Assessment (PCA) are used sequentially to understand the WEFE governance system and elicit stakeholders' policy preferences for exploring pathways toward improved integration.

The NXGAT evaluates how the current governance system supports or restricts a nexus-oriented approach to resource management -- identifying enablers, barriers, and entry points for change. This builds a shared understanding of nexus issues and governance challenges, forming the basis for setting case-study goals to include in NEPAT assessment.

Using this shared understanding, relevant policy documents are selected for analysis with the Policy Coherence Assessment Tool, which identifies cross-sectoral policy gaps and key instruments to address them. Stakeholder validation then selects a subset of these policy instruments for further investigation in NEPAT regarding their impacts on the nexus. An understanding of governance structures and stakeholder dynamics guides the design of stakeholder dialogues, determining who to involve and which nexus challenges to focus on.

Nexus Governance Assessment Tool (NXGAT)

The NXGAT helps stakeholders understand the governance system surrounding the WEFE nexus interlinkages and identify entry points for change towards more WEFE nexus governance [Huesker et al. 2022; La Jeunesse et al (under review)]. It is a systematic diagnostic method developed to:

- Assess the extent to which the current governance system in a given case study supports or restricts a nexus-oriented approach to resource management;
- Identify the enablers, barriers, and entry points for transforming the governance system toward a more nexus-oriented approach to resource management.

The NXGAT does so by identifying key factors contributing to the supportiveness or restrictiveness towards WEFE nexus governance. The tool assesses five governance dimensions: levels and scales, actors and networks, problem perspectives and goal ambitions, strategies and instruments, and resources and responsibilities. These five dimensions are in turn assessed based on 5 quality criteria:

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comprehensiveness, coherence, flexibility, intensity of action and fit. The assessment is based on in-depth interviews with relevant stakeholders across the different WEFE nexus sectors. See ***Appendix 4.***

Methodological Foundation

The NXGAT is based on the Governance Assessment Tool (GAT) which was developed to assess governance systems in the context of water management (Bressers et al. 2015). The GAT, and therefore NXGAT in its extension, is based on Contextual Interaction Theory (CIT) (Bressers & Kuks, 2004; Bressers, 2009), which views policy implementation not as a linear, top-down process but as the outcome of dynamic multi-actor interactions. The theory is grounded in a conceptual framework that examines how actors' motivations, knowledge, and resources interact with their specific institutional and societal contexts. This framework is used to assess how effectively governance instruments and structures enable the implementation of policies and the achievement of intended outcomes (La Jeunesse et al., 2023).

The GAT was developed to assess the governance systems of a single sector. Therefore, the GAT has been expanded and adapted to assess the complexities and challenges of governance across the Water-Energy-Food-Ecosystems (WEFE) nexus (See Mooren et al. 2025b on WEFE nexus governance challenges). Based on an extensive literature review (see Huesker et al. 2022, La Jeunesse et al. under review), the NXGAT methodological matrix was developed (La Jeunesse et al., 2023) - see ***Appendix 4***.

Based on data gathered from interviews with stakeholders, each cell in the NXGAT matrix is scored using a four-level scale: Very Low, Low, High, Very High. Every score is accompanied by a brief, one-sentence justification summarizing the rationale behind the assessment. Once the matrix is fully completed, an overall evaluation is carried out to determine the extent to which the governance system is supportive or restrictive towards WEFE nexus governance. This evaluation is done based on the distribution of scores across the five governance quality criteria:

- If three or more criteria are scored as Low or Very Low, the governance system is considered restrictive toward WEFE nexus governance.
- If three or more criteria are scored as High or Very High, the system is considered supportive of WEFE nexus governance.

The assessment is conducted by a multi-disciplinary team of social science experts with the support of CS leaders and is complemented by a stakeholder self-assessment, which provides insight into how local actors perceive the nexus orientation of the current governance system. At the end of the interview stakeholders are asked to indicate how many of the four (WEFE) sectors do they think have integrated decision-making and to identify them (no integration; 2 sectors are integrated; 3 sectors are integrated; all 4 sectors are integrated).

The final evaluation includes a summary of key barriers and leverage points to move the system towards improved nexus governance, each supported by a clear justification. This also provides the data needed to inform the governance roadmaps (see Section 3, Chapter 6)

Implementation Steps *[based on Huesker et al. 2022, La Jeunesse et al. 2023, La Jeunesse et al. (under review)]*

Step 1: Assemble team and prepare for in-person interviews

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Begin preparations at least two months before the planned field visit to allow sufficient time for coordination and planning. Assemble a multidisciplinary team of 3 to 6 members that includes governance and policy experts, supported by one or two local experts familiar with the specific case study context. Governance and policy experts should lead the overall planning and analysis, while local experts provide essential support by identifying relevant interviewees, offering contextual insights, assisting with translation, and contributing to reflections on preliminary results.

Hold preparatory meetings between governance and local experts to clarify objectives and draft a preliminary agenda. During these meetings, select stakeholders for interviews and collaboratively develop an interview guide tailored to the case study's specificities, ensuring comprehensive coverage of each NXGAT dimension and governance quality criterion. For example, questions under the "Extent" dimension of actors and networks might explore stakeholder involvement in resource decision-making, identification of key and excluded stakeholders, and the role organizations play in cross-sectoral management. Make arrangements to conduct interviews in local languages, leveraging translators or bilingual colleagues when possible.

Aim to interview 15–20 stakeholders per country involved in the case study, with flexibility to conduct additional interviews later to address data gaps. Use purposive sampling from a stakeholder register combined with snowball sampling to identify participants. Ensure representation from each WEFE domain—water, energy, food/agriculture, and ecosystems—across local, regional, and national levels. Include stakeholders from public, private, and NGO sectors, while also maintaining gender balance and actively involving marginalized groups to capture diverse perspectives.

Care should be paid to managing stakeholder relationships during the process. For example, this may entail:

- Sensitive delivery of interview questions (e.g., avoid placing interviewees in uncomfortable conversations)
- Consideration for the limited time availability of interviewees (e.g., accommodation to their schedules, well-designed interview questions which are relevant rather than perfectly comprehensive, etc.)
- Respecting social traditions in interactions (e.g., introductory communications via professional connections versus cold calls)

Step 2: Conduct the Interviews

Interviews should be conducted individually or in small groups, depending on stakeholder availability and the nature of their relationships. This flexible approach helps accommodate different contexts and encourages open, comfortable discussions.

At the start of each interview, introduce the project and the governance assessment team to establish rapport and transparency. Clearly frame the interview as a discussion focused on cross-sectoral collaboration and integration within the WEFE nexus. It is also important to ensure that stakeholders understand the data collection and results validation process so they could contribute effectively. Adequate time for explaining the process should be built into the interview time slots. Plan for a minimum interview duration of 1.5 hours. Allow additional time if language translation is needed to ensure clear communication.

Transparency regarding data collection, storage, and usage for research purposes is mandatory to maintain ethical standards. Stakeholders must be fully informed about these issues and about their rights regarding participation in this research activity and must provide free, voluntary consent. Therefore, it is essential to request that the interviewee signs an informed consent form.

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Use a structured, context-specific interview guide designed to cover the 25 main questions of the NXGAT Matrix. While the guide ensures coverage of key topics, adapt the discussion dynamically based on the stakeholder's role and the specific circumstances of the case study. Interviewers should remain flexible, adjusting questions in real time as the conversation evolves to capture relevant insights.

Towards the end of the interview, ask stakeholders to assess the level of integrated decision-making across the four WEFE sectors. Request that they specify which of the following best describes the current situation: no integration (each sector operates in silo), two sectors integrated, three sectors integrated, or all four sectors integrated. Additionally, pose the question: "If you were to score cross-sectoral management in the river basin concerning the problems we discussed, which score would you give between 0 and 3, where 0 indicates no cross-sectoral management and 3 represents good cross-sectoral management across all four sectors?"

Step 3: Analyze and Interpret Findings

After each interview, hold team debrief sessions to reflect on preliminary insights and develop a shared understanding of findings. Compare notes and transcribe interviews if recordings are available to capture detailed information accurately. Involve local experts in the analysis process to benefit from their contextual knowledge. Desktop research may be needed to further contextualize the interview data within the socio-economic, environmental, institutional, and political framework. There will be a need to strike a balance between time, resources, and comprehensive data collection (e.g., data saturation). In some cases, the local knowledge of project team members can compensate for the absence of certain local perspectives by stakeholders, if there are insufficient participants for interviews. Review, organize, and interpret interview data using the NXGAT matrix as the analytical framework. Score each governance dimension against the five quality criteria following the methodological guidance in **Appendix 4**, providing one-sentence justifications for each matrix cell. Based on these individual scores, assign an overall score for each quality criterion to summarize the governance assessment.

Step 4: Evaluate nexus governance supportiveness

Based on the overall score per quality criteria, combined with the stakeholder self-assessment, evaluate the supportiveness of the governance system towards nexus governance by combining the overall scores assigned to each quality criterion with stakeholder self-assessments. This evaluation should be accompanied by a clear identification of key enablers, barriers, and entry points that can facilitate the transformation of the governance system toward a more nexus-oriented approach to resource management. Each aspect of this assessment must be supported by clear justification to ensure transparency and validity.

Step 5: Validation of assessment results

A workshop is organised to validate the results. Main barriers and drivers toward WEFE nexus governance are shared with stakeholders in a factsheet prior to the workshop. At the workshop, they are discussed extensively and a voting exercise is conducted to validate. **Box 1** gives a summary of the results of the NXGAT from the Nestos-Mesta case study in the NXG project.

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Box 1: Results of Nexus Governance Assessment of Nestos-Mesta case study of NXG case-study
In the Nestos-Mesta case study, the governance system was found to be generally restrictive toward WEFE nexus integration. However, the assessment revealed several potential drivers and strategies to shift toward a more nexus-oriented approach. One key finding was the importance of raising awareness and understanding interdependencies among sectors. On the Greek side of the river basin, the local fishery sector recognizes that declining water quality reduces fish populations, directly threatening its economic viability. Consequently, the sector has been actively advocating for stronger environmental protection measures. This lobbying effort emerged as a concrete strategy through the NXGAT analysis and could potentially be replicated in other contexts. This example illustrates how NXGAT can generate actionable recommendations to support governance transitions toward the WEFE nexus.

The NXGAT analysis reveals how supportive or restrictive the current governance system is toward WEFE nexus integration. It fosters reflection on cross-sectoral interdependencies and helps stakeholders understand their impact on other sectors. It establishes a shared definition of nexus issues, guiding the selection of relevant policies for the Policy Coherence Assessment.

Policy Inventory and Policy Coherence Assessment Tool

In contexts where multiple sectors influence and depend on shared natural resources, coherent policy-making is essential for reducing conflicts and maximizing synergies. Policy coherence arises from integration and coordination processes that align policy goals and instruments, minimizing negative impacts while enhancing positive interactions across sectors (Mooren et al., 2025b). The Policy Coherence Assessment Tool (PCAT) evaluates the coherence of policies across the WEFE nexus to identify cross-sectoral gaps. It examines how sectoral policies and their instruments interact, highlighting conflicts, gaps, and opportunities for alignment. Based on these results and the nexus issues identified from the NXGAT, stakeholders select relevant policy instruments to be further investigated in the NEPAT.

Methodological Foundation

The PCAT is adapted from Munaretto & Witmer 2017), which is a simplified version of the approach by Papadopoulou et al. (2020), originally developed by Nilsson et al. (2017). It scores policy documents on a 4-point scale (see Table 14): “no coherence,” “weak coherence,” “strong coherence,” and “not applicable,” based on the extent to which policy documents account for expected cross-sectoral interactions.

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Table 14: Policy coherence assessment scoring table *(adapted from Munaretto & Witmer in Mooren et al., 2024 & La Jeunesse et al. 2023; Mooren et al., 2025b)*

	Not applicable	No coherence	Weak coherence	Strong coherence
DEFINITION	The policy document is **not expected to refer to other sectors** or sectors' policies.	The policy document **does not refer** to other sectors or sectors' policies although impacts and/or potential synergies exist.	The policy document **only mentions/ acknowledges** possible impacts/ synergies with other sectors or sectors' policies but there are no mandatory measures.	The policy document **prescribes specific measures** to ensure that impacts on other sectors are managed and/or synergies exploited.

Step 1: Identify Relevant Policies

Led by policy experts, this step involves identifying key policies and legal documents relevant to the WEFE nexus issues across multiple governance levels, including international, national, regional, and local. The selection of relevant nexus issues is guided by the NXGAT assessment. Both binding and non-binding instruments, such as laws, strategies, action plans, and white papers, should be included. Ideally, these nexus challenges and related policy documents are defined collaboratively with local stakeholders during a dedicated workshop to ensure contextual relevance.

Three interconnected issues with trade-offs need to be addressed at this stage:

- Consider policies beyond WEFE domain with strong WEFE impacts—for example, land use policies were highly relevant in the Lielupe case study of the NXG project.
- Keep the policy list manageable. The inventory will become very long and overstretch resources in later analytical stages. Define clear criteria to focus only on the policies most relevant for the nexus issues under discussion.
- Be aware of stakeholder influence. The policies identified depend on which stakeholders are engaged. This can introduce bias, so aim for balanced and inclusive participation.

Step 2: Build the Policy Inventory

Using the structured Policy Inventory Excel worksheet, policy meta data is systematically recorded to create a comprehensive inventory. Each policy document undergoes a two-phase review: a quick scan to understand its structure, followed by a deep read to extract detailed data. Extracted information includes country, policy area, title, issuing organization, release date, policy goals, instruments, binding status, governance scale, time horizon, and expected revision date, providing a solid foundation for subsequent analysis. See *La Jeunesse et al. 2023 – NXG D1.2 Governance and policy assessment in case studies.*

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Step 3: Conducting the Policy Coherence Assessment

The project team evaluates each policy document for its recognition of trade-offs and synergies with other WEFE sectors, scoring them on a 4-point scale for each nexus sector (see **Table 14** - above). At least two policy experts independently assign scores supported by textual evidence from the documents. The project team then cross-verifies these scores, asking clarifying questions and referencing the evidence base to agree on final scores. A focus group including at least one expert per WEFE domain reviews and validates the results, discussing any disagreements and adjusting scores as necessary to ensure robust and consensual assessment outcomes. The discussion teases out issues such as where the coherence (or lack thereof) was found in the policy document in terms of prescriptions to mitigate negative impacts on other sectors or exploit potential synergies with other sectors (i.e. no prescriptions even if impacts/synergies exists; only mentioning impacts/synergies but no mandatory actions; mandatory actions to mitigate impacts/exploit synergies).

To minimize bias, use triangulation by gathering results from three sources: (1) at least two project team members independently conduct in-depth reading and initial scoring; (2) other team members review and discuss the scoring; (3) local stakeholders validate the results.

Figure 9 (below) shows the results from the PCA for Greece of the Nestos-Mestos case-study in the NXG project. The overall coherence is low (31 interactions showing no coherence, 22 weak coherence and 27 strong coherence) (Mooren et al., 2025b). Policies in the land/soil and ecosystem sectors show the least alignment with energy sector policies. Water sector policies appear poorly integrated with others via policy gaps, even though energy, food, and biodiversity policies consider water. The food and agriculture sector mainly aligns with the water sector. Moreover, policies from the European Union Water Framework Directive are not (fully) implemented in the Mesta-Nestos River basin. From these results, stakeholders and case-study leads selected several policy instruments to be included in the Policy Portfolio (see below) to be evaluated in the NEPAT, since water quantity was identified as the main issue by all WEFE sectors (e.g., for agricultural irrigation, ecological base flow, hydropower production).

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Figure 9. Policy coherence assessment results in Nestos (Greece) *(La Jeunesse et al., 2023)*

Sector	Policy	Water	Energy	Food/ Agriculture	Land/ Soil	Biodiversity/ Ecosystems	Climate
Water	Law 3199/2003 on the protection and management of water resources - Reconciliation with the WFD 2000/60/EC						
Water	Legislative Decree 51/2007 on the determination of measures and procedures for the integrated protection and management of water resources in compliance with the WFD 2000/60/EC						
Water	Measures for the protection of groundwater from pollution and deterioration in compliance with the European Directive 2006/118/EC						
Water	Assessment and management of flood risk in compliance with the provisions of the European Directive 2007/60/EC						
Water	General rules regulating the costs and pricing system of water services. Method and processes for recovery of costs for water services and relevant water uses						
Energy	Special legislative framework of spatial planning and sustainable development for the renewable energy sector and the respective strategic environmental impact assessment						
Energy	Electricity production from RES and cogeneration of high performance electricity and heat						
Energy	Promotion of cogeneration from two or more types of energy - Issues concerning Mesochora hydroelectric power project						
Energy	Operation of electricity markets and natural gas markets - Research, production and transmission networks for hydrocarbons						
Energy	Support electricity production from RES and high performance electricity and heat production from cogeneration - Legal and operational separation of natural gas supply and distribution						
Energy/ Climate	Ratification of the National Energy Plan for Energy and Climate						
Agriculture/ Food	Pesticides market in Greece - Rational use of pesticides						
Agriculture/ Food	Development of the aquaculture sector						
Food	Administrative measures, processes and penalties for the implementation of EU and National legislation in the sectors of food, feed, health and protection of animals						
Biodiversity/ Ecosystems	Preservation of Biodiversity						
Biodiversity/ Ecosystems	National Strategy for biodiversity between 2014-2029 and 5-years action plan						

The results of a PCA help stakeholders better understand the local policy system, including which sectoral policies complement each other and which potentially contradict each other, leading to trade-offs that need to be managed. Through stakeholder validation, insights are gained into how the policy coherence plays out in practice. The practical barriers are also to be used to inform the governance roadmaps which map outcomes and actions in the governance landscape that should be changed to enable improved nexus governance (see Section 3, Chapter 6).

Defining the Policy Portfolio

The policy portfolio is the 'master set' of policy instruments that will be included within the NEPAT to be evaluated for interactions and impact on the WEFE nexus, and from which it will recommend optimal combinations to reduce trade-offs, enhance synergies, and achieve multiple policy targets.

These policies are co-selected by stakeholders and case-study experts of the project team as expected to have a substantial positive or negative impact on one or multiple WEFE sectors in the case study region. Based on the governance challenges elicited through the NXGAT and policy tensions identified in the PCAT, stakeholders select the policy instruments they consider (based on expert and local knowledge) most relevant for addressing nexus issues. Importantly, stakeholders

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may also propose instruments that do not yet exist in the current policy landscape. In such cases, there is an opportunity to test how a hypothetical new policy instrument could impact the nexus. The selection process takes the following steps:

The step-wise process for selecting the policies:

1. **Identify key cross-sectoral issues:** Define the most critical WEFE interactions in the region (e.g., hydropower and water use, agricultural water demand, or water pollution from farming). This draws on: local and expert knowledge via discussions with stakeholders and initial work with the draft conceptual maps (an activity that takes place in parallel to these governance assessments – see Section 2, Chapter 4).

2. **Map existing instruments and goals:** Using the policy inventory and PCA, identify policy instruments (and their associated goals, targets and indicators – as specified in the respective policy documents) which address key nexus issues.

3. **Spot policy gaps:** Identify which selected cross-sectoral interactions are not addressed in current policies and propose new or adapted policy instruments to strengthen nexus governance. The process also includes reviewing data requirements, model assumptions, and the variables affected by each policy instrument to assess their feasibility for integration into the system dynamics models (SDMs) (see Section 2, Chapter 4). For policies that cannot be modeled, this should be clearly communicated to stakeholders with an exploration of finding feasible alternatives.

4. **Define the Policy Portfolio:** Based on step #2 and step #3, select the master set of policies to include in the NEPAT. The number of policies to be considered is not fixed. However, additional work is required for them to be integrated into the SDMs and translated into parameters to be operational within the NEPAT. Therefore, start with a manageable number per nexus sector (ca. 3-5) to first gauge the workload, and expand the set as desired by stakeholders. However, ambition is also possible, since the NEPAT is designed for handled demanding combinatorial analysis and there is an opportunity to evaluate the complexity of interactions of a comprehensive set of policies within the nexus.

5. **Specify policy data to operationalise into the NEPAT**

   The data in **Table 15** below is required to be translated and operationalised into the NEPAT to assesses the achievement of multiple policy objectives.

Table 15: Policy data required for the NExus Policy Assessment Tool. *The policy instruments in the Policy Portfolio must be defined with the following information to be translated and operationalised within the NExus Policy Assessment Tool.*

Policy Instrument Element	Definition & Notes	Example from Inkomati Case Study of the NXG project
Policy Goal	• Defines a strategic objective for a particular policy • Related only to one nexus sector • Found in official policy documents	Increase local food security via subsistence farming production

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Policy Target*	• Make policy goals measurable by quantifying them • Serves as a reference point to measure achievement a certain ambition • May be aligned with or more ambitious than official policies*	Increase subsistence farming production by 50% of 2015 baseline, by 2050
Policy Goal Indicator	• Asses achievement of policy target using a metric • Calculated using outputs of the SDMs	Rainfed Subsistence Area

** Some existing policy instrument may not have quantified targets in policy documents. It is possible to use expert opinion and literature to set a target (e.g., a target may be aligned with an international policy ambition or another national policy imperative).*

4.2.3 Chapter 3 - Biophysical & Socio-economic Future Scenarios

INTRODUCTION

Systems dynamics modelling depends on structured data inputs that reflect the underlying state of the WEFE system and its potential future drivers. Therefore, data are the backbone of both qualitative and quantitative analyses and form the foundation for developing SDMs that are scientifically robust and decision-relevant.

This chapter provides an overview of how data, models, scenarios, and projections are used to support the complexity science modelling tools used in the CFNG. The focus is on the integration of climate, biophysical and socio-economic data to create structured and harmonized usable inputs for SDMs to represent interlinkages across WEFE domains and assess how trends from alternative plausible global scenarios (i.e., Shared Socioeconomic Pathways) impact a specific region.

Furthermore, these datasets define the 'starting point' for stakeholder engagement in designing context-specific WEFE policies and scenarios. Engaging stakeholders helps guide the selection and interpretation of data, ensuring the models reflect local priorities and conditions.

Creating a **'knowledge repository'** helps to:

- Capture long-term trends in climatic, hydrological, environmental, and socio-economic systems using IPCC-aligned scenarios, to support integrated and future-oriented policy analysis

- Characterise relevant nexus interlinkages and case-specific nexus dynamics to structure understanding of cross-sectoral interactions.

- Enriching and refining representation of system dynamics with local insight by incorporating stakeholder knowledge and local data sources

- Translate macro trends and projections into thematic system components across the WEFE nexus, ensuring modelled projected dynamics are aligned and falls along empirical perspectives

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- Create a harmonised and accessible data repository which provides foundation input for SDMs
- Identify WEFE footprint indicators to assess policy impacts on the nexus

The Basics of Climate & Biophysical Projections

Biophysical scenarios describe the dynamic interactions between climate systems, environmental processes, and anthropogenic drivers of change. These drivers include socio-economic, technological, demographic, and environmental developments, such as land use change, population growth, and atmospheric CO_2 concentration trajectories.

Within the WEFE nexus, systems exhibit high sensitivity to climate variability and long-term change, which significantly influence key biophysical parameters including hydrological regimes, agricultural productivity, and ecosystem integrity. These variables are explicitly integrated and interlinked through System Dynamic Models (SDMs) to assess interdependencies and feedbacks.

General Circulation Models (GCMs) are physically-based numerical models used to simulate the behavior of the Earth's climate system under varying boundary conditions. They integrate complex interactions among the atmosphere, ocean, land surface, and cryosphere, employing a three-dimensional grid structure with horizontal resolutions typically ranging from 70 to 300 km, and multiple vertical layers to resolve atmospheric and oceanic processes. Due to their computational intensity, GCMs produce coarse-resolution projections suitable for large-scale climate impact assessments.

Future climate conditions are simulated using Representative Concentration Pathways (RCPs) (**Table 15**) in line with specific Shared Socioeconomic Pathways (SSPs) (**Table 16**), developed under the auspices of the Intergovernmental Panel on Climate Change (IPCC). RCPs represent distinct trajectories of radiative forcing by 2100, associated with varying levels of greenhouse gas emissions and land-use patterns driven by human activity. Each RCP scenario reflects a specific socio-economic development pathway influencing emissions, including changes in energy systems, agriculture, and industrial practices. RCPs serve as input drivers for climate and ecosystem impact models, enabling assessments of potential WEFE system responses under the forcing of alternative GHG levels. Projected shifts in temperature, precipitation patterns, evapotranspiration, and extreme events inform analyses of water demand, crop yields, ecosystem services, and resource trade-offs within the nexus framework. It also helps with understanding uncertainty in the system to evaluate which policies are robust across a range of climate scenarios.

A global effort to compare and refine models is coordinated through the Coupled Model Intercomparison Project (CMIP). CMIP organizes climate modelling into simulation rounds that align with the timeline of the IPCC reports. For example: CMIP5 supported the 5th Assessment Report, CMIP6 informed the 6th Assessment Report, etc. These coordinated efforts improve the reliability and comparability of climate projections, to ensure that climate science evolves alongside decision-making needs.

The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) provides a framework for assessing the impacts of climate change across multiple sectors. It does so by linking the climate projections from the CMIP with impact models across domains such as water, agriculture, forests, biomes, and biodiversity, to assess climate change impacts. ISIMIP is also organized into simulation rounds (i.e. 2b, 3b) that align with the CMIP runs (i.e., CMIP5, CMIP6). Each round is guided by a

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detailed simulation protocol, which defines which input data (climate scenarios, socio-economic drivers) and methodological approaches to use. The outcome is a harmonized modelling framework that supports cross-sectoral comparison of climate impacts. Each simulation round covers specific sectors, namely: global and regional water, energy supply and demand, regional forests, global biomes, and agriculture, agro-economic modelling, terrestrial biodiversity, permafrost, coastal systems, health, lakes, and fire. This alignment between CMIP and ISIMIP strengthens the scientific basis for integrated assessments and climate change mitigation and adaptation planning.

Table 16. Representative Concentration Pathways (RCPs) used in NEXOGENESIS. RCPs represent distinct trajectories of radiative forcing by 2100, associated with varying levels of greenhouse gas emissions and land-use patterns driven by human activity. Each scenario reflects a specific socio-economic development pathway influencing emissions, including changes in energy systems, agriculture, and industrial practices. RCPs were developed by the Intergovernmental Panel on Climate Change (IPCC). (Adapted from Moss et al. 2008)

RCP 2.6 (Low emissions scenario) **"Stringent Mitigation**	**RCP8.5 (High emissions scenario)** **"Business-As-Usual"**
The scenario is characterized by declining CO_2 emissions to reach net zero after 2050, followed by varying levels of net negative CO_2 emissions. Under this potential best scenario, global CO_2 emissions are cut severely with strong mitigation effort to keep radiative forcing to 2.6 W/m^2 and raising temperatures below 2 °C by the end of the century, in accordance with Paris Agreement goals.	It is a scenario with prolonged and high fossil fuel development, and consequently strong increases in CO2 emissions, throughout the 21st century. It is considered a potential worst-case outcome, with current CO2 emission levels roughly doubling by 2050 and continuing afterward, with radiative forcing reaching 8.5 W/m2 and average global temperature rising 4–5 °C above preindustrial levels by 2100.

The Basics of Socio-Economic Projections

Socio-economic projections are generated from ***Computable General Equilibrium (CGE) models***, which simulate how an entire economy works and reacts to changes. ere, the economy is a system where different parts - such as households, businesses, government, and markets - interact with each other. The models use real economic data and mathematical equations to simulate how resources like labor, capital, and goods are allocated across sectors (e.g., agriculture, industry, and services) and how changes in policies, markets, technology, or other economic events have economy-wide impacts (e.g., in production, consumption, trade, incomes). Because CGE models provide a 'general equilibrium' picture of the economy (i.e., they consider interactions simultaneously), they are useful for studying policy impacts and long-term structural change. These models are based on national accounts and are capable of producing many variables of interest for any case-study: physical gross industry output, industry output in real value terms, industrial value added, total salaries, household real consumption, exports/imports, anthropogenic GHG emissions, land use, energy consumption, real Gross Domestic Product, Purchasing Power Parity and population.

As an example of what a CGE model could simulate: in a hypothetical case-study in which a policy to put a price on water is introduced to encourage the agricultural sector to use water more efficiently, a CGE model could give information on:

- How higher water costs changes *food* production levels (e.g., farmers reduce water-intensive crops or invest in water-saving technology)

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- A shift in *energy* demand and costs if farmers adopt energy-intensive irrigation methods to reduce water use
- *Ecosystem* service valuations from improved ecological flow and biodiversity if less water is extracted
- How *food* prices and availability affect household consumption and income and national trade

WEFE nexus systems are highly sensitive to large-scale socioeconomic changes. To simulate plausible socioeconomic futures, Shared Socioeconomic Pathways (SSPs) developed by the IPCC framework are widely used. SSPs are global scenario narratives that describe alternative trajectories of societal development up to the year 2100. Each pathway outlines a different combination of factors such as population growth, economic development, education levels, and urbanization trends, providing both qualitative storylines and quantitative datasets. These quantitative components include projections of national population by age and gender, urbanization rates, Gross Domestic Product (GDP), and educational attainment, among others. In the context of system dynamic modelling, SSPs offer consistent, long-term boundary conditions for simulating how social, economic, and demographic trends might influence (the variables of) WEFE systems. **Table 16** provides an abridged description of the SSPs used in NXG.

Table 17: Shared Socioeconomic Pathways (SSPs) used in NEXOGENESIS. *SSPs are global scenario narratives that describe alternative trajectories of societal development up to the year 2100. Each pathway outlines a different combination of factors such as population growth, economic development, education levels, and urbanization trends. SSPs are developed* under the auspices of the Intergovernmental Panel on Climate Change (IPCC). (Adapted from IPCC 2023).

SSP2 (Middle of the road)	**SSP4 (Inequality - A Road Divided)**
The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceed unevenly, with some countries making relatively good progress while others fall short of expectations. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall, the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly, and challenges to reducing vulnerability to societal and environmental changes remain.	Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally connected society that contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labor-intensive, low-tech economy. Social cohesion degrades, and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. The globally connected energy sector diversifies, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle- and high-income areas.

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To operationalize the SSPs, CGE models are used to translate the narrative scenarios into regionally disaggregated economic indicators. These indicators are then used to populate the SDMs, to reflect, for example, projected changes in demand, land use, or investment patterns over time. In NXG, the GTAP-based Recursive Dynamic Extended Model (G-RDEM) model was used to provide long-term socioeconomic projections covering a 40-year time horizon. G-RDEM is a recursive dynamic extension of the *Global Trade Analysis Project (GTAP)* model, G-RDEM simulates economic equilibrium across multiple interconnected markets, capturing the interactions between supply, demand, and sectoral production over time.

The underlying quantitative economic data on which the simulations of the model are based is derived from the data repository maintained by the Global Trade Analysis Project (GTAP) (which is made available through institutions like the *International Institute for Applied Systems Analysis*). Specifically, the *Global Social Accounting Matrix* (SAM) is used. These datasets are based on national accounts and therefore, the outputs of the models are expressed as national-level aggregates.

To make the CGE outputs suitable for more precise analysis and modeling of interactions at the sub-national levels (river basins, municipalities), they must be spatially disaggregated (broken down into finer geographic units) by combining with local or regional data sources. In Europe, this can be done using *Eurostat***,** which provides sub-national statistics at various *administrative levels*. In other parts of the world, different sources would be needed.

G-RDEM can be employed to assess several WEFE-related socio-economic indicators under different global scenarios on climatic and demographic changes. There are >100 activities distinguished in G-RDEM. There are two issues to be considered with G-RDEM results:

- Results are generated at 'administrative level' in the Europe Union and at national level for non-European countries. Therefore, there are spatial mismatches between the results from G-RDEM and data and analysis requirements for case-studies scoped at sub-national scales.

- Results are generated as 'percentage of change over time' (e.g., water extraction increases by 10%). Percentage change reflects 'averages' at broader scales, so applying them to smaller areas does not capture important local variations. Therefore, local baseline data is needed to convert these percentages into absolute amounts (e.g., water extraction will increase to 1,100 litres).

On one hand, G-RDEM results give more flexibility for assessing the range of complementary local socio-economic data that can be employed in a case-study. On the other hand, it provides little or no integration with indicators that contain high spatial variability (e.g. land use, land productivity, water use). Therefore, downscaling methods are necessary to get meaningful, spatially detailed projections for decision-making purposes. Downscaling of national indicators have implications for the development of the SDMs (e.g., introducing uncertainty into the results) and this particularly the case for land use indicators.

For downscaling purposes, ***MagnetGrid*** was employed to downscale G-RDEM national projections on land use. MagnetGrid is a framework based on *MAGNET* CGE model (which is used for scenario analysis, in the context of agriculture, food security, and climate policy - see Diogo et al. 2020). MagnetGrid simulates spatial patterns of agricultural land use resulting from economic decisions on the use of the land (i.e., allocation based on land economic optimization). In the NXG project, it generated spatially explicit land-use-related input data (indicators) at the river basin scale, for the SDMs.

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MagnetGrid works by combining future scenario-based projections on the supply, demand, prices, and production costs of various agricultural commodities (which are simulated by CGE models) with spatially explicit projections of the biophysical suitability of the land for agricultural production (which may be simulated, e.g., from gridded crop growth models such as LPJmL- *Lund-Potsdam-Jena managed Land model*). Hence, MagnetGrid projects and visualises future agricultural land-use change patterns that emerge from climatic and socio-economic developments specified in scenarios (i.e., RCPs/SSPs).

MagnetGrid downscales aggregated land-use projections into high-resolution land-use maps. While the input data reflect broad-scale totals (e.g., hectares of cropland needed in a region), the model allocates these totals to smaller land units (e.g., grid cells) based on probabilistic rules and information about local land suitability and constraints. It applies a probabilistic allocation algorithm, according to which each unit of land (e.g., a grid cell) within a region is allocated to a percentage for each simulated land-use type (i.e., the share of total area of the grid cell used by that land-use type), so that the scenario projections for total aggregated land claims in a region (as projected by MAGNET) are simultaneously fulfilled for all simulated land-use types. This enables a consistent translation of macroeconomic projections into spatially detailed land-use patterns. The spatial resolution of results should match the specific scope of the case study. For example, in transboundary river basins with multiple administrative regions, economic values (e.g., income, land use) can be estimated by calculating weighted averages of model outputs from the respective jurisdictions. This translation from macroeconomic projections to spatially detailed land-use patterns provide critical insights for territorial planning, environmental regulation, and climate adaptation strategies.

Furthermore, and what is particularly interesting and relevant to modelling the WEFE nexus, MagnetGrid can account for **discontinuities**. This is **non-linear behaviour typical in complex systems**, such as the emergence of new land-use types (e.g., second generation biofuel crops), the effects of policies affecting the economic performance of production systems (e.g., subsidy schemes, tax reductions/exemptions, removal of trade barriers), and the economic decisions leading to the adoption of innovative agricultural practices. These are the types of factors that are important to consider in understanding inherent uncertainty often observed in WEFE nexus systems.

The configuration of the model is based on flexible templates, which allows for different scenario alternatives and configurations to be seamlessly and efficiently accommodated (e.g., grouping crops into broader sectors, aggregating countries into custom simulation regions**).**

Models can produce different results depending on their structure, the input and parameterization they use, climate forcing, or internal variability (natural randomness in complex systems). As a result, their outputs are inherently uncertain due to several compounding factors, including divergence between climate drivers and structural or parametric biases in impact models (e.g., imperfect or simplified representations of complex biophysical processes). For example, models that rely on precipitation as a primary driver (e.g. hydrological models) tend to show greater uncertainty, given the variability of future precipitation trends. In contrast, models more sensitive to temperature (e.g. biomass or crop models) generally present lower (though still significant) uncertainty. Downscaling methods also introduce uncertainty, as they are typically limited to specific regions. Differences in model behaviour across regions may result from heterogeneity of local conditions, the spatial extent of the study area, and biases in the selection of grid cells. **These uncertainties propagate through the entire modelling chain upon which all WEFE sector models are driven.**

Uncertainty is assessed by comparing outputs from multiple models run under common input scenarios - an approach known as multi-model ensemble analysis. Therefore, uncertainty analysis shows the range of possible outcomes in the simulation results. ISIMIP and CMIP outputs are

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typically analysed using ensemble approaches, which visualise the range and distribution of potential outcomes, showing:

- Multi-model means: Central estimates derived from averaging multiple model outputs
- Uncertainty ranges: Expressed through standard deviations and quantile ranges
- Outlier detection: Extreme or inconsistent projections, prompting further technical review or stakeholder discussion, and subsequently eventual subsetting of modelling results

Overall, this shows where projections converge (suggesting greater confidence) and where they diverge (indicating higher uncertainty). Defining and describing uncertainty ranges facilitate a preliminary understanding of both conservative and outlying projections for preliminary validation and screening.

In many cases, uncertainty ranges are widened by one or two outlier models that project significantly different results from the ensemble mean. A model ensemble with a high number of members ensures broader coverage of model uncertainty and allows for robust statistical analysis, such as quantile-based evaluation. This approach was applied in NXG, where both RCP2.6 and RCP8.5 scenarios were used to capture a wide range of temperature-driven responses (Portman et al., 2013), ensuring that the ensemble reflected a broad response space relevant to the policy context.

Uncertainty analysis supports the screening and validation of model results, increasing confidence in the data used for SDMs. It also helps stakeholders better understand and interpret uncertainty, which is often underappreciated in risk management processes. These insights are crucial for decision-makers seeking to design robust, flexible strategies that can perform well under a range of plausible future scenarios.

For more details on how multi-model ensemble analysis was performed in the NXG project, see *Trabucco et al. (2024) - NXG D2.5 - Future Trends and Validation of biophysical data for uncertainty assessment* *and* *Sušnik at al. (2024) – NXG D3.6 Sensitivity/Uncertainty Analysis Report*.

Step 1: Identify the target variables across WEFE domains

Begin by identifying which biophysical and socio-economic variables are required to represent the WEFE system dynamics. This selection should be aligned with the conceptual framing of the WEFE nexus in the context and based on input from case study leaders and model developers. The goal is to determine which variables are essential to characterize the WEFE nexus and usable in the SDMs. Common variables applicable for WEFE nexus systems are monthly and annual values for precipitation, irrigation demand, surface runoff, crop yields, biomass growth, soil carbon, land use changes, population trends, GDP changes of different sectors, resources demand, amongst many others. In the NXG project, ca. 150 variables were included (identified through various consultation rounds with stakeholders and modelers, as the SDMs matured).

For more information on the variables and global datasets that were used in NXG, see *Trabucco et al. 2022b NXG D2.1 - Document information and consolidated data available according to specific Nexus dimensions from Modelling, Repository and Inter-Comparison projects.*

Step 2: Screen harmonised, high-quality data sources

Once variables are identified, scope and select harmonised (and preferably open-access) global datasets that could provide the necessary information. In NXG, five key modelling data sources were used: ISIMIP, CORDEX, SIMETAW-GIS, C3S (Copernicus), and GLOBIO. These platforms are well-recognised, cover key sectors, and offer scenario-based outputs that are compatible with system dynamics modelling. **Table 17** provides an overview of each data platform for biophysical variables and their relevance to WEFE domains.

Table 18: Sample of data platforms with global datasets for developing future biophysical & climate projections. *Key global data platforms with accompanying global datasets that were used in the NXG project to develop future biophysical & climate scenarios. More or less datasets may be used for other projects depending on the data modelling needs. (Source: Trabucco et al. 2022 – NXG D 2.1 - Document information and consolidated data available according to specific Nexus dimensions from Modelling, Repository and Inter-Comparison projects)*

Platform	What it offers for modelling WEFE nexus systems
Inter-Sectoral Impact Model Intercomparison Project ISIMIP	• Harmonized simulations from climate impact models using common input scenarios, providing data on climate, water, agriculture and ecosystem domains (terrestrial biodiversity, biomes) • Cross-sectoral consistency & supports for uncertainty analysis
COordinated Regional climate Downscaling EXperiment CORDEX	• Improves regional downscaling of global climate projections enabling more accurate spatial resolution for application at sub-national levels
SIMETAW-GIS	• Tailored agricultural projections for large number of crop types with high regional relevance • Estimates crop water requirements & irrigation needs based on soil, crop type & climate projections.
C3S (Copernicus)	• Hydrology-related climate impact indicators at regional level (e.g., daily mean river discharge, climate impact indicators) of water quantity & quality (phosphorus and nitrogen concentration).) derived from hydrological impact modelling.
GLOBIO	• Indexes of biodiversity (mean species abundance and average population/level across species) - as a function of stressors land use, road disturbance, habitat fragmentation, nitrogen deposition and climate change • Data at global level; further analyses possible with regional data.

Step 3: Choose future scenarios for uncertainty assessment

Select the RCP/SSPs to simulate the effects of climate change on the WEFE nexus system. Any suite of scenarios can be applied based on the analytical and decision-making objectives. The climate trajectories of different emission scenarios (e.g., between RCP2.6, RCP6.0 and RCP8.5) do not substantially diverge before the middle of the 21st century, therefore it is advisable that the most remarkable and expected differences for assessments are inferred for scenarios on the low-high end. Accordingly, in NXG, the contrasting RCP2.6 (strong mitigation) and RCP8.5 (high emissions) were used to span a plausible range of future outcomes.

Step 4: Downscale global data for regional relevance

Data from the global models is too coarse for case study needs at regional, national or sub-national levels. Statistical or dynamical downscaling methods should be used to create spatial alignment with

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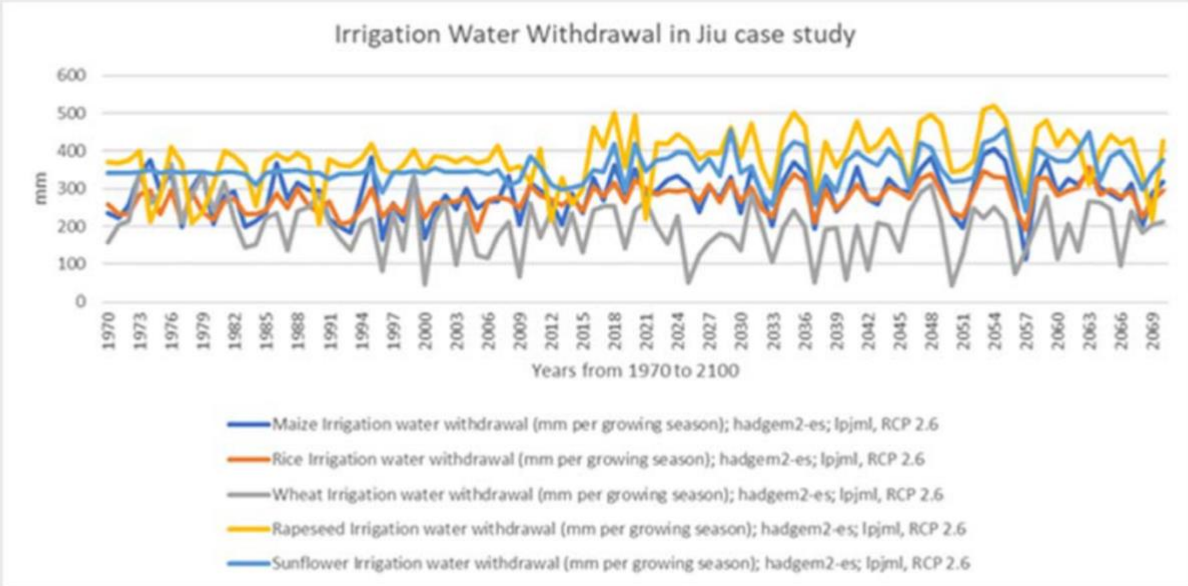
the scale of the SDMs and support more credible regional analysis. CORDEX data often provide already-downscaled climate projections, but local station data and correction methods may be needed to improve accuracy. In Europe, regional statistics provided by Eurostat or land use data with high granularity by COPERNICUS or ESA, may facilitate disaggregation of *some* data to the (NUTS) 2/3 regional level or even at higher resolution. **Figure 10** provides an example of biophysical data trends at a downscaled river-basin level for the NXG project.

Figure 10: Example of biophysical data trends according to climate drivers, model impact or emission scenario. *Trends of yearly crop irrigation requirements for Jiu Case Study of NXG, according to Lpjml, HADGEM-ES GCM climate projections and RCP2.6 scenario. (Trabucco et al. 2023 – NXG D2.2. Nexus data vector of biophysical data for each case study).*



For socio-economic data, the basic workflow for the downscaling framework is illustrated in **Figure 11**. In **Figure 12**, sample grid-level results are shown from downscaling of G-RDEM results using MagnetGrid. A technical step-by-step description of how the downscaling can be accomplished (e.g., the mathematical equations to be applied) is available in *Rossi Cervi et al. (2023) - D 2.4 - Downscaling land use projections from the socio-economic, on the NXG website*.

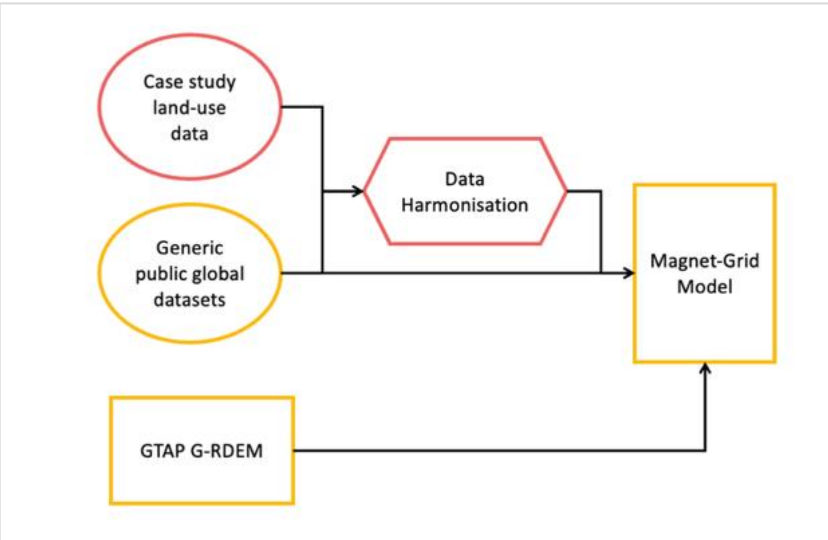


Figure 11: Workflow of model integrations for generating downscaled land use simulations. *The yellow blocks show the established process of integration of MagnetGrid and G-RDEM. The red blocks show the processes that are yet to be enable jointly with the case studies. (Rossi Cervi et al. (2023) – NXG D 2.4 - Socioeconomic data at grid level).*

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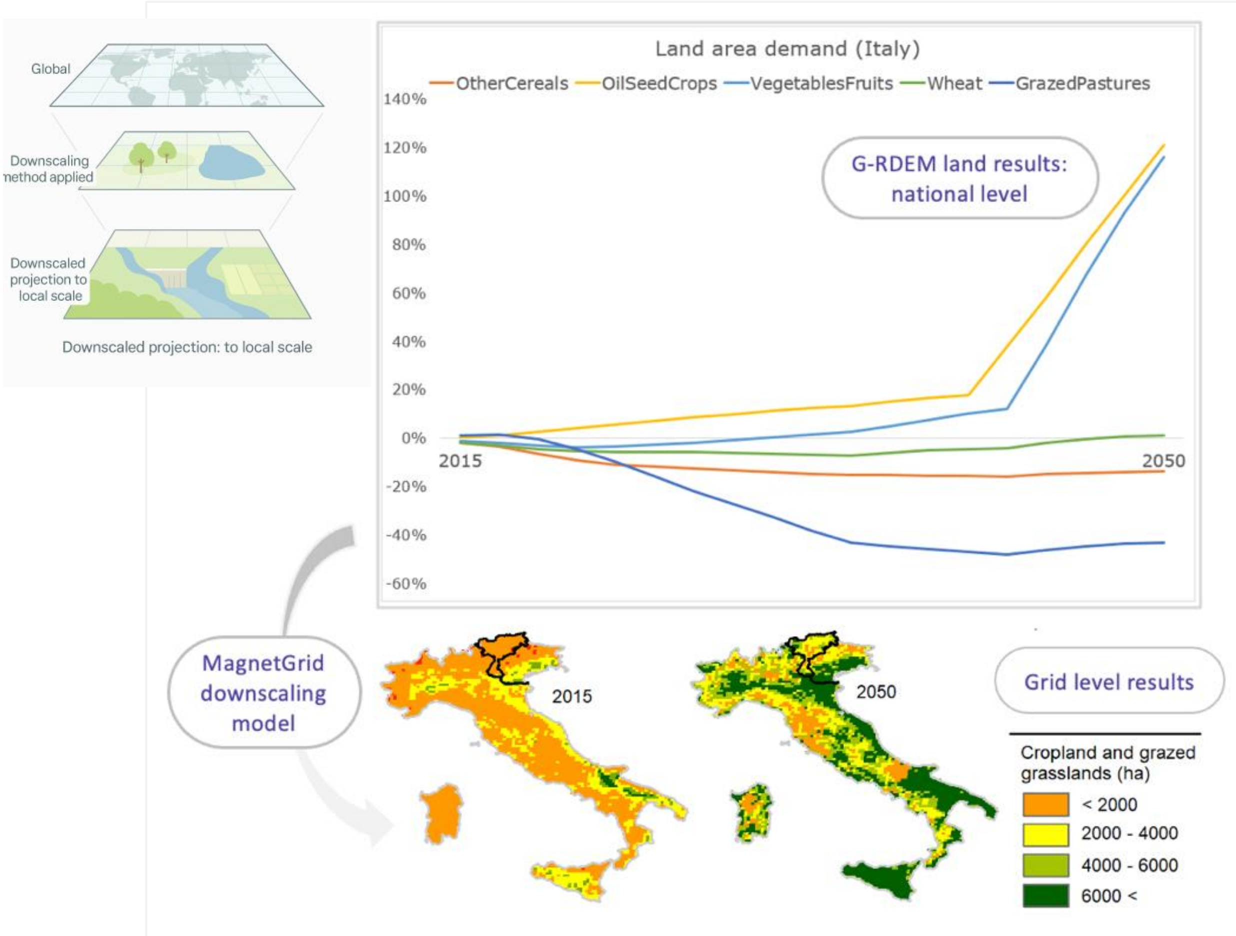
Figure 12: **MagnetGrid downscaling of G-RDEM land-use results for Italy.** *Example of the spatio-temporal distribution of the demand driven land use types which are endogenously modelled and downscaled from G-RDEM Projections using MagnetGrid. (Rossi Cervi et al. (2023) – NXG D2.4 - Socioeconomic data at grid level).*



Accomplishing the final results of the downscaling will require a data harmonization process to reduce mismatches across the different spatial datasets; this can be data-intensive and time consuming. Local stakeholder input is valuable in streamlining this process, by offering local knowledge (e.g., land uses of locally-grown crops) for validation of results. Therefore, in the co-creation process, preliminary results are validated with the stakeholders and specific requests for indicators are discussed. From this, common agreements can be established on what input can still be provided upon and incorporated in the modelling framework. For example, in the NXG project, after stakeholder and expert feedback, crop models were later extended in specific case studies to include regionally important crops: in the Adige basin, grape and apple production were added and in the Inkomati-Usuthu basin, macadamia and citrus production was included.

Step 5: Harmonise and format datasets for SDM integration

Causal loop diagrams of the nexus (see Section 2, Chapter 4 on SDMs) should be refined based on data availability and stakeholder input. To support integration into SDMs, variables need to be standardised so that the datasets can be compared and reused across different case study contexts. Standardise the datasets by aligning all units (e.g., mm of rainfall, tonnes/ha), time steps (monthly, yearly), spatial resolution, uniform driving climate projections and modeling protocols. Special care should be taken to maintain consistency in the historical baseline period (1971–2005) and the future projection period (2006–2070). Compile the datasets into structured data frames, which should also

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include metadata such as variable names, variable units, the RCP scenario applied, the description and intended use of the variables, and source references. This structured formatting facilitates usability and transparency across modelling teams and replication in other case-study contexts.

Step 6: Validate data with Retrospective Analysis

Retrospective analysis is used to evaluate how well the biophysical models simulate observed past conditions. This step strengthens confidence in the models' ability to reflect real-world processes before they are used to inform long-term projections. It involves comparing historical simulations of key biophysical variables (e.g., river flow, evapotranspiration, crop yields, etc.) against observational datasets over a past period (e.g., 1980–2015). Key aspects of model performance assessed:

- Temporal accuracy**:** Do the models capture long-term trends or interannual variability?
- Spatial consistency**:** Are geographic distributions and patterns realistic?
- Biases**:** How much do the models over- or under-estimate key values?

In the NXG project, outputs from global biophysical models that participate in the large-scale intercomparison international initiatives – ISIMIP CMIP6, and the Copernicus Climate Change Service (C3S) were used, and relevant variables validated with local observations available at case study.

For more details on how retrospective analysis was performed in the NXG project, see *Trabucco et al. (2024) - NXG D2.5 - Future Trends and Validation of biophysical data for uncertainty assessment and Sušnik at al. (2024) – NXG D3.6 Sensitivity/Uncertainty Analysis Report*

Step 7: Validate data with Uncertainty Analysis

Conduct a multi-model ensemble analysis - comparing outputs from multiple models run under common input scenarios. The project team should draw on literature describing uncertainty of modelling outputs, together with stakeholders' expert knowledge, to understand the uncertainty presented in the results and thereafter validate the use and reliability of model outputs.

If models show good agreement amongst each other, it can be assumed they can be used interchangeably within the SDMs, with no significant difference in the outcome (simulation results). The choice should be based on the specific region and scenario studied. As a general rule, in the absence of a reference observational dataset, the preferred model should be the one with the highest correlation with the inter-model mean (Trabucco et al. 2024).

Trade-offs must be made when interrogating the results. For example, there may be a situation in which there is a large spread of results across the models, therefore it is not possible to determine the most reliable impact projections. A project team might take a conservative approach that reduces the chances of error maximization, however, at the trade-off that it may not ensure accuracy of results (Trabucco et al. 2024).

For more details on how uncertainty analysis was performed in the NXG project, see *Trabucco et al. (2024) - NXG D2.5 - Future Trends and Validation of biophysical data for uncertainty assessment and Sušnik at al. (2024) – NXG D3.6 Sensitivity/Uncertainty Analysis Report*

Step 8: Populate the SDMs and run scenario simulations

This step translates the qualitative causal loop diagrams into quantitative simulations. The insights from retrospective analysis and uncertainty analysis are used to select and prepare biophysical data inputs for the SDMs. Work closely with modelers to make sure the data vectors (RCP & SSP specific trends for each variable) feed directly into SDM parameters. Ensure that each SDM is labelled according to its RCP & SSP scenario set input, so that the SDM outputs can be compared. This means that there will be an SDM for every RCP-SSP scenario set. For example, for NXG, two RCPs were used, therefore, there are two versions of each SDM corresponding to each RCP. If a project has multiple case-studies and cross-case comparison is desired, RCP scenarios should be applied uniformly across all models to maintain consistency within the modelling framework.

Step 9: Validate SDMs with stakeholders and update datasets as necessary

The first set of simulations should be validated with stakeholders and domain experts on the project team to ensure that the modelling results 'makes sense' given the scientific knowledge and local knowledge of the nexus system dynamics. From there, the data can be adapted as additional modelling needs emerge. The validation process (updates to the data repository-SDM simulations-validation) iterates until the project team and stakeholders agree that the simulations are sufficiently credible for decision-making purposes.

Box 2. Two-stage modelling strategy for future projections. *Example of the two-stage modelling strategy that was applied in NEXOGENESIS project in the 'data--model results--stakeholder input' validation cycle. (Trabucco et al. 2022a).* A proposed modelling strategy is a progressive refinement of aggregated scenarios. In NXG, we were concerned on one hand, about the correct interpretation of variables by stakeholders, and, on the other hand, about the possible delay which could occur when stakeholders needed to wait for the model to generate the data defining the relevant scenario framework. We decided to implement a two-stage strategy to bridge the delay. To start, we provided a "minimum demonstration data set" which, for the economic part, consists of estimates of GDP per capita, referring to SSP4 and the year 2050, for all case studies. Secondly, we delivered a non-exhaustive "menu" of other variables, which could be possibly generated. We then undertook an interactive dialogue between the researchers and stakeholders to progressively define, over time, the most useful information set for the identification of future scenarios, in the different contexts.

Final remarks on biophysical & socio-economic future scenarios

The overarching method presented here is designed to help other project teams replicate and tailor this approach to their own regional or thematic focus. To allow for cross-case comparability and ensure scientific rigour, data should be sourced from **open-access, peer-reviewed platforms** that are widely recognised within the research community. **Multiple sources** should be used to account for **modeling uncertainties** according to different impact models and driving climate projections. Furthermore, **data should be generated under a structured, coherent, and uniform methodology and modelling framework.** Key criteria for selecting suitable data sources include:

- Consistency across sectors (climate, water, agriculture, ecosystems)
- Availability of both historical and projected datasets
- Coverage of relevant variables at monthly or annual time steps;
- Capacity to simulate multiple future climate scenarios (e.g., RCPs)
- Compatibility with the structure and data needs of the SDMs.

Datasets should be **refined over time through stakeholder engagement.** Engaging stakeholders helps guide the selection and interpretation of data, ensuring the models reflect local priorities and conditions. As stakeholders help validate the most relevant nexus interlinkages and policy questions, modelers and data experts can iteratively improve the knowledge repository. This cycle continues

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until the results are considered **credible, relevant, and usable** for decision-making — within the practical constraints of time and resources.

The datasets should be iteratively modified and improved to accommodate eventual further data needs, as stakeholder validation of nexus resource and policy interlinkages are refined in the co-creation process. The iterative validation rounds can continue until the data experts, modelers and stakeholders feel they have adequately captured the nexus dynamics credibly and with relevance for decision-making purposes, within time and resource limits.

4.3 Section 2: Co-design phase

The co-design phase revolves around enabling stakeholders to actively shape technical content and outputs such as system dynamics models, WEFE Nexus indicators, and policy packages. This stage emphasises continued co-framing of the problem space, further clarifying priorities and validating assumptions and outputs. Therefore, it involves establishing numerous feedback loops between technical teams and stakeholders to enhance legitimacy of outputs. Engagement is also broadened to include grassroots and institutional actors.

4.3.1 Chapter 4 - System Dynamics Modelling

System Dynamics (SD) is a modelling methodology used to gain insights into the structure and behaviour of dynamic, complex systems. In the context of the Water-Energy-Food-Ecosystems (WEFE) nexus, it helps understand how system structures (such as the connections between WEFE resources), policies (the actions taken by decision-makers), and system response patterns (how resources behave in response to those policies) continuously interact to shape the development and stability of socio-ecological systems (Drew, 1995). A central concept in SD is feedback - the way information generated by a system provides perspectives for future decision-making. These feedback loops are important for understanding how actions affect outcomes and how the system evolves over time.

System dynamics models (SDMs) simulate real-world systems, under a set of assumptions, to improve our understanding of dynamic complexity. Dynamic complexity is the outcome of the interplay of system parts over time (i.e., the behaviour that emerges from the system over time as a result of feedbacks between structure-action-response). SD is a simulation tool that can be used to support decision makers in analysing the implications of their decisions, in order to construct better policies (Forrester, 1992).

As an example of the relevance of SDM simulations for real-world scenarios: introducing water-saving irrigation techniques in agriculture may reduce water withdrawals, which improves river ecosystem health, but could also reduce groundwater recharge if return flows diminish. Similarly, expanding bioenergy production can increase energy security and rural income, yet may intensify competition for land and water, potentially reducing food crop yields and altering nutrient flows into aquatic ecosystems. For policy-making purposes, SDMs enable the systematic testing of how policy interventions affect the system and help anticipate trade-offs in policy decisions.

SDMs are an optimally suitable technique for tackling nexus issues because they:

- Flexible to incorporate various types of data and multiple interacting variables within feedback loops into a single model (Forrester, 1992, 2009).
- Capable of representing policies and information flows within the system.

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- Holistic in nature, emphasizing the input/output dynamics characteristic of real-life systems.
- Are efficient, relying on dependable aspects of system understanding, while correcting for less certain aspects;
- Can make use of aggregated downscaled datasets of specialised 'themed models' (e.g., crop models, hydrological models)
- Incorporate methods that acknowledge the influence of "soft variables" that are difficult to quantify
- Has a graphical interface that makes information understandable to a wide cross-section of stakeholders, thereby facilitating stakeholder engagement in co-creation modelling exercises.
- Can be immediately translated from the *Stella Architect* environment (a dedicated SDM modelling software) to Python programming code, which is required for its use in the NEPAT

Understanding how complex systems behave is aided greatly by the concept of modelling them as continuously changing over time and by focusing on broader categories rather than fine details (Forrester, 1997). To this end, SDMs are created using two complementary tools - conceptual maps and causal loop diagrams – which visualise how information, materials, or resources move through the system, and how related elements can be grouped for analysis. These diagrams are ultimately translated into a modelling framework (stock-and-flow diagram) that quantifies the current state of the system and the potential system responses to introduced changes (i.e., the potential implementation of policies).

STEPS IN DEVELOPING SYSTEM DYNAMIC MODELS

Step 1: Developing conceptual maps of the WEFE nexus

Defining the core structure of the conceptual maps

A conceptual map is an abstract representation of a system, that is used to understand and visualise the system under study (e.g. Helmig, 1997; Sterman, 2000; Dullea et al., 2003; Sokolowski and Banks, 2010). They are used for:

- Framing the core nexus issues, giving structure to the different nexuses being considered;
- Elucidating how policies 'enter' the nexus and the wider systemic impact of potential policy implementation;
- Elucidating interconnections and interactions within and between the nexus sectors.

Conceptual maps capture the linkages within and between the WEFE domains. The aim is to identify and visualise the major components (or sectors) and interlinkages between them using scientific literature, stakeholder knowledge and expert judgement.

Two levels of conceptual maps can be produced: First, a high-level map on the major connections between nexus domains at the systemic level. Following from this, 'extended' sectoral maps go into detail about the processes within each nexus domain, and how they relate to the other domains.

Developing maps is a creative and open-ended process that starts with a group discussion between modelling experts and stakeholders to develop a common understanding of the system. A series of workshops is necessary to elicit and record the collective perception and knowledge of stakeholders regarding what are the WEFE nexus sub-systems that play a crucial role in the WEFE resources management. Conversations should explore:

- System boundaries (i.e., the scope of the case-study, e.g., river-basin boundaries)
- Focal issues of concern (i.e., what the stakeholders think as relevant and important in the nexus domains)

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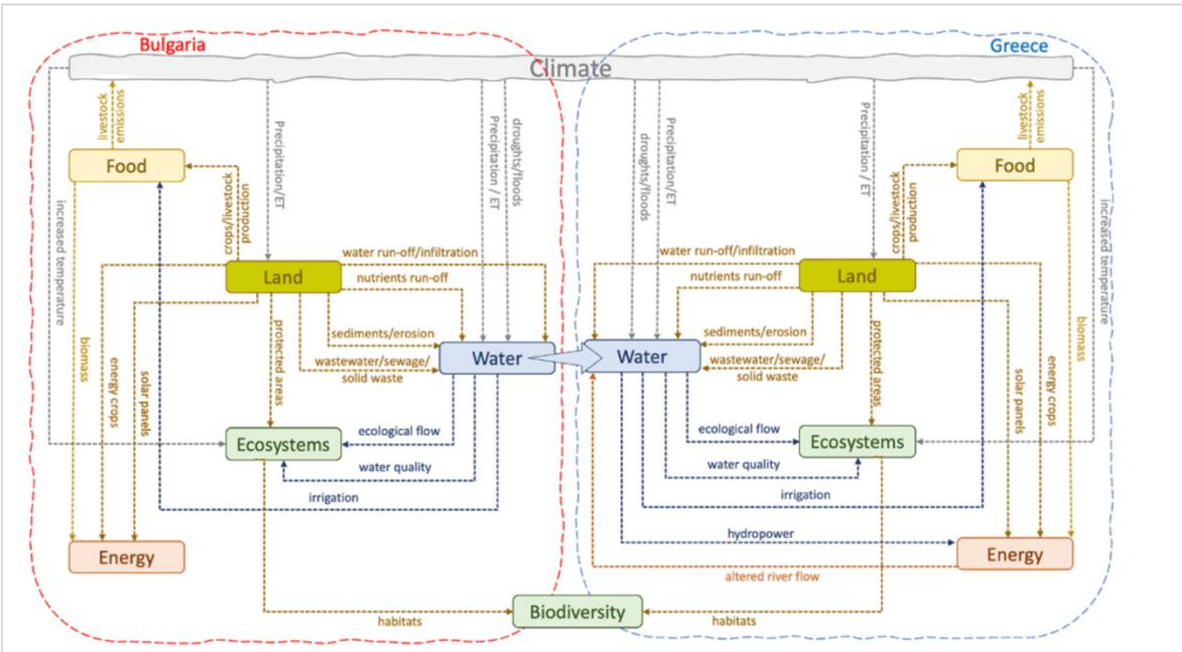
- Structure of the (sub)-systems (i.e., resource sectors of the nexus)
- Nature of sector connections (within and outside of the system boundaries)
- What are the drivers of change in each nexus domain and across the domains
- What are the stresses and impacts on WEFE resources and the potential responses of the system to those impacts

Each domain within the nexus has its own conceptual map, describing connections within the domain and with other domains. The analysis is then extended by describing each of the nexus elements separately, per jurisdiction, providing greater detail as needed to describe the socio-ecological interlinkages in the WEFE nexus. For transboundary cases (at any scale) an overarching high-level conceptual map is made which captures the transboundary element of the interconnecting effect that, for example, upstream activities have to downstream communities to account for differences in connections between two countries (if desired/needed) (see **Figure 13**).

Figure 13: High-level conceptual map depicting nexus interlinkages for Nestos/Mesta River basin. *The transboundary element is captured in the 'water' domain, showing the interconnecting effect that upstream activities have to downstream communities. (Laspidou et al. 2023 – NXG D3.1 - Conceptual models completed for all the case studies*).



Refining the conceptual maps with data-mapping exercises

The conceptual maps offer an entry point for the discussion (and managing expectations) of what can or cannot be modelled based on data requirements and data availability. The eventual SDMs are quantified using data from biophysical and socio-economic trends generated by global simulations based on specific models and scenario drivers (see Section 1, Chapter 3) and from local datasets. While data from global models offer insights into overarching structuring biophysical and socio-economic trends, it is limited in accounting for the specific nexus dynamics that are evident sub-national scale. Therefore, local data are essential for building out and validating the SDMs to account for such granular nexus interactions. In addition, in international transboundary cases, local data in each country needs to be accounted separately, with relevance to, for example, the river basin scale. In addition to filling data gaps, local data is used to validate trends simulated from the global models

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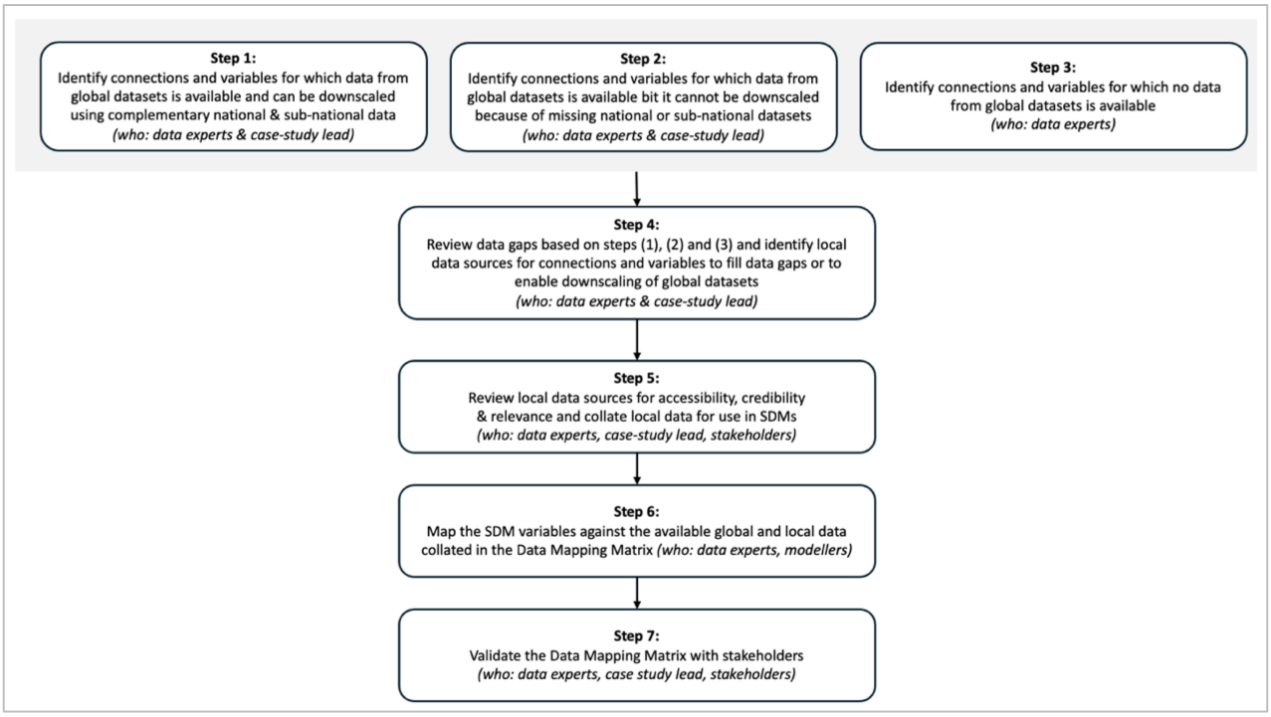
(e.g., changes in water availability), serve as a baseline for constructing socio-economic scenarios (e.g., food consumption) and for conducting uncertainty analysis.

Each conceptual map is reviewed to identify which sources have the data for transitioning from qualitative mapping to quantitative modelling. Mapping the variables against available data helps assess how well existing datasets meet the modelling needs. A data mapping matrix spreadsheet can support this process. It should list all SDM variables and cross-reference them with outputs from the global models. The aim is to identify which variables can be directly sourced from these datasets and which require supplementary local data, particularly for region-specific issues not captured in global models. For instance, in the Inkomati-Usuthu case study within NXG, mining is a major concern, yet mining-specific data are absent from global datasets and must be locally sourced. **Figure 14** illustrates how the data mapping exercise progresses.

Figure 14 Data-mapping exercise for system dynamic models. *High-level summary of the data mapping that is required for developing system dynamic models – as was implemented in the NEXOGENESIS Project. (Source: Adapted from [Laspidou, C. et al. 2023 – NXG D3.3 - Final report on the application of biophysical models and stakeholder recommendations](#)).*



Based on the results of this data mapping, the SDM can be refined to better reflect the available data - by addressing unfillable gaps, removing redundant variables, and introducing new ones where needed (see **Table 15**). As policy objectives are incorporated into the model, further modifications may be required, including adjustments to data requirements. This may necessitate the collection of additional data and corresponding changes to the SDM structure.

To guide this process, stakeholders should be engaged to identify the most pressing nexus issues in the case-study. This ensures that the most relevant WEFE issues are prioritised in their reflection in the conceptual maps and in the sourcing of data. Ideally, this exercise should take place in a workshop setting, although it can also be conducted through focus groups. It can also be conducted via remote online exercises. This was done in the Lielupe case-study in the NXG project, in which stakeholders were asked to score the importance of nexus interlinkages on a Google form, which they could complete on their own time.

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Chapter 3 provides an overview of the global and regional datasets that were used in NXG project. Typical local datasets that can be used are:

- International repositories from government agencies, civil society organisations, international development agencies (e.g., UN agencies)
- Local repositories from government agencies, civil society organisations, research organisations (e.g., national statistics agency)
- Results of other models (e.g., local hydrological models)
- Scientific and grey literature

Table 19: Data availability and the construction of conceptual maps. *Overview of how to construct conceptual maps, as the first step towards constructing system dynamics models, based on various data availability scenarios. (Source: Adapted from Laspidou, C. et al. 2023 – NXG D3.2 - Final report on the complexity science and integration methodologies).*

Data availability scenario	Strategy for constructing conceptual map
Connection or variable which can be quantitatively represented because data are available	Keep connection or variable in map
Connection or variable in which data gaps cannot be filled with either globally downscaled, national or sub-national data	Remove Connection or variable from map
Connection or variable which has no precisely defined data	Explore how connection or variable can be credibly represented with proxy data and if this is possible, keep them in the map
Connection or variable can be sourced from multiple global and local datasets	Keep connection or variable in the conceptual maps. Case-study lead, data experts and modellers discuss the best course of action on which dataset should be primary used in the eventual SDM.
Connection or variable which has only local datasets available	Keep connection or variable in map

The data mapping matrix could be validated with stakeholders, either at the end of the data mapping exercise, or in parallel steps during the exercise. This helps to identify additional sources of credible datasets that may have been missed by the project team and verifies the scientific credibility and legitimacy of the methodology applied, therefore facilitating greater confidence in the final modelling results. As the stakeholders continually offer feedback, the conceptual maps are continually refined. Because the conceptual maps and the data have both been validated separately and iteratively with stakeholders, it can be expected that no large structural changes would be needed to the conceptual maps, and therefore also the causal loop diagrams and the eventual SDMs.

This integrated approach - combining centralised (global) model outputs, local data, experts' knowledge, literature review and stakeholder insights - ensures that each SDM reflects the specific context of the case study area and is well-suited to support modelling the impacts of policies on the WEFE nexus.

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Conceptual maps as "boundary tools" for cross-sector discussions

It is important that considerable effort is put into this stage of involving a wide range of stakeholder groups. By engaging stakeholders in co-designing the diagrams, they adopt a systems-thinking approach to resource management and policy design, as they are required to go beyond the traditional sectoral siloes and become more aware of the wider cross-sectoral impacts. Now, inter-sectoral discussions can be promoted. Furthermore, when they are involved in the co-design process, the intention is that the results and recommendations from the SDMs and the NEPAT will have more practical relevance for these stakeholder groups, promoting uptake in formal decision-making processes.

Step 2: Developing causal loop diagrams of the WEFE nexus

Defining the core structure of the causal loop diagrams

Causal loop diagrams (CLDs) are a qualitative approach applied in the process towards developing the quantitative SDMs (Ford, 2009). Like the conceptual maps, they translate mental models of a complex system into a more tangible visual representation to be shared and discussed amongst stakeholders. Therefore, they help expert and non-expert stakeholders develop greater understanding of the interconnections in systems which may otherwise not have been apparent or which may even be counterintuitive. This draws a greater appreciation of how the whole system behaves and responds to imposed changes.

CLDs are essentially extensions of the previously developed conceptual maps. However, CLDs are simplified - removing non-essential details, and indicating the main causal relationships in the nexus. Therefore, CLDs will not necessarily have as many 'components' as the conceptual maps. For example: energy demand may be broken down by energy type and economic sector (i.e., who is using what type of energy). In a CLD, a simplified causal relationship between, for example, population and energy demand per-capita, would suffice to capture the relevant causal information – any further detailed breakdown is unnecessary. The level of detail necessary is determined by the expert judgement of the modeler.

CLDs give explicit detail about system dynamics behaviour. This is represented in CLDs as feedback loops. Feedback loops illustrate how changes in one part of the system ripple through other variables and eventually influence the original change. A positive feedback loop indicates reinforcing behaviour (amplifying a trend) and a negative feedback loop represents regulating or stabilising behaviour (counteracting a change), and together they help explain how complex behaviour such as system growth (e.g., agricultural expansion via irrigation and energy development), system collapse (e.g., overextraction of groundwater for agriculture), or system oscillation (e.g., reservoir operations balancing energy and irrigation demands) emerge over time. Having these qualitative insights is a necessary bridge to support the policy evaluation processes. Furthermore, they open the possibility for stakeholders to discuss potential policies that that could leverage feedback loops for improved nexus governance. **Figure 15** illustrates a CLD for the Lielupe case-study of the NXG project.

Each conceptual map is translated into a causal loop diagram and this takes the approach of a simple one-to-one translation. In the translation process, it will become apparent the 'sub-sectors' that need to be defined across the nexus domains, within the SDMs. These are "mini-models" nested within the CLD, which group related logic, making them easier to manage, understand, and reuse within the larger SDM. Examples of sub-sectors:

- **Water** Demand: Calculates total water demand based on population, agriculture, and industry

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- **Energy Production:** Energy generation linked to water use, or linked to land-use (for solar and wind technologies – as was demonstrated in the Lielupe case-study of the NXG project)
- **Agricultural Yield:** Calculates food production as a function of water availability, land use, and fertilizer inputs
- **Pollution Transport:** Tracks nutrient or chemical loads through **water** bodies and estimates ecosystem impacts

Two types of sub-sectors will become apparent as the CLDs are being developed:

- Sub-sectors reflected to inputs from the central bio-physical and socio-economic global datasets;
- Sub-sectors addressing important factors that should be considered at the river basin scale (e.g., local hydrological or infrastructure models) and reflected to inputs from local data sources.

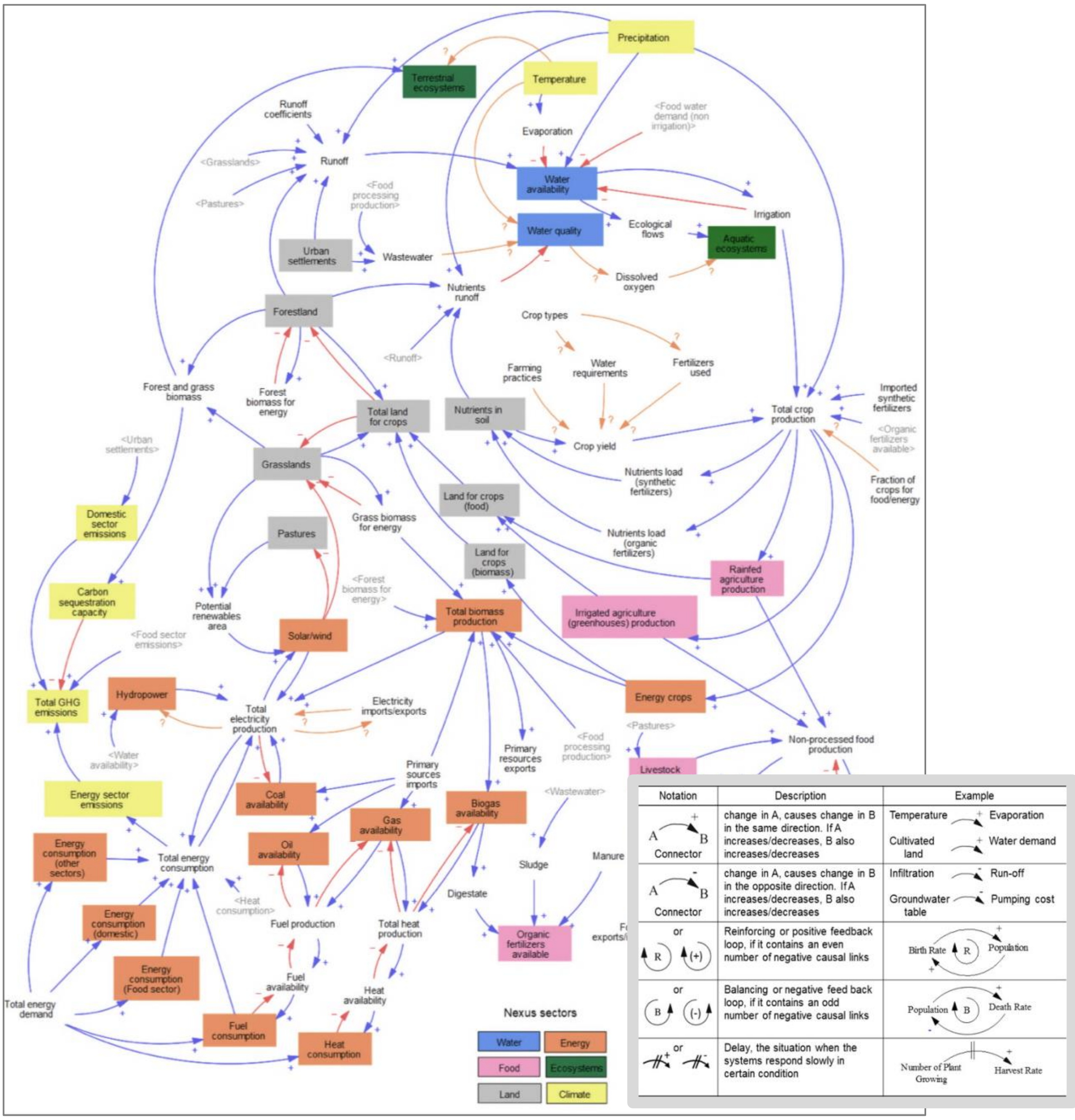

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Figure 15. Causal loop diagram for Lielupe case-study in the NEXOGENESIS project. *The causal loop diagram represents an effort to extensively map the interlinkages among the variables of the nexus system in the basin - to be shared and discussed amongst stakeholders. The variables are clustered into six nexus sectors: Water, energy, food, ecosystems, land and climate. (Laspidou et al. 2023 – NXG D3.4 - Complexity science models implemented for all the Case Studies: Prototypes and explanatory report/manual for each case-study methodology).*

Step 3: Integration of policy interactions within the SDMs

In parallel to Step 1 and Step 2, assessments of policy instruments (Nexus Governance Assessment and Policy Coherence Assessment) are carried out with stakeholders to identify policy interventions that may be important to consider in the local nexus context (see Section 1, Chapter 2). The assessment culminates in a list of policies (Policy Portfolio - see Section 1, Chapter 2). which have to be translated into the SDMs as policy entry points that interact with the nexus and which might have potentially wider implication beyond the sectoral policy ambitions. The results from this work determine which WEFE variables may be affected by policies and in what way they are affected. The integration of these policy interactions within the SDMs also depends on data availability, therefore, a subsequent round of data-mapping needs to be done.

At this point, it is important to start thinking about relevant nexus-wide output indicators or metrics (tied to the major nexus issues of importance in the case-study) are needed or desired to be able to assess impact to the system and the state of the system. These must be understandable and intuitive to the final users of the data for decision-making. Related to this exercise is another round of mapping which data and other information might be needed in order to arrive at the desired index/metric/number/assessment, and which stakeholder input might be necessary.

Step 4: Developing Stock-and-Flow Diagrams (System Dynamic Models)

The qualitative CLDs are now ultimately translated into SDMs, which are represented as Stock-and-Flow Diagrams (SFD). SFDs are the systems dynamics state-of-the-art approach to model complex problems in a quantitative way (Ford, 2010; Sterman, 2000).

Transitioning from a CLD to SFD is a complex process in itself (Freebairn et al., 2019). It is a more operative approach, providing a formal structure that defines how system elements interact mathematically over time. Therefore, it requires quantifiable variables and defining more clearly a problem to be studied. This modelling effort aims to narrow down the system structure as identified in the CLDs. That is, to reach a level in which quantification is not only possible but it is also policy relevant.

In NXG, the SFD were developed using Stella software. The operationalisation of the nexus domains is evident in the form of a network of stocks, flows and variables aiming to capture a river basin's structural issues from a nexus perspective. "Stocks" represent accumulations of material or non-material quantities (e.g., water stored in a reservoir, population in a region), which change over time through inflows and outflows. "Flows" capture the rates of change of these material or non-material quantities (e.g., water use, birth rates). Together, they enable simulation of dynamic patterns over time. This structured format makes it possible to run scenarios, test policy interventions, and explore the long-term consequences of decisions within complex systems.

Creating thematic models for the SDMs

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In some cases, very specific "thematic models" can or may need to be developed and included in the SDMs to represent aspects of the WEFE nexus that require a very high level of detail for decision-making by stakeholders. These thematic models are developed with other modelling tools to deal with site-specific issues and challenges and are complemented with locally-relevant statistical datasets to capture the specific variables not dealt with in the global datasets. The development of the thematic models requires the following collaborative work in this approximate order:

1. Stakeholders and modellers identify if such thematic models are necessary
2. Modellers define the additional modelling tools to develop the thematic models
3. Data experts and modelers reconcile and vet the use of global-to-local datasets
4. Stakeholders validate the thematic model and data experts and modelers refine based on feedback
5. Modelers define how the thematic models will be integrated into the SDMs

In NXG, this approach was taken for the Adige and Nestos-Mesta case studies, which used external thematic modelling outputs to augment the SDMs. For the Adige case-study, the *ARIES - ARtificial Intelligence for Environment & Sustainability* tool was used to create a specific thematic model of ecosystem service supply, demand and flow for the ecosystem domain of the WEFE nexus (see *Laspidou et al. 2023 – NXG D3.3 - Final report on the application of biophysical models and stakeholder recommendations*).

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Figure 16: Causal Loop Diagram of WEFE sectors for Adige River Basin case-study. *The diagram was developed by integrating information coming from experts' knowledge, literature review and opinions of different stakeholders. Its corresponding stock-and-flow diagram is presented in Figure X below. ([Laspidou et al. 2023 – NXG Deliverable 3.4 - Complexity science models implemented for all the Case Studies: Prototypes and explanatory report/manual for each CS methodology](#)).*

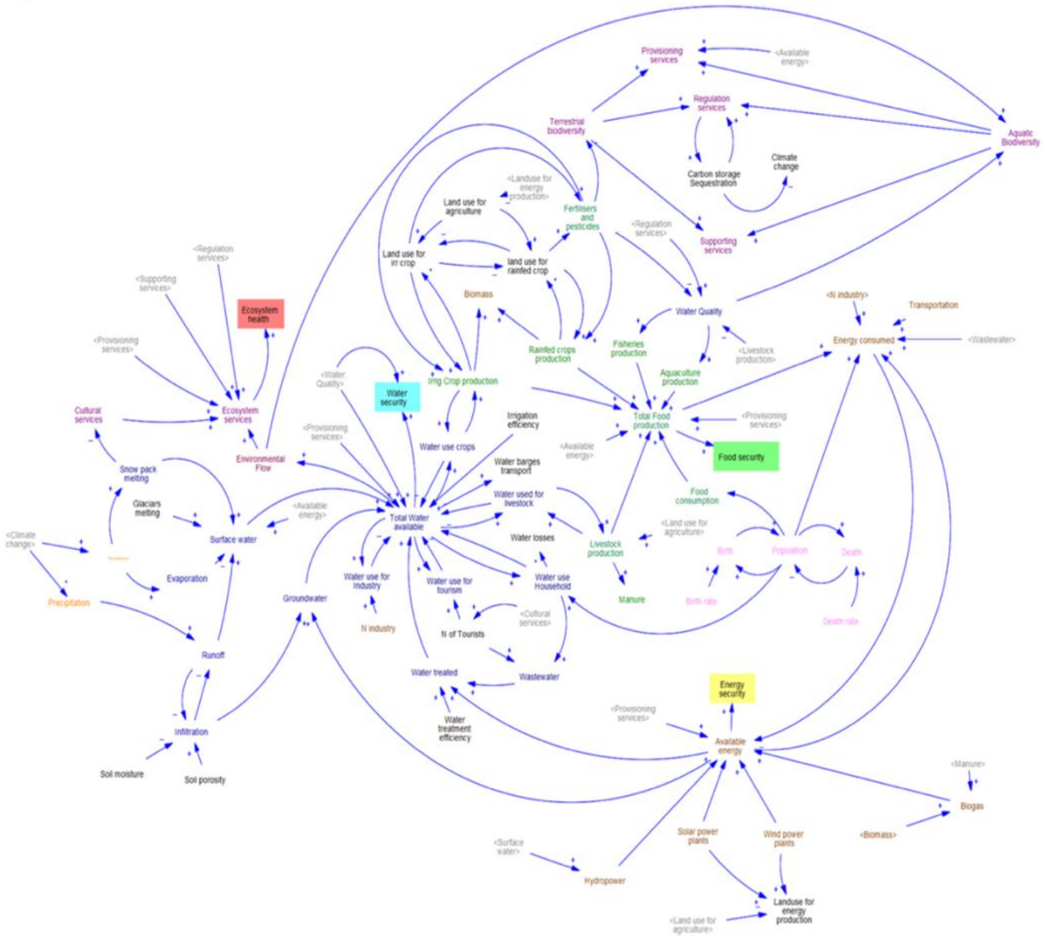

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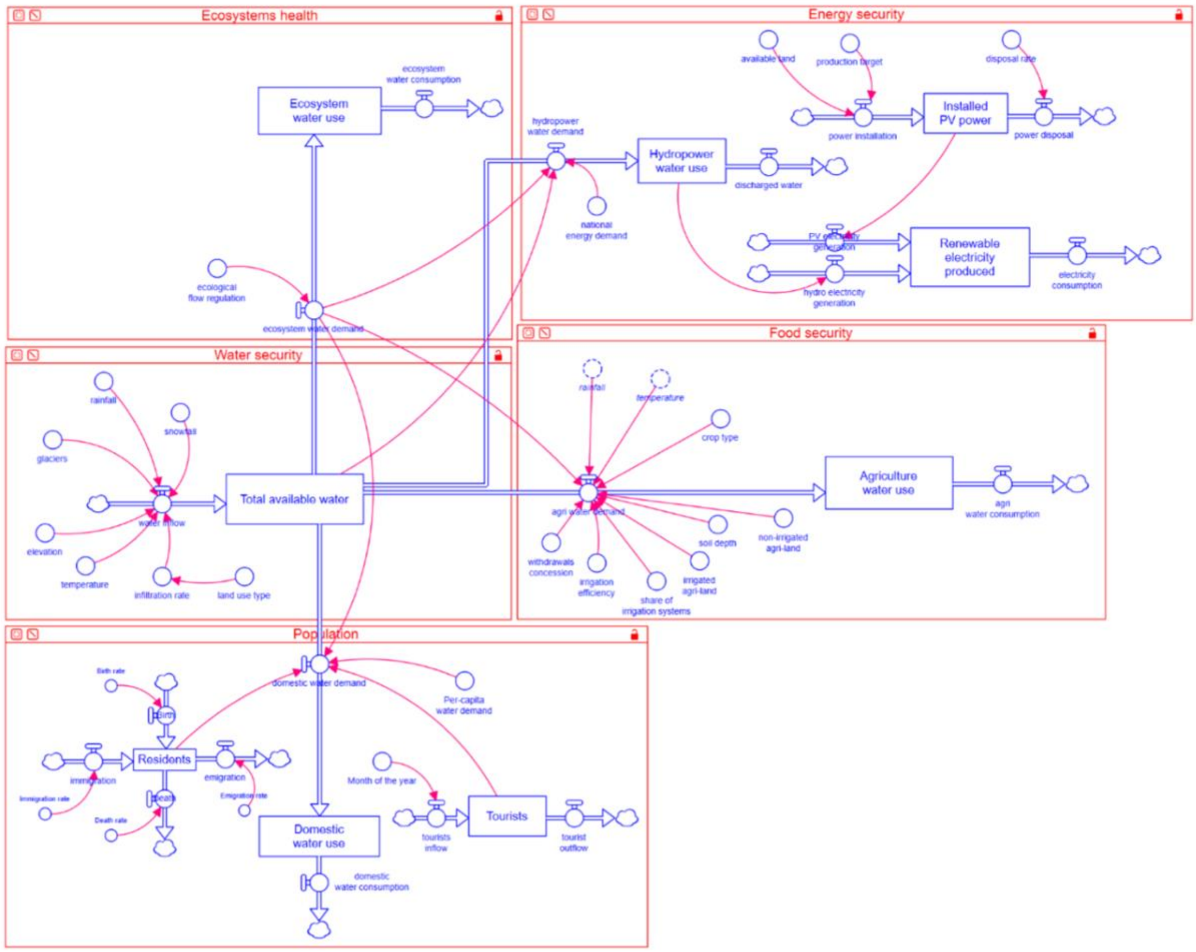
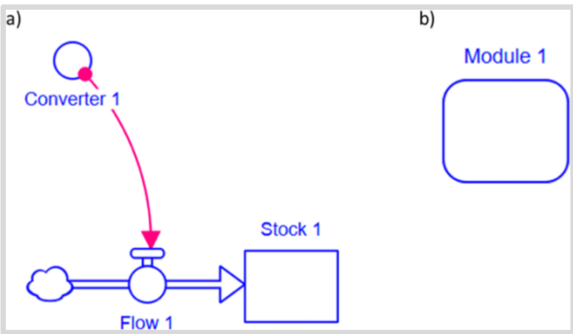
Figure 17: Stock-and-flow diagram prototype for WEFE sectors for Adige River Basin*. The prototype for the system dynamics model for the Adige River Basin case-study in the NEXOGENESIS Project. This is the stock-and-flow diagram developed in Stella Architect. For some of the selected sectors, dedicated physically-based models have been applied to represent complex conditions of water availability and sectorial water demand. Its corresponding causal loop diagram is in Figure 15 above. ([Laspidou et al. 2023 – NXG Deliverable 3.4 - Complexity science models implemented for all the Case Studies: Prototypes and explanatory report/manual for each CS methodology](#)).*





The core modelling elements in STELLA SDMs, comprising stocks (square box), flows (large arrow with the 'valve' and 'cloud' marked "Flow 1") and converters (small circle). Connectors (pink arrow) transmit information between model elements; b) the STELLA 'rounded box' within which nexus sector (e.g. water, energy) modules are contained, or within which parts of nexus sectors (e.g. water supply, electricity consumption) are contained. (Sušnik et al. 2021)

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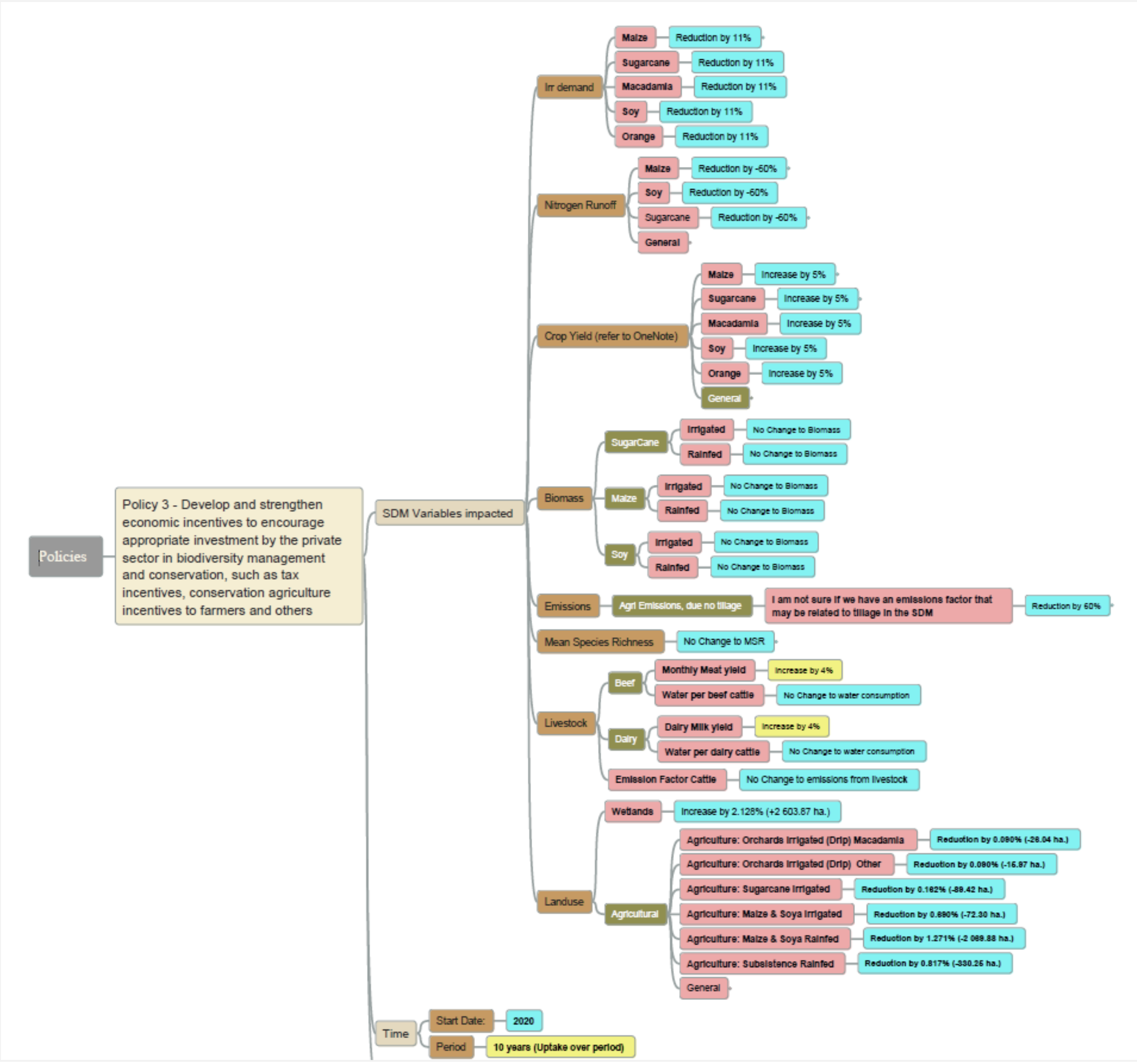
Step 5: Populating the SDMs with data

To quantify the connections and variables in the SFDs, the process of data mapping that was conducted in Step 1 is now repeated again. The exercise is conducted using the same 'data mapping matrix' in previous steps. Figure X shows the mapping out of SDM variables for each policy instrument and determining what data (indicator) is available to model reference scenario and policy impacts.

Figure 18: Quantification of system dynamic variables for policy instruments. *The figure shows the variables considered and included in system dynamic models for Policy 3 of the Inkomati-Usuthu case-study of the NEXOGENESIS project. The brainstorming process is highlight with the note for the 'emissions' variable, in which the NXG team is determining what can or cannot measured and included in the SDM. (Figure: Jones & Wagener, 2024)*



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Step 6: Simulation and model validation

Once the SDMs have been built, test simulations must be run to evaluate how the model behaves under different scenarios. Results are validated by comparing the simulated results (generated from the global and local datasets with observed data). The modelling team, data team and stakeholders should be collectively involved in the process of vetting whether the simulation outputs make sense, cross-referencing their expert and local knowledge, also against scientific literature. If there is gross unalignment, the following measures can be conducted:

- Connections between the variables in the models are rechecked (missing connections, inaccurate connections)
- Variables are rechecked (missing variables, inaccurate variables)
- Dataset is rechecked (missing data, incorrect data)

Step 7: Uncertainty, Sensitivity & What-If Analysis

Decision-making in the policy realm is not straightforward because there are unpredictable factors that can affect the certainty of any particular outcomes. For example, a new technology may affect how resources are used. Unpredictable elements introduce variability in the response of nexus systems to policy actions, making it challenging to make decisions with confidence. This is where uncertainty and sensitivity analysis become important; it helps policy-makers understand the range of possible outcomes rather than just one fixed result.

Sensitivity analysis helps to explore how changes in input parameters of the SDMs influence the outputs of the SDMs. Uncertainty analysis quantifies the likelihood of different outcomes and its impact on system behaviour. These analyses are ongoing processes carried out to assess the system response to likely changes (e.g. climate, socio-economic futures) and hypothetical changes (i.e., elements that can change randomly, e.g., economic factors or public behaviour). Therefore, it helps stakeholders explore “what if” scenarios to see how a policy might perform under different conditions.

If a singular deterministic projection was used as for policy and planning, the ‘bandwidth’ of potential uncertainty in the future unfolding of the world would be missed, with only the single future being considered. This means that circumstances might be missed, for example higher or lower water availability, higher or lower crop water demands. By seeing and considering the range of uncertainty, the full range can be taken into account when planning for different futures. This means that policy, development, and strategies are likely to be more flexible and adaptive to a wider range of conditions that may be faced.

In policy-making, uncertainty analysis is particularly crucial for:

- Risk Assessment: Evaluating policy performance under best -and worst-case scenarios and devising contingency plans.
- Strategic Planning: Devising policies that are resilient and robust even if future conditions change unpredictably.
- Communications: Competent and responsible communication of risks and trade-offs to stakeholders and the public.

Sensitivity Testing

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Sensitivity testing explores how changing one parameter in the SDM (e.g., changes of +/-20% from the original, baseline value) at a time and impacts the model's outputs. Model outputs that are more sensitive will display a greater level of variability to these changes in the input parameter, and vice versa. If output variable changes are relatively large for a given input change, this is referred to as a sensitive parameter. Likewise, if large input changes reveal little change in output parameters, then this is an unsensitive situation. Identifying sensitive parameters in a model is important because:

- Checking model accuracy: If outputs are seen to be highly sensitive to the value of specific input parameters, then it is critical to ensure that those input parameters are as accurate as possible. Small changes in those inputs (e.g., due to inaccuracies in data collection) could lead to large responses in model output variables, with outputs potentially no longer being representative or reasonable for a given variable. As such, it can be seen where to focus effort in ensuring that model inputs are as accurate as possible.

- Identifying policy levers: Identifying the most sensitive output variables in response to changes in inputs can help in highlighting which potential policy changes may lead to the greatest impacts on the WEFE system, and can also indicate if there may be significant unintended consequences on other WEFE domains that were not anticipated. The nature of that impact can also be assessed – is the impact on the system desired (a positive impact) or not (a negative impact)?

Sensitivity analysis can be conducted as:

- **One-Factor-at-a-Time (OAT) Sensitivity Analysis**: To identify which parameter most influences the SDM's output, by changing the value of one uncertain parameter and observing how the model output changes, while all other parameters are kept at their nominal values or their mean

- **Multi-Factor Sensitivity Analysis**: To understand the joint effects of multiple uncertain parameters, by running simulations with combinations of simultaneous parameter variation

What-if Testing

What-if analyses are subtly different to sensitivity and scenario analyses. They are concerned with asking questions of "what if such an event were hypothetically to occur? What would be the system response?" So, what-if analyses do not necessarily need to reflect reasonable futures scenarios, but can be used to stress test systems to see for example where collapse points lie – is there a threshold beyond which system behaviour qualitatively changes or beyond which a certain system parameter (e.g., water availability) collapses (e.g., water is no longer available). Such analyses can be at least instructive, and can start to demonstrate where such thresholds may lie. As such, real-world variables can be monitored, and warnings can be sounded if they start to approach a critical or threshold value that should not be approached or crossed because it would lead to undesirable system behaviour or undesirable system state that is irreversible. As evident, what-if analysis in simulation models allows safe and efficient testing of an unrealistic or dangerous situation that would be unsafe, expensive or unethical to reconstruct in the real-world. Such analyses can be instructive for real-world decision making. What-if tests can be carried out within the SDMs, for example on individual policies, or on extreme climate scenarios, etc.

Uncertainty Testing

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This testing allows for the variability and unknown knowledge in data to be characterised and quantified, including its impact on SDM outputs. Two main sources of uncertainty should be tested: parametric uncertainty and scenario uncertainty.

Parametric uncertainty deals with exploring the uncertainty associated with the values of the SDM parameters and assessing its overall impact to SDM results. It acknowledges that these parameter values might not be precisely known or that there is variability in the true values of these parameters and therefore, this uncertainty influences the model's projections. For example, crop yield data given by different global datasets (produced by different external models), often have a range of values for the same variable (e.g. irrigated maize yield per hectare). As a result, it is worth exploring the entire ensemble of the range of values coming in from the various global datasets and assessing the impact of this on the SDM outputs. **Figure 19** (below) illustrates how this this range of model uncertainty can be explored.

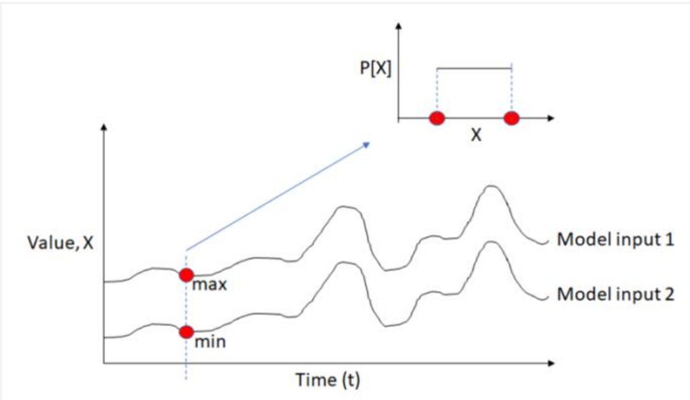

Figure 19: Concept behind model parametric uncertainty in the System Dynamics Models. *A variable, X, is given by multiple external models. These models give a range of values for this variable over time. At each time point, the range in model values gives a minimum and a maximum. Between the min and max values, one can assume, in the absence of better information, a uniform statistical distribution of values. All values between min and max have equal probability of occurrence. Outside this range, the probability is zero. (Source: Sušnik, J., et al. 2024 – NXG D3.6, Sensitivity/Uncertainty Analysis Report).*

The figure above shows that a variable, X, is given by multiple external models. These models give a range of values for this variable over time. At each time point, the range in model values gives a minimum and a maximum. Between the minimum and maximum values, one can assume, in the absence of better information, a uniform statistical distribution of values, illustrated by the inset in the figure. In this concept, all values between minimum and maximum have equal probability of occurrence. Outside this range, the probability is zero. Stochastic Monte-Carlo sampling of a uniform distribution between minimum and maximum for this parameter is propagated through the SDMs, with all affected variables being impacted by the value selected on each Monte-Carlo simulation. In this way, by performing a sufficient number of sample runs (e.g. 100), the uncertainty associated with a given parameter, as well as its impact across the entire SDM output, can be assessed. **Figure 20** below gives a tangible example of applying parametric uncertainty testing to streamflow dynamics. Ioannou and Laspidou (2022) also present how parametric sensitivity analysis was performed in the Nestos (Greece) case-study of the NXG project to identify which parameter the SDMs were most sensitive to. This was then used to quantify the extent to which policies supported the resilience of the WEFE nexus system.

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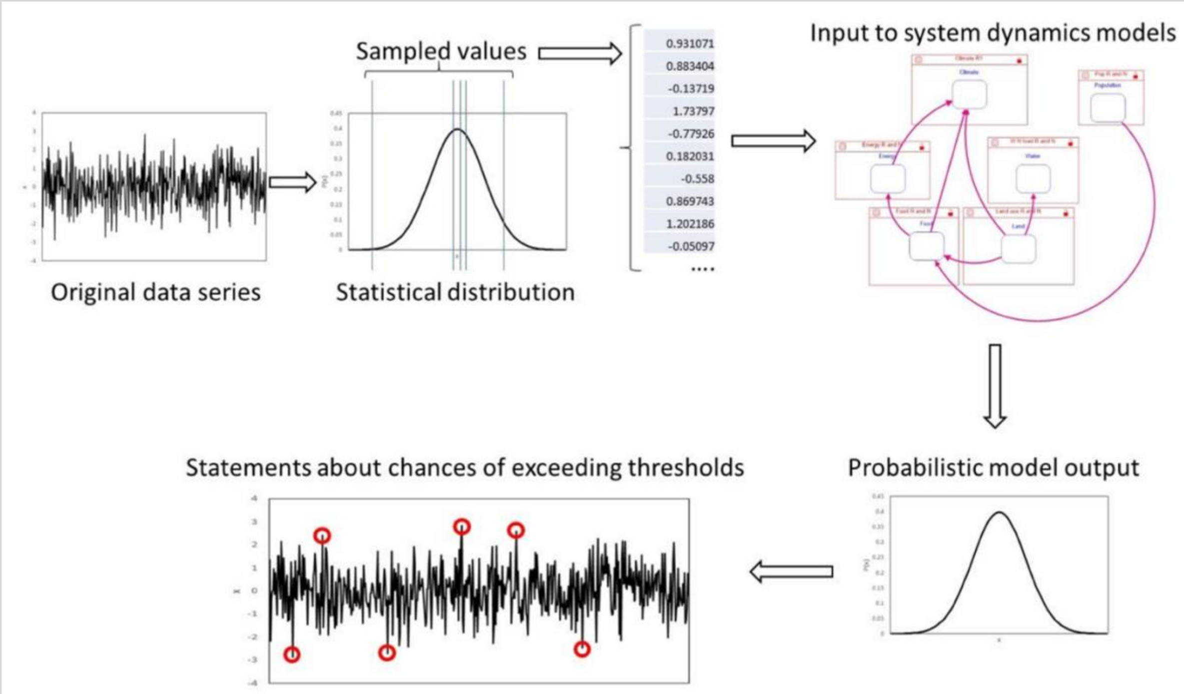

Figure 20: Schematic of parametric uncertainty testing. *Example using streamflow: under a deterministic set of results, policies would be designed considering only one streamflow value in the future. With a bandwidth of possible streamflow values in the future (via parametric uncertainty testing), a policy can be designed more flexibly to account for average streamflow with a lower probability of extreme events such as floods and droughts (red circles). (Source: Sušnik, J., et al. 2024 – NXG D3.6, Sensitivity/Uncertainty Analysis Report)*

Scenario uncertainty acknowledges that the future is uncertain and deals with assessing future projections of a system's development across different climate and socio-economic development scenarios, which are not known a-priori. For example, different SSPs give rise to a variety of estimations around population trends, the level of demand for certain products, the supply and availability of different materials, and so on. Likewise, different RCPs give rise to differences in, for example, precipitation patterns, temperature patterns, crop yields, and crop water requirements. There is also some relationship between the RCPs and the SSPs. The differences between SSPs and RCPs represent scenario uncertainty, which can be captured by testing different scenario combinations: RCP26-SSP2; RCP26-SSP4; RCP85-SSP2; RCP85-SSP4. **Figure 21** illustrates the concept of uncertainty associated with different scenario sets.

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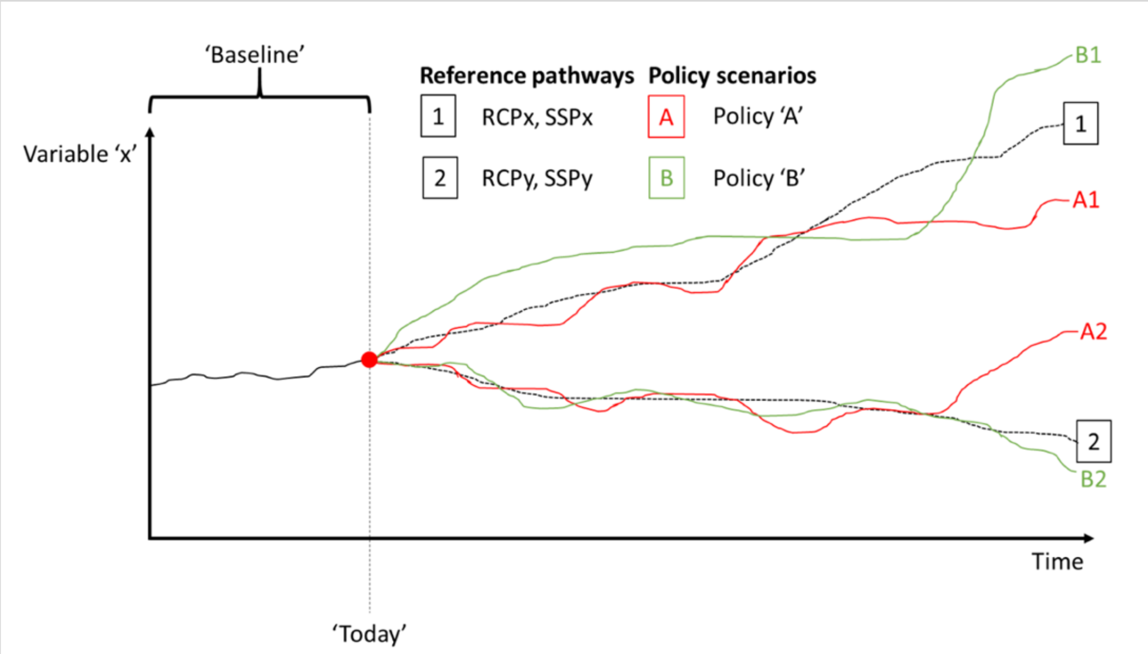

Figure 21. Concept of uncertainty associated with different scenario sets. *System Dynamics Model outputs can be derived from different combinations of Representative Concentration Pathways and Shared Socioeconomic Pathways. The 'baseline' (solid black line), 'reference scenarios' (dashed black lines), and 'policy scenarios' (red and green lines) concepts are shown. The given impact for any specific policy (Policy 'A' or 'B') can change depending on the underlying reference scenario ('1' or '2') on which it is imposed (denoted 'A1', 'A2', 'B1', 'B2'.). (Source: Sušnik, J. 2022)*

More information about and the detailed workflow for conducting uncertainty assessment, scenario analysis, and sensitivity tests are available in the *Sušnik et al. 2024 – NXG D3.5 - Sensitivity and uncertainty analysis* and *Sušnik et al. 2024 – NXG D3.6 - Sensitivity and uncertainty analysis report.*

Step 8: Translating the SDMs from Stella Architect to Python into the NEPAT

SDMs become the 'simulation environment' or the 'foundation models' that feed into the NEPAT to assess the impacts of multiple policy implementations against multiple (competing) objectives. The SDM data files (Stella Architect format) are automatically translated into Python code, for use within NEPAT via its SDM Translator.

Step 9: Summary of policy data for the NEPAT

For NEPAT to conduct its multi-objective analysis, the following data must be systematically collated and organised. These data would have already been decided upon throughout the previous steps: policy goals, policy targets, policy instruments, entry point of the policy in the nexus, assumptions for the models, and variables/ parameters to include policies into the models. For examples of the type of data needed, see *Echeverria et al. (2024) – NXG Deliverable 4.3 Simulation policy framework*

WEFE FOOTPRINT INDEX

The WEFE Footprint Index shows the status of water, energy, food, and ecosystems in a given case study, at a particular point in time, for a particular modelling scenario. It was designed as:

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- A tool to communicate the status of each resource sector and their synthesized contribution to sustainability and resource security;
- A means to communicate the integration/aggregation of sectors and any trade-offs, impacts, or conflicts that may exist; and
- A tool to demonstrate how governance and policies can facilitate sustainability.

The WEFE Footprint is built using a **composite indicator methodology** developed by the *Joint Research Centre's Competence Centre on Composite Indicators and Scoreboards* (JRC-COIN). An **indicator** is a quantified representation of a specific system attribute. It can take the form of numbers, symbols, graphics, or colours and is always interpreted relative to a baseline or reference value. A **composite indicator** combines multiple socio-economic and biophysical variables into a single, aggregated measure (or score). For more detailed information on the development of the WEFE Footprint, see *Haupt et al. (2024) - NXG D3.7 - Final report on the WEFE Nexus Index methodology and visualisation*. ***Figure 25*** also provides an overview of the major steps of the process, corresponding to the methodological steps of the Joint Research Centre's Competence Centre on Composite Indicators and Scoreboards.

The footprint compares the status of the WEFE system under a Reference Scenario (based on combinations of SSPs and RCPs - without policy interventions) with the status of the system if one or more policy interventions were introduced to a given reference scenario, aiming to meet specific goals.

The WEFE nexus indices represents the interconnectedness of water, energy, food, and ecosystems across scenarios, spanning a 35-year period (2015–2049). The calculation is based on the input and output data from the SDMs. For example, in NXG, sample of these were: water-related parameters (water withdrawals, surface water resources, etc.), energy-related parameters (CO_2 emissions), food related parameters (crop per drop), and ecosystems-related parameters (total protected area, total nitrogen load, species richness, forest area). Each indicator is also linked to specific Sustainable Development Goals (SDGs).

Indicators are organised into pillars (Water, Energy, Food, Ecosystems), sub-pillars, and individual indicators (see **Figure 22** and **Figure 23**). The indicator selection process has to be a rigorous and participatory process amongst the data experts, modelling experts and stakeholder – to ensure both scientific credibility and stakeholder relevance.

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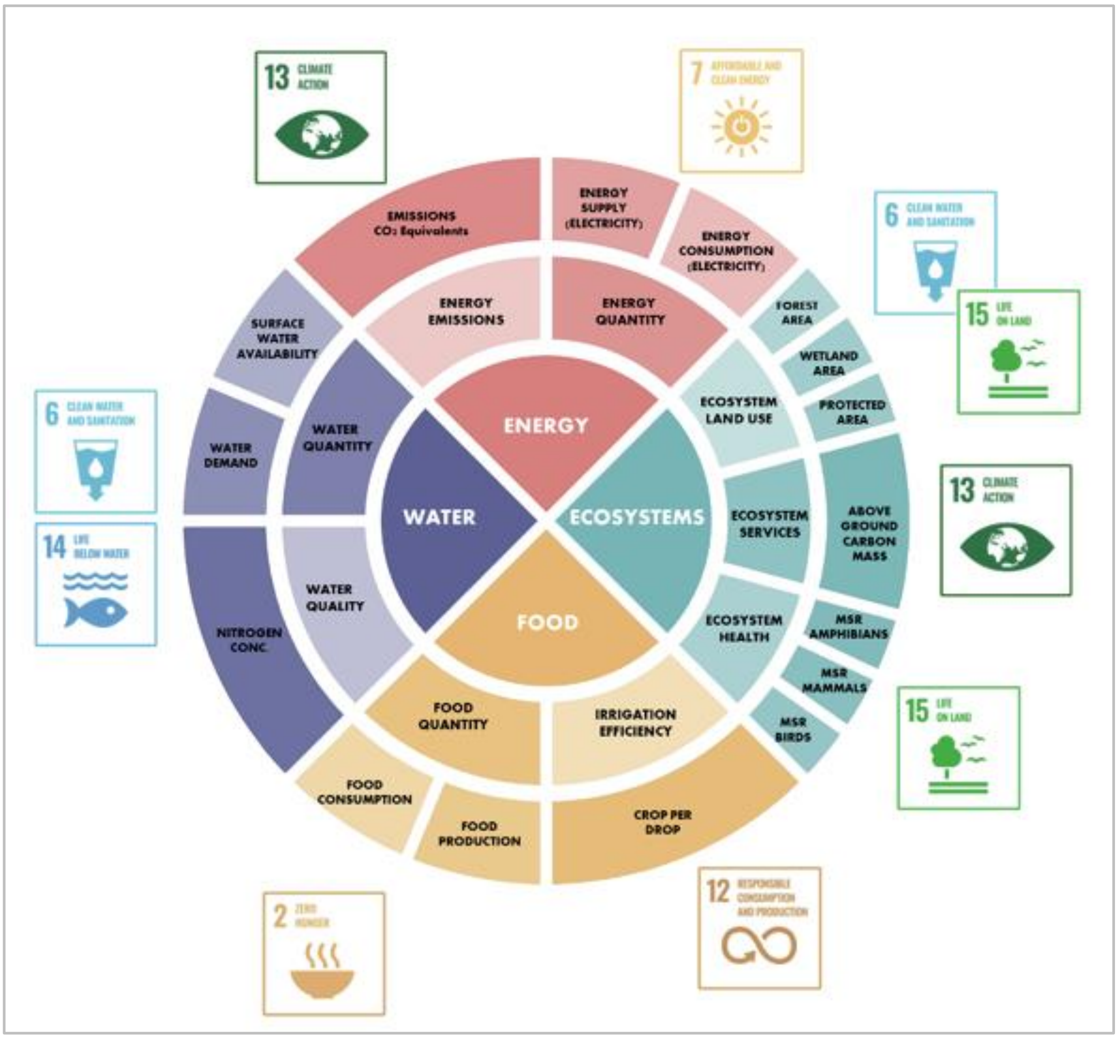

Figure 22: Schematic 1 of the concept of the WEFE Footprint Index. Pillars (central circle), sub-pillars (middle circle) and indicators (outer circle) of the Water-Energy-Food-Ecosystem (WEFE) Footprint Index, developed in the NXG project. Linkages to the UN SDGs are also highlighted. (Source: Jones & Wagener Consultants, 2024)

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Figure 23: Schematic 2 of the concept of the WEFE Footprint Index. *Pillars, sub-pillars and indicators of the Water-Energy-Food-Ecosystem (WEFE) Footprint Index, developed in the NXG project. (Source: Jones & Wagener Consultants, 2024)*

Figure 24 (below) represents the final WEFE footprint at a pillar level. This provides an indication of the status of the Nexus and the four sectors for a given case study, reference or policy future scenario, at a point in time with an overall index score of 15.68 for the Nexus. When looking at the circle one can see a score of -100 towards the centre of the footprint and a score of 100 toward the outside of the footprint. In between there is a value of zero. The value of zero in this case indicates that the pillar value has not changed from the value at the initial timestep. A value between 0-100 means a move in a positive direction and a value between 0 and -100 represents a move in a negative direction from the initial value. This image represents the footprint at a sub-pillar level, one can see that for Water, Food and Ecosystems all sub-pillars appear to have moved in a positive direction; however energy quantity has moved in a negative positive direction however as this is the Inkomati case study where coal is the most prolific source of energy the emissions sub-pillar moves in a negative direction.

For more detailed information on the development of the WEFE Footprint, see Haupt et al. (2024) - NXG *D3.7 - Final report on the WEFE Nexus Index methodology and visualisation.*

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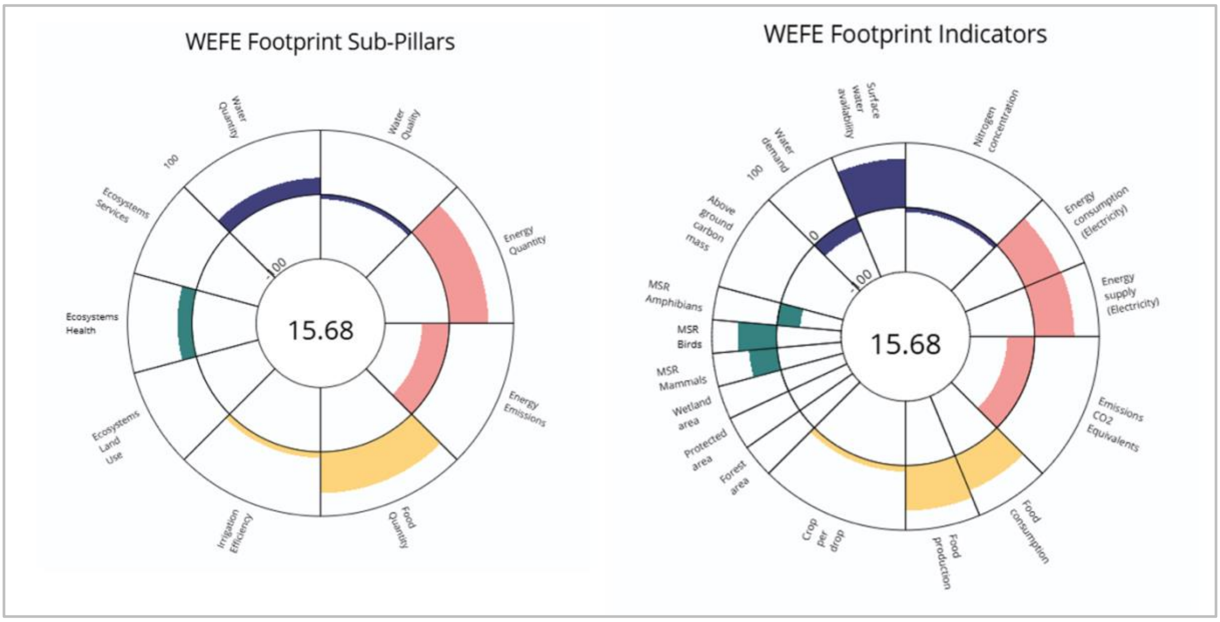
Figure 24: Sample radar plot of WEFE Footprint Index. *Sub-pillars (left) and corresponding indicators (right) of the Water-Energy-Food-Ecosystem (WEFE) Footprint Index – as is visualised in the NExus Policy Assessment Tool – NEPAT. The radar plot show contributions from each indicator, sub-pillar, and pillar to a composite index score (centre). (Source: Figure produced by Jones & Wagener Consulting, as visualised in the NExus Policy Assessment Tool – NEPAT, Eurecat 2025)*



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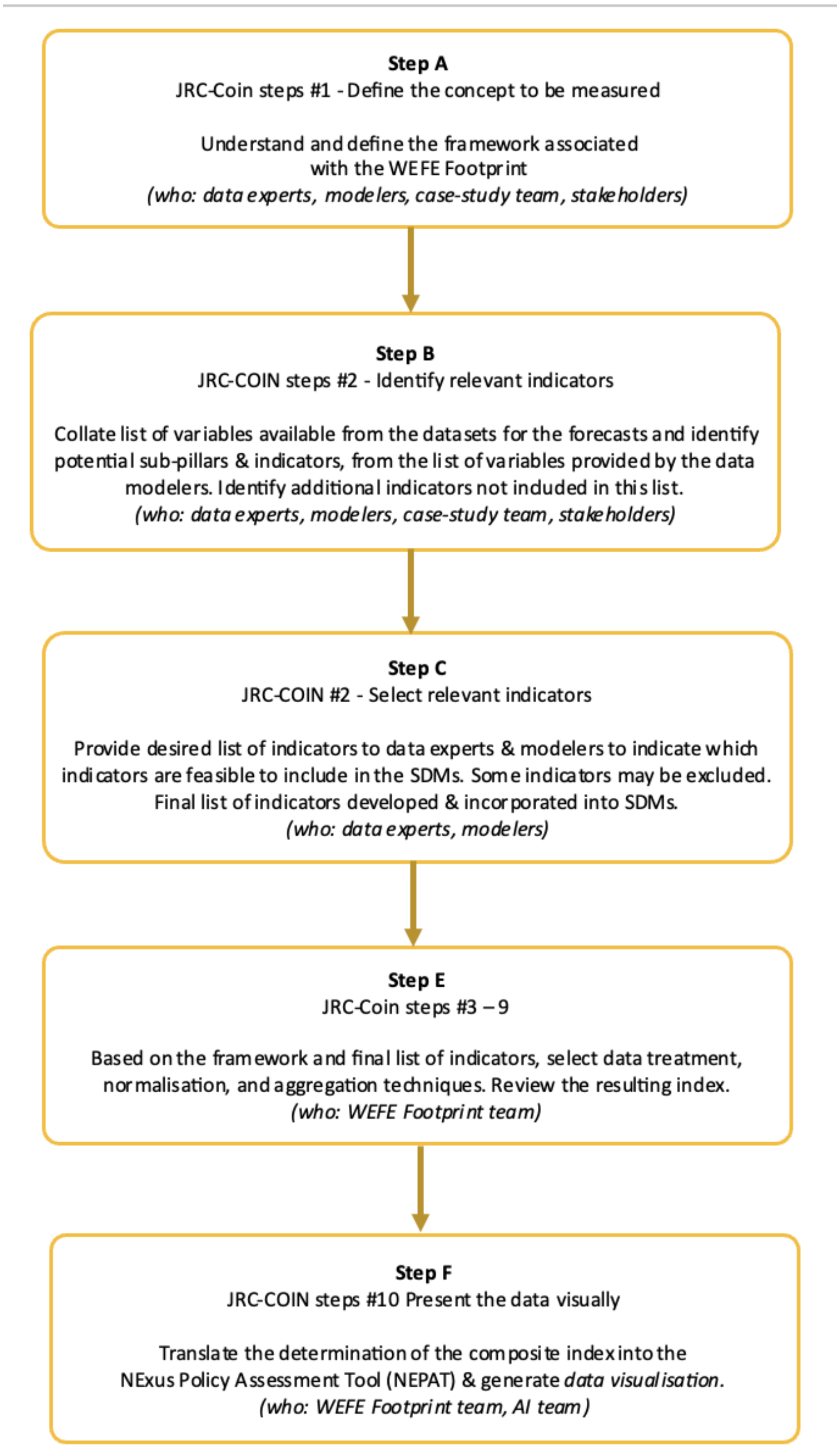

Figure 25: Overarching steps in creating the WEFE Footprint Index. *Overview of the major steps corresponding to the methodological steps of the Joint Research Centre's Competence Centre on Composite Indicators and Scoreboards.* For more detailed information on the development of the WEFE Footprint, see *Haupt et al. (2024) - NXG D3.7 - Final report on the WEFE Nexus Index methodology and visualisation.*

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FINAL REMARKS

Complexity science modelling requires 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 already, *through dialogue alone*, significant progress in integrative actions can be made without recourse to quantitative modelling. As stakeholders are already invested at this stage, and have offered input and advice, future model and NEPAT results are more likely to be engaged with and proposed solutions considered for real-world implementation.

4.3.2 Chapter 5 - Nexus Policy Assessment & Stakeholder Validated Policy Packages

NEXUS POLICY ASSESSMENT USING ARTIFICIAL INTELLIGENCE

Integrative policy-making is essential for achieving the UN Sustainable Development Goals (SDGs), but achieving this requires analyzing numerous policy combinations to understand how they produce trade-offs and synergies amongst the SDGs. The sheer number of combinatorial possibilities that could be vetted (and because of the high stakes, should be vetted) exceeds the capabilities of current manual modeling tools. **This is where machine learning comes in.**

The ***NExus Policy Assessment Tool*** **(NEPAT)**[1] is an interactive online platform that facilitates the analysis of these complex and numerous interactions and offers policy-makers the possibility of evaluating the outcomes of decisions before policy implementation. It uses systems dynamics models and multi-objective reinforcement learning to assess policy performance against multiple policy objectives, handling billions of combinatorial policy configurations, within seconds[2]. Specifically, NEPAT analyses the interactions between the WEFE resources and associated policies across different coupled climate and socio-economic scenarios. It provides stakeholders with the following functionalities to support policy design:

1. **Policy Impact Evaluation**: Assesses the effects of policies on WEFE sectors under future scenarios that integrate long-term climate change projections and structural societal change projections;

2. **Artificial Intelligence Tool for Policy Recommendations**: Delivers customized policy suggestions to efficiently achieve nexus-related goals; and

3. **Facilitates Collaboration**: Encourages informed dialogue and cooperative decision-making on WEFE challenges.

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[1] Use "guest login" to explore NEPAT. Use the user guide: https://nexogenesis.eu/wp-content/uploads/2025/04/NEPAT-User-Guide.pdf

[2] *In the NXG project, the Inkomati-Usuthu river basin case-study had the largest amount of policy scenarios that were evaluated, which is* 8^{10}*. NEPAT can conduct the analysis of each policy scenario within seconds.*

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NEPAT integrates the outputs that are developed in the Co-Explore (Section 1) and Co-Design (Section 2) phases of the co-creation process.

- **Policy Portfolio**: Policy goals and policy instruments to be assessed for interactive impacts across the WEFE domains (synergies, trade-offs)
- **System Dynamic Models:** Complexity science tool which provides the foundation models (simulation environment) against which the NEPAT impact analysis is run
- **WEFE Nexus Footprint Index:** An index linked to the SDMs that is based on a (WEFE)-domain specific indicators describing the degree to which the reference and policy instruments affect these indicators

A use case–driven methodology guided the design of NEPAT, enabling the systematic evaluation of diverse user scenarios to determine the required and feasible system functionalities. Initial proposals were then informed by feedback from the NXG project team and stakeholders during interactive, hands-on training, demonstration and validation sessions, focus groups and workshops with the project team and with stakeholders.

This chapter provides a high-level overview of the artificial intelligence approach deployed in NEPAT, the functionalities offered to support handling the complexity of nexus decision-making challenges and NEPAT's role within the NXG co-creation process. Specifically, to the latter point, in this co-design phase, stakeholders use NEPAT to explore the performance of policy packages (achievement of nexus policy goals) and impact on the nexus resources within decision-making scenarios and make joint decisions on acceptable results to move forward with elaborating policy design and implementation.

A step-by-step manual (Eurecat 2025) for using NEPAT is available on the *NXG website here.*

WHY USE NEPAT?

NEPAT was developed to address the inherent complexity of WEFE nexus systems, which are characterized by non-linear dynamics (i.e., system responses are not proportional to inputs, and interactions can produce feedback loops or threshold effects) and systemic uncertainty (arising from variability in natural processes, incomplete data, and unpredictable human responses). In such systems, stakeholder interventions—expressed as policy combinations—represent a wide array of possible responses to system behaviour.

Further complexity arises from scenario constraints (e.g., institutional feasibility, etc.), a high number of temporal decision points (i.e., moments when interventions can be implemented), and the interconnected, path-dependent nature of response of WEFE systems to policy interventions. When a lack of knowledge and inherent variability are considered, the problem becomes non-deterministic; even with a complete model structure, future outcomes cannot be precisely predicted. This significantly increases the difficulty of identifying robust policy solutions capable of performing well across a range of possible futures.

The number of these combinations increases exponentially with the number of policy levers and objectives. Nexus governance is inherently multi-objective, involving trade-offs across WEFE domains. Furthermore, identifying effective interventions among all combinations of policy instruments constitutes a combinatorial optimization problem. Traditional optimization approaches are insufficient for exploring this vast solution space, as evaluating each policy combination

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individually would incur prohibitively high computational costs and would not be feasible within the timeframes relevant for policy-making.

NEPAT was designed to provide support in such extremely complex and challenging policy decision-making scenarios, reducing cognitive overload in navigating these combinatorial considerations. Specifically, NEPAT enables quick iterative (stakeholder) testing and optimizing policies before implementation, saving time and reducing the risk of policy failure and maladaptive outcomes. It facilitates credible policy decisions by increasing understanding of policy impacts and providing a seed to kick-start discussions on the cross-sectoral coordination required for problem-solving. This leads to greater acceptance and participation in co-creation processes and uptake of outputs into decision-making.

HOW DOES NEPAT WORK?

NEPAT is a web-based decision-support tool designed to assist policymakers by simulating climate and socioeconomic scenarios, providing analytical capabilities, and streamlining the decision-making process.

The **Simulation Policy Framework (SPF)** is a key module of NEPAT, responsible for integrating complexity science models (i.e., the SDMs), WEFE nexus policies, and nexus goals of a case-study, along with the Nexus Footprint Index. This integration results in a module that can be used to simulate the impact of a policy or a policy package across the WEFE nexus at different spatial and temporal scales.

The SPF runs simulations based on user-defined requests, which specify the case study, reference scenario (i.e., an SSP–RCP combination), and the policy package to be applied. It then generates outputs for all nexus variables within the SDMs, quantifying the impact of the selected policy package on the nexus and assessing its performance against policy goals.

Decision Support System

One of NEPAT's most powerful features is its ability to suggest effective policy combinations to achieve predefined goals and policy targets within the WEFE nexus. Therefore, it can perform the analysis using this logic: *Given a set of nexus policies, identify which are the best policy combinations that achieve a set of nexus targets while satisfying a set of restrictions (e.g., policy incompatibilities).*

To do this, NEPAT employs AI and Machine Learning (ML) algorithms to analyse nexus interlinkages and provide policy advice across projected biophysical and socio-economic scenarios. Reinforcement Learning (RL) is the technique used to solve the task of recommending policy packages for achieving different policy goals or improving footprint indicators.

Reinforcement learning techniques are based on the definition and self-training of a set of AI-powered agents. "Agents" are virtual 'decision-makers' designed to mimic the logic of how decisions may be made in the real-world (by decision-makers), according to certain assumptions. Agents interact with the 'simulation environment' – which are the foundational system dynamic models (see Section 2, Chapter 4).

An agent and the environment interact in an iterative cycle: the agent selects an action, the environment responds with a *reward* (feedback on the quality of the action) and a new situation, and the agent adapts its strategy accordingly. Over time, through repeated interaction, agents learn to

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choose actions that maximise rewards. **Figure 26** provides a schematic of this mechanism. This is called the "training" stage.

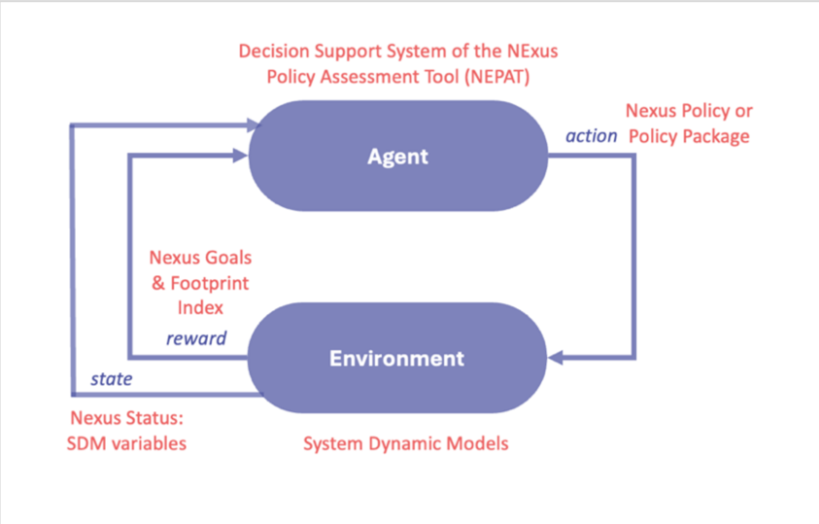

Figure 26. Schematic of the agent-environment-reward mechanism used in the NExus Policy Assessment Tool. *Schematic of the training stage of the artificial intelligence agent. This is operationalised before the agent is deployed to be used in the decision support system of the NExus Policy Assessment Tool (NEPAT). (Adapted from Echeverria et al. 2024 – NXG D4.4 - Core module of the self-learning nexus engine)*

Because nexus challenges are inherently **multi-objective**, the DSS is designed applying **multi-objective reinforcement learning (MORL)**. Unlike standard RL, which optimises a single numeric reward, MORL assigns a separate reward to each objective. By using this technique, agents are able to manage tradeoffs and synergies, ultimately producing a set of optimal solutions representing the most efficient trade-offs. This feature is particularly useful for identifying the most impactful policy measures, optimizing resource management, and adapting policies to different future conditions. Each SDM represents a distinct problem in which an agent is trained until its convergence. This trained agent is then used to provide recommendations in the NEPAT's DSS.

To enable all the simulation functionalities, several main tasks must be completed:

Translation of SDMs into Python: The SDMs describe how nexus variables change over time based on their interactions and are built using Stella (Richmond, 1985), a visual modeling tool. In Stella, users construct models graphically using stocks, flows, converters, and connectors, which implicitly define the mathematical equations governing system behavior. To run simulations within NEPAT, which requires a programmable environment for policy testing and optimization, these models must be translated into Python, where all relationships and dynamics are explicitly coded using functions, equations, and numerical methods. This translation preserves the structure and logic of the original Stella models while enabling step-by-step simulation of system behavior over time. The process produces two Python versions: a deterministic version**,** used by default in NEPAT, and an uncertainty version**,** which allows advanced simulations incorporating variability and stochastic scenarios. The SDMs must have the policies, goal indicators and footprint variables (see Section 1, Chapter 2 and Section 2, Chapter 4) included and to run with no errors. When the translation is complete, it is validated by comparing the results of the executions of Stella and the Python translation with and without the application of the policy instruments. NEPAT's SPF conducts this translation process automatically (more details in *Echeverria et al. (2024) - NXG D4.3 Simulation policy framework*).

Integration of policy instruments and policy goals: As components of the NEPAT Simulation View, metadata for policy instruments (including name and description) and policy goals (including name, description, indicator, target, and target year) are integrated into NEPAT's backend. The Data Manager handles the loading and management of this metadata within the platform.

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Calculation of the WEFE Footprint: The WEFE Footprint calculation within the NEPAT incorporates the normalization function detailed in *Haupt et al. (2024) – NXG D3.7 - Final report on the WEFE Nexus Index methodology and visualisation*. This function requires minimum and maximum values for each WEFE Footprint Indicator, which is computed by the NEPAT Core Service (see *Nievas et al. 2024 - NXG D4.5 Final version of the self-assessment nexus engine with the corresponding validation).*

Training and integration of DSS AI agents: Developing and integrating AI agents that provide tailored recommendations.

The inputs used for these tasks (SDMs, policies, goals, nexus footprint) are under constant validation. This means that as stakeholders deliberate on the NEPAT results, they may choose to add new policies to the Policy Portfolio (see Section 1, Chapter 2), which subsequently requires the collection and integration of new data and re-configuration of the SDMs, meaning all the tasks must be repeated. Similarly, as new global and local data sets are released, the SDMs need to updated, triggering a repetition of these processes.

MAIN FEATURES OF NEPAT

User Experiences for Decision-Making Support

NEPAT has two distinct user experiences, each with its own level of detail and way of visualizing data. The views are interlinked; therefore, stakeholders can switch from one view to the other within the same simulation exercise.

Technical Experience: For users with some level of knowledge and expectation of an extensive and detailed study. It enables in-depth analysis of policy impacts, allowing users to work with detailed simulations, customizable settings, and advanced modelling techniques. It provides insights into numerical evaluations, cause-effect relations, and statistics for scientific reasoning. Examples of technical users are scientists and academics.

Strategic Experience: For users who require easily interpretable information, synthesized and presented in a succinct and clear way, to support high-level policy-making. It presents simplified yet insightful visualizations of policy impacts without requiring in-depth technical expertise. It offers visualization elements (graphs, diagrams) for quick comprehension, easily understandable comparisons of policy effects across different scenarios, summarized simulation results (e.g., indicator evaluations). Examples of strategic users are policymakers, authorities, associations, and general users.

In both experiences, stakeholders have an opportunity to interrogate the results of the analysis through the “Detailed View.” **Figure 27** shows how two policy packages perform in achieving policy goals. **Figure 28** shows how the data is presented in the ‘detailed view’, with regards to the evolution of the impact of the two policy packages on certain WEFE indicators over time. Here, “baseline” indicates the “reference scenario” in which no policy package has been applied in the simulation and therefore, it allows stakeholders to see how an indicator changed in its response to the application of a policy package. Stakeholders can also More information about the full features of NEPAT and how to interpret these visualized results are available in the ***NEPAT user guide here*****.**

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Figure 27: Achievement of policy goals per policy package in the NExus Policy Assessment Tool. *Evolution of the impact of a policy or policy package on the achievement of WEFE goals. The data can be viewed scaled or normalized. (Figure visualised in the NExus Policy Assessment Tool – NEPAT, Eurecat 2025)*

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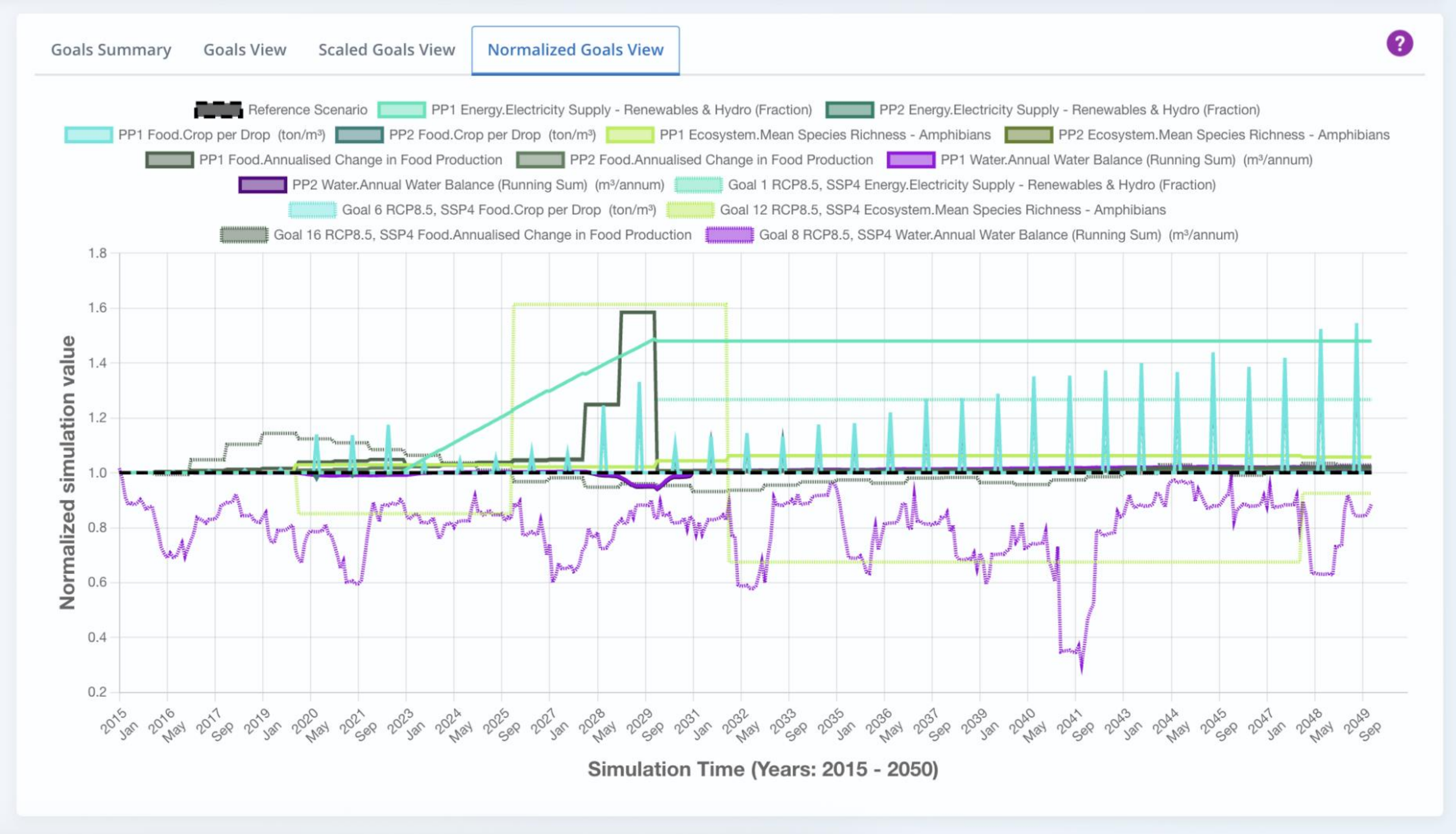
Figure 28: Impact of policy packages on nexus system indicators of system dynamics models. *Evolution of the impact of policy packages on indicators of a system dynamics model. Comparisons can be made between the reference scenario (no policy package applied) and policy scenario (policy package applied). (Source: Visualised in the NExus Policy Assessment Tool – NEPAT, Eurecat 2025)*



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WEFE Footprint Index

The WEFE Footprint provides an assessment of the WEFE system's status, at a particular point in time, for a particular modelling scenario. It visualizes this assessment in a way that is accessible for policymakers, researchers, and decision-makers in identifying key issues on the impact of policies on the WEFE resources.

The visualization includes a breakdown of the index through pillars (water, energy, food, ecosystems), sub-pillars, and indicators (measurable variables of the pillars and sub-pillars), with the **aggregated WEFE Footprint Index** displayed at the center of the diagram (**Figure 29**). The index value will vary between -100 (centre of the circle) and 100 (outside of the circle), where 0 represents the index and associated indicator value at the start of modelling. When modelling is executed, the results may be:

- Positive Values (0 to 100): Indicate beneficial impacts or an improvement of the WEFE system status
- Negative Values (-100 to 0): Indicate detrimental impacts or deterioration of the WEFE system status
- Neutral Value (0): Indicating no impact on the WEFE system status

The particular impacts of policy packages on the WEFE Footprint, pillars, sub-pillars and indicator index values can be observed in the "Nexus Footprint Detailed View" of NEPAT. The view compares reference scenario and policy future scenarios over time (see **Figure 31** below).

For information on the data treatment, normalisation, weighting, direction and aggregation behind the WEFE Footprint Index, see *Haupt at al. 2024 - NXG D3.7 - Final report on the WEFE Nexus Index methodology and visualisation*.

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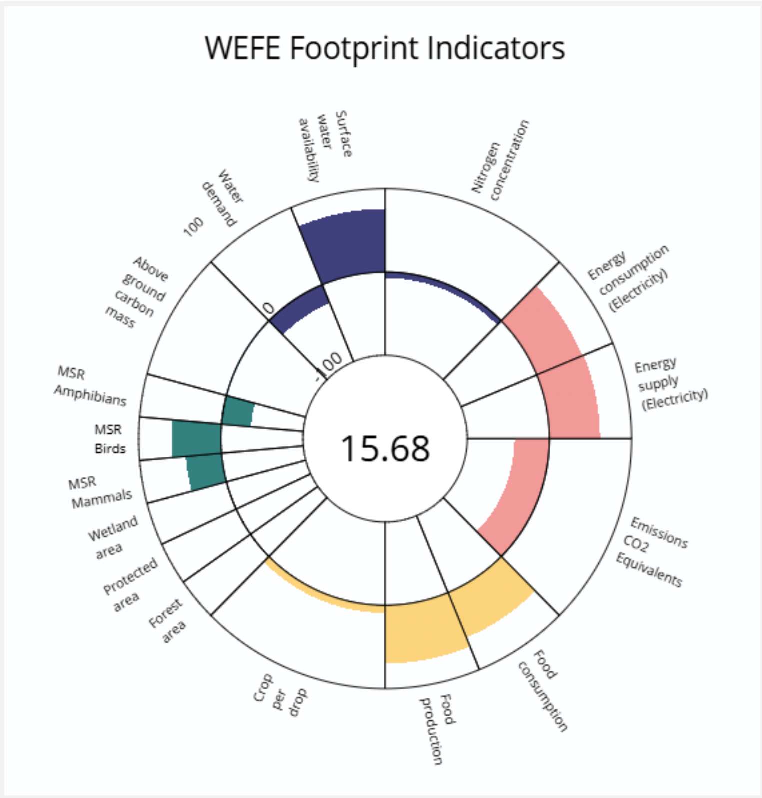

Figure 29 Visualisation of the WEFE Footprint Index in the NExus Policy Assessment Tool. *A breakdown of the WEFE Footprint Index through pillars [water (blue), energy (red), food (yellow), ecosystems (green)], sub-pillars, and indicators. The aggregated WEFE Footprint Index is displayed at the center of the diagram. The index value will vary between -100 and 100, where 0 represents the index and associated indicator value at t0 in the reference scenario. Positive values Indicate beneficial impacts and negative values indicate detrimental impacts on the WEFE system status.* In this example, *"CO_2 emissions" shrink toward the centre over time, thereby reflecting increased emissions. Conversely "local food availability" expands outward, indicating improvement. [Figure produced by Jones & Wagener Consulting, as visualised in the NExus Policy Assessment Tool (NEPAT) - Eurecat 2025]*

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Figure 30: Impact of policy packages on the WEFE Footprint Index. *The 'Nexus Footprint Detailed View' within the NExus Policy Assessment Tool (NEPAT) compares the policy package impact on the Water-Energy-Food-Ecosystem (WEFE) Index (i.e., WEFE system status) against the reference scenario (system status at year 2015, without application of policy package), in timesteps. In this example, the WEFE index is improving over time for both scenarios but the applied policy package (solid line) is showing a higher improvement than the reference scenario (dashed line). (Figure produced in the NExus Policy Assessment Tool – NEPAT, Eurecat 2025).*

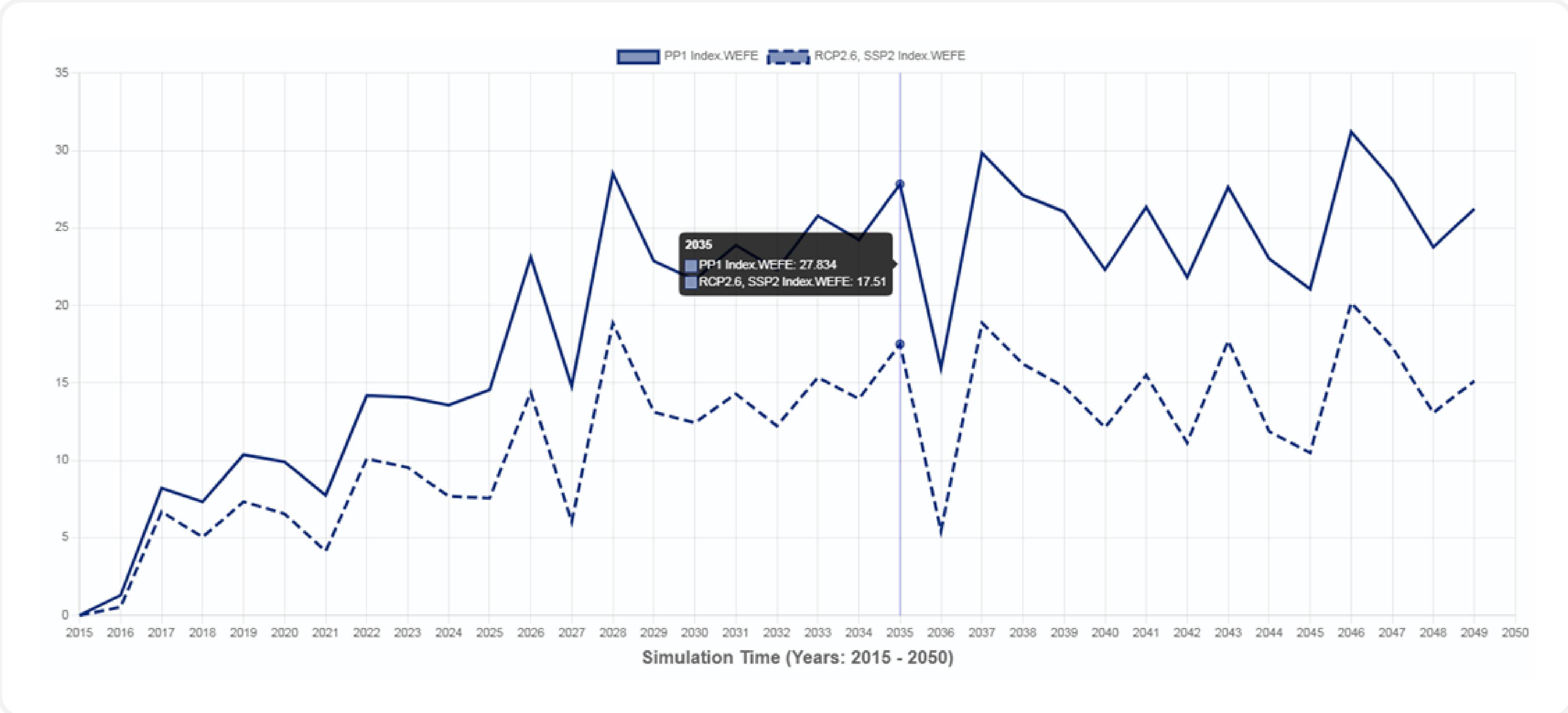

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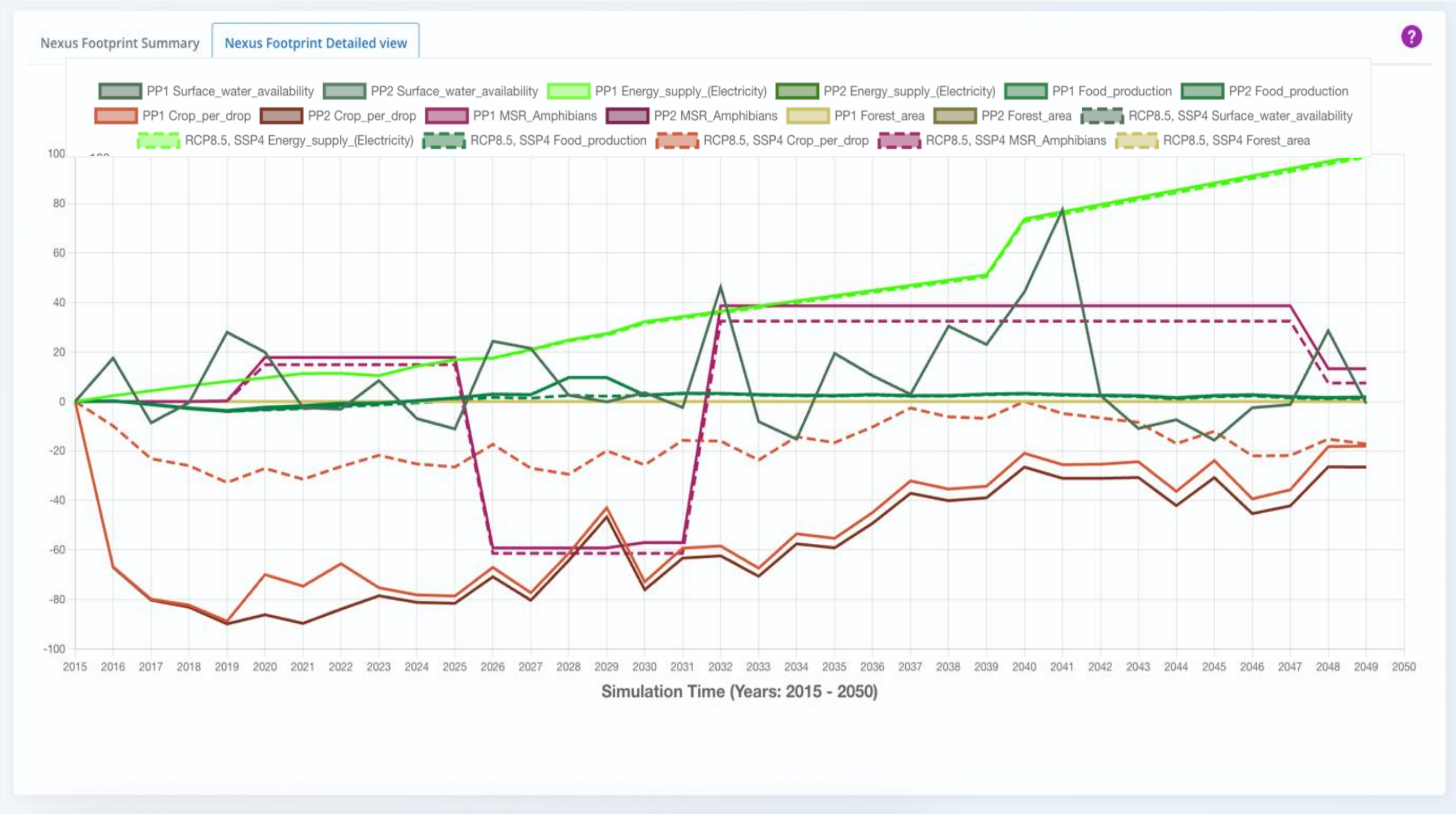
Figure 31. Detailed analysis of impact of policy packages on the WEFE Nexus Footprint. *In the 'Detailed View' of the NExus Policy Assessment Tool (NEPAT), compares the policy package impact on the WEFE Footprint Index (i.e., nexus system status) against the reference scenario (system status at year 2015, without application of policy package), in timesteps. In this example, the comparison is showing the impact of a policy package on various WEFE Footprint indicators. It can be seen that for some indicators the policy future scenario (solid line) improves and for other indicators the indicator deteriorates. (Figure produced in the NExus Policy Assessment Tool – NEPAT, Eurecat 2025).*



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Uncertainty Analysis

Decision-making in the policy realm is not straightforward because there are unpredictable factors that can affect the certainty of any particular outcome. For example, what if a new technology affects how resources are used? Unpredictable elements introduce variability in the response of nexus systems to policy actions, making it challenging to make decisions with confidence. This is where uncertainty analysis becomes important; it helps policy-makers understand the range of possible outcomes rather than just one fixed result. It helps stakeholders explore "what if" scenarios to see how a policy might perform under different conditions.

NEPAT can simulate policy scenarios with elements of uncertainty accounted for and visually represented. Uncertainty is first incorporated and operationalised within the SDMs (see Section 2, Chapter 4). Only then can uncertainty be represented within the analysis that NEPAT produces.

To conduct the uncertainty analysis, NEPAT runs multiple executions of a simulation, each execution with a different set of random inputs. For example, if you're testing a policy to increase renewable energy use, NEPAT would run the simulation several times, each time with the stochastic SDMs. These simulations will give a distribution of results, showing how much the outcome could vary depending on these unpredictable factors. In the simulation results, NEPAT uses quartiles to show how the values of key variables (e.g., greenhouse gas emissions) vary over time and are distributed across all of the simulation runs. Quartiles divide the range of results into sections (**Figure 32**):

- Q1 (First Quartile): The value where 25% of the results fall below.
- Q2 (Median): The middle value, where 50% of the results fall below and 50% above.
- Q3 (Third Quartile): The value where 75% of the results fall below.

This gives a clearer picture of the spread of potential outcomes. For example, you might see that in most simulations, a policy results in a moderate reduction of greenhouse gas emissions, but in some cases, it could be much higher or lower depending on external factors. NEPAT also shows a deterministic baseline - the result of the simulation without uncertainty factored in. It acts a reference point for comparing how much uncertainty affects the overall predicted policy outcomes

Uncertainty analysis is an optional advanced functionality that can be accessed in NEPAT. To run a simulation in NEPAT with uncertainty considered, simply access the "advanced mode" and define how many executions of the simulation should take place *(see NEPAT User Guide here).*

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Figure 32: Uncertainty Analysis in the NExus Policy Assessment Tool (NEPAT). *The results of uncertainty analysis in the NExus Policy Assessment Tool - NEPAT is visualised into quartiles. The range of potential outcomes enables the design of more robust policies, for example, policies which may perform well under a broader breadth of system responses (Figure produced in the NExus Policy Assessment Tool – NEPAT, Eurecat 2025).*

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STAKEHOLDER VALIDATED POLICY PACKAGES

NEPAT has a valuable role as a collaborative platform that facilitates discussions between science, policy, practice and societal actors for the co-creation process. NEPAT supports:

- **Informed policy dialogue:** Exploring different policy options and their potential consequences, using a credible scientific base which also incorporates other knowledge systems
- **Cooperative decision-making:** Encouraging stakeholders to work together to develop strategies that benefit multiple domains, stakes and interests

In the NXG project, NEPAT was used as an entry point for discussions with stakeholders (often technical staff of ministries, river basin authorities, civil society organisations, research entities) on the above points. Thereby, NEPAT enhanced learning about policy analysis, sustainable resource management and water diplomacy.

The steps that follow outline how NEPAT is configured with the system dynamic models and used in stakeholder discussions on the co-design of policy solutions.

Step 1: Preparation of NEPAT for Policy Evaluation

Translating the SDMs into NEPAT: The SDMs are automatically translated from Stella format into Python code. This translation process generates two Python translations: the deterministic version of the Stella model and the uncertainty version of the Stella model. The former version is the default that is used for NEPAT's simulations (with the uncertainty advanced mode off). The SDMs must have the policies, goal indicators and footprint variables included and to run with no errors. When the translation is complete, it is validated by comparing the results of the executions of Stella and the Python translation with and without the application of the policy instruments.

Test Simulations: Modelers, data experts and case-study team run various test simulations within NEPAT to validate the policy analysis results. This involves checking the results for gross inconsistencies with the scientific understanding of the behaviour of WEFE nexus systems, which may indicate an incorrect configuration of the SDMs. If errors are found, the modelers, data experts and NEPAT team (Eurecat) work together to identify the source of the error and rectify accordingly. In some cases, the case-study team may invite selected local experts to also validate the results, as their local knowledge is instrumental to deciphering errors vs. nuanced nexus system behaviour. Some exercises to test the simulations for error:

- Running simulations for different reference scenarios. These results should be reviewed in the Results View, Footprint Index View, and Goals View to understand the baseline performance.
- Select different policy scenarios that are expected to lead to noticeable changes. Run the simulations again and compare the outputs in the same views (Results, Footprint, Goals) to assess whether the expected changes occur. If they do not, it may indicate that something is misconfigured or not functioning properly. This process should be repeated using multiple policy and reference scenarios to ensure consistent behavior across different configurations.

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- Request recommendations from the DSS (AI-based agent) and evaluate whether the suggested policy packages align with expectations. Then, run simulations using these recommendations and verify in the Results View, Footprint Index View, and Goals View whether the outcomes align with the stated objectives.

Step 2: Preparation for stakeholder discussions

Understanding system dynamics: Modelers, data experts and policy experts in the project team run simulations focusing on exploring some policy goals and policy instruments that have been identified in previous workshops as priority topics. The group explores the results in various views offered in NEPAT (e.g., Results, Footprint, Goals) to understand the nexus systems dynamics.

Workshop plan: A plan must be made on how to explore and discuss results with stakeholders.

- Workshops should be designed so that stakeholders have ample time to (a) learn to use the functionalities of the tool; and (b) explore policy options and deliberate on results.
- An interdisciplinary team (modelers, data experts, AI experts, policy experts) should be at all workshops in which policy packages are discussed. A wide range of domain expertise is needed to skillfully cope with the technical inquiries regarding inputs, outputs and the NEPAT.
- A workshop handout should be created which gives summarized information about the policy goals and indicators, so that stakeholders can easily refer to it when exploring policy packages.
- The NEPAT user guide should be printed, several copies, and be available for quick reference.

Step 3: Co-designing policy packages with stakeholders

Stakeholder introduction to the co-creation process: The process of selecting policies to model in NEPAT should be briefly explained, including information on the development of the SDMs and WEFE Footprint Index. Being transparent about the scientific content from the onset builds trust in the NEPAT results and helps the discussions run smoother.

Stakeholder exploration of NEPAT: The workshop should have sufficient time allocated for stakeholders to learn about the functionalities of NEPAT. The facilitator can use the *NEPAT user guide* to walk participants through the features, using the key policy topics, goals or instruments as demonstrations. **Figure 33** shows a scenario exercise that can be used to orient stakeholders to the various features of NEPAT.

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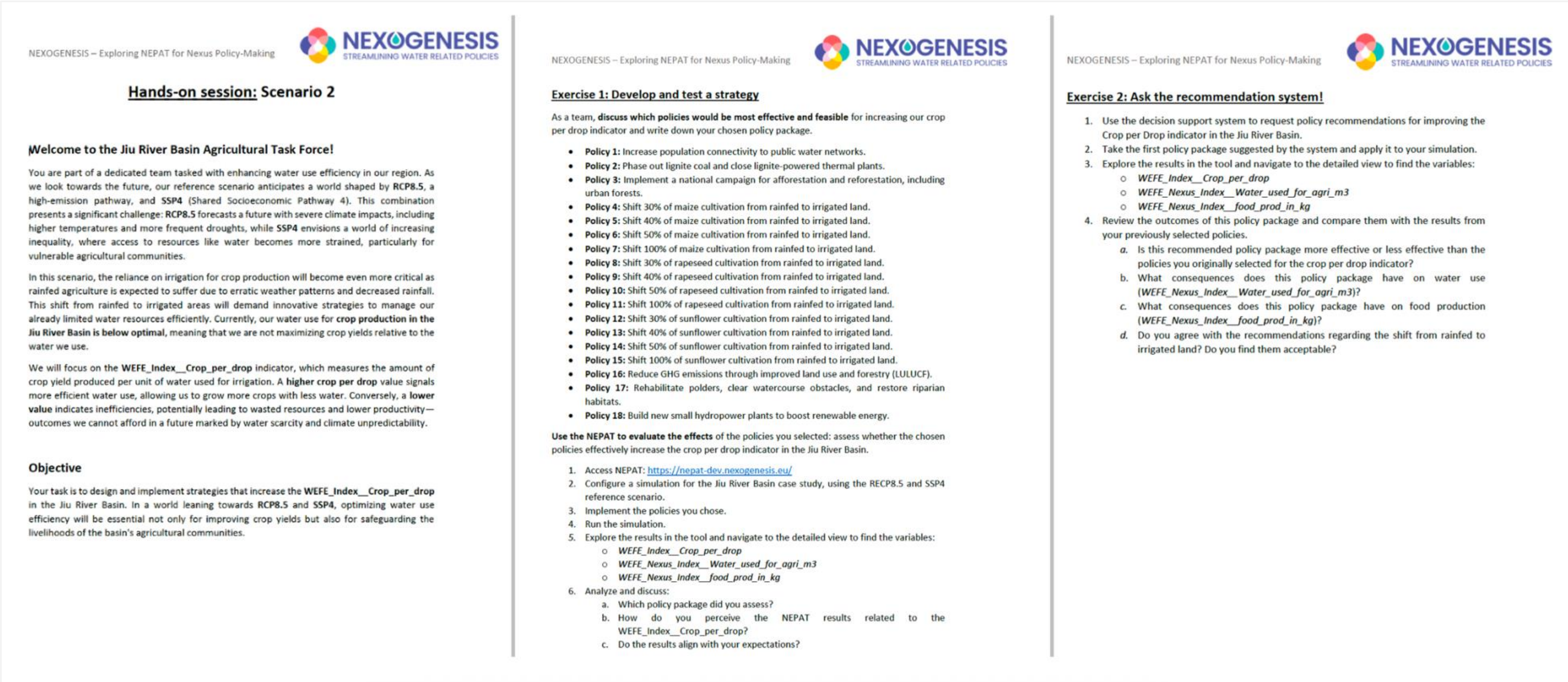
Figure 33: Example of scenario exercise to orient stakeholders to NEPAT. *This is an exercise that can be used as a first orientation to stakeholders of the policy evaluation functionalities of the NEPAT. It starts with simple analysis and prepares stakeholders for understanding how to use NEPAT for exploring more complex policy scenarios. (Source: Eurecat, 2024)*



NEXOGENESIS – Exploring NEPAT for Nexus Policy-Making

NEXOGENESIS STREAMLINING WATER RELATED POLICIES

Hands-on session: Scenario 2

Welcome to the Jiu River Basin Agricultural Task Force!

You are part of a dedicated team tasked with enhancing water use efficiency in our region. As we look towards the future, our reference scenario anticipates a world shaped by **RCP8.5**, a high-emission pathway, and **SSP4** (Shared Socioeconomic Pathway 4). This combination presents a significant challenge: **RCP8.5** forecasts a future with severe climate impacts, including higher temperatures and more frequent droughts, while **SSP4** envisions a world of increasing inequality, where access to resources like water becomes more strained, particularly for vulnerable agricultural communities.

In this scenario, the reliance on irrigation for crop production will become even more critical as rainfed agriculture is expected to suffer due to erratic weather patterns and decreased rainfall. This shift from rainfed to irrigated areas will demand innovative strategies to manage our already limited water resources efficiently. Currently, our water use for **crop production in the Jiu River Basin is below optimal,** meaning that we are not maximizing crop yields relative to the water we use.

We will focus on the **WEFE_Index__Crop_per_drop** indicator, which measures the amount of crop yield produced per unit of water used for irrigation. A **higher crop per drop** value signals more efficient water use, allowing us to grow more crops with less water. Conversely, a **lower value** indicates inefficiencies, potentially leading to wasted resources and lower productivity—outcomes we cannot afford in a future marked by water scarcity and climate unpredictability.

Objective

Your task is to design and implement strategies that increase the **WEFE_Index__Crop_per_drop** in the Jiu River Basin. In a world leaning towards **RCP8.5** and **SSP4**, optimizing water use efficiency will be essential not only for improving crop yields but also for safeguarding the livelihoods of the basin's agricultural communities.

NEXOGENESIS – Exploring NEPAT for Nexus Policy-Making

NEXOGENESIS STREAMLINING WATER RELATED POLICIES

Exercise 1: Develop and test a strategy

As a team, **discuss which policies would be most effective and feasible** for increasing our crop per drop indicator and write down your chosen policy package.

- **Policy 1:** Increase population connectivity to public water networks.
- **Policy 2:** Phase out lignite coal and close lignite-powered thermal plants.
- **Policy 3:** Implement a national campaign for afforestation and reforestation, including urban forests.
- **Policy 4:** Shift 30% of maize cultivation from rainfed to irrigated land.
- **Policy 5:** Shift 40% of maize cultivation from rainfed to irrigated land.
- **Policy 6:** Shift 50% of maize cultivation from rainfed to irrigated land.
- **Policy 7:** Shift 100% of maize cultivation from rainfed to irrigated land.
- **Policy 8:** Shift 30% of rapeseed cultivation from rainfed to irrigated land.
- **Policy 9:** Shift 40% of rapeseed cultivation from rainfed to irrigated land.
- **Policy 10:** Shift 50% of rapeseed cultivation from rainfed to irrigated land.
- **Policy 11:** Shift 100% of rapeseed cultivation from rainfed to irrigated land.
- **Policy 12:** Shift 30% of sunflower cultivation from rainfed to irrigated land.
- **Policy 13:** Shift 40% of sunflower cultivation from rainfed to irrigated land.
- **Policy 14:** Shift 50% of sunflower cultivation from rainfed to irrigated land.
- **Policy 15:** Shift 100% of sunflower cultivation from rainfed to irrigated land.
- **Policy 16:** Reduce GHG emissions through improved land use and forestry (LULUCF).
- **Policy 17:** Rehabilitate polders, clear watercourse obstacles, and restore riparian habitats.
- **Policy 18:** Build new small hydropower plants to boost renewable energy.

Use the NEPAT to evaluate the effects of the policies you selected: assess whether the chosen policies effectively increase the crop per drop indicator in the Jiu River Basin.

1. Access NEPAT: https://nepat-dev.nexogenesis.eu/
2. Configure a simulation for the Jiu River Basin case study, using the RECP8.5 and SSP4 reference scenario.
3. Implement the policies you chose.
4. Run the simulation.
5. Explore the results in the tool and navigate to the detailed view to find the variables:
   - *WEFE_Index__Crop_per_drop*
   - *WEFE_Nexus_Index__Water_used_for_agri_m3*
   - *WEFE_Nexus_Index__food_prod_in_kg*
6. Analyze and discuss:
   a. Which policy package did you assess?
   b. How do you perceive the NEPAT results related to the WEFE_Index__Crop_per_drop?
   c. Do the results align with your expectations?

NEXOGENESIS – Exploring NEPAT for Nexus Policy-Making

NEXOGENESIS STREAMLINING WATER RELATED POLICIES

Exercise 2: Ask the recommendation system!

1. Use the decision support system to request policy recommendations for improving the Crop per Drop indicator in the Jiu River Basin.
2. Take the first policy package suggested by the system and apply it to your simulation.
3. Explore the results in the tool and navigate to the detailed view to find the variables:
   - *WEFE_Index__Crop_per_drop*
   - *WEFE_Nexus_Index__Water_used_for_agri_m3*
   - *WEFE_Nexus_Index__food_prod_in_kg*
4. Review the outcomes of this policy package and compare them with the results from your previously selected policies.
   a. Is this recommended policy package more effective or less effective than the policies you originally selected for the crop per drop indicator?
   b. What consequences does this policy package have on water use (*WEFE_Nexus_Index__Water_used_for_agri_m3*)?
   c. What consequences does this policy package have on food production (*WEFE_Nexus_Index__food_prod_in_kg*)?
   d. Do you agree with the recommendations regarding the shift from rainfed to irrigated land? Do you find them acceptable?

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Stakeholder exploration of optimised policy options: In groups, stakeholders discuss with each other nexus issues and policy options to explore and evaluate for implementation. NEPAT allows stakeholders to assess the impact of one or a combination of policies among those in the Policy Portfolio and will display the effect of these policies in terms of progress towards the policy targets. When using the DSS (AI system of the NEPAT), based on the assessment, the DSS can will recommend an optimal combination of policies that would improve all WEFE nexus sectors and minimize trade-offs. Some exercises that can be used to explore policy combinations in NEPAT (with the basic or Decision Support System modes):

- Maximize one WEFE domain
- Achieve a group of nexus targets (e.g., maximise goals or minimise footprint variables) while minimizing the number of policies in the policy package
- Achieve a group of nexus targets while optimising a given sector
- Compare reference scenario (no policies applied) with policy scenario (effects of policy package)
- Build policy recommendations on top of an existing policy package
- Limit the number of recommended policy instruments
- Restrict policy recommendations to specific sectors
- Prioritise policy recommendations according to specific goals or specific footprint variables
- Apply policy with different start-end parameters (time range)[3]
- Compare results of DSS recommendation vs. user-defined policy packages

Stakeholders conduct several rounds of exploring different policy packages, evaluating NEPAT's analysis of how well the various packages achieve multiple policy goals and the associated trade-offs in WEFE footprint indicators. This deliberation process may take several rounds of intensive workshops and focus groups, depending on how complex (and contentious) are the nexus issues, how many policies have been considered, how large is the stakeholder participation, how many sectors are participating in the discussion, etc. In some cases, one-to-one complementary sessions with certain stakeholders may be necessary.

Figure 34 is a schematic of how this iterative policy package exploration and evaluation process works with stakeholders.

Figure 35 shows sample policy package recommendations using NEPAT's Decision Support System – as visualised within NEPAT. In this instance, stakeholders first prioritised Goals #1, 6, 8, 10, 12 and 16 as being more important to be achieved and asked the DSS to provide policy packages recommendations. NEPAT provided the top 10 policy package recommendations and their corresponding overall achievement levels. Each policy package can be interrogated – which goals are achieved to which level, which tradeoffs in footprint variables, etc. More information on the various policy package exploration functionalities of NEPAT can be found in *Nievas et al. 2024 – NXG D4.5 Final version of the self-assessment nexus engine with the corresponding validation.*

[3] Adjusting the start-end parameters for time range is currently only available for the Inkomati-Usuthu case-study of the NEXOGENESIS project. In future projects, it would be possible to have this functionality as well.

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Figure 34. Schematic of the iterative policy package exploration with stakeholders. *(Figure: Sabina J. Khan, Helmholtz Centre for Environmental Research UFZ, NEXOGENESIS project, 2025).*

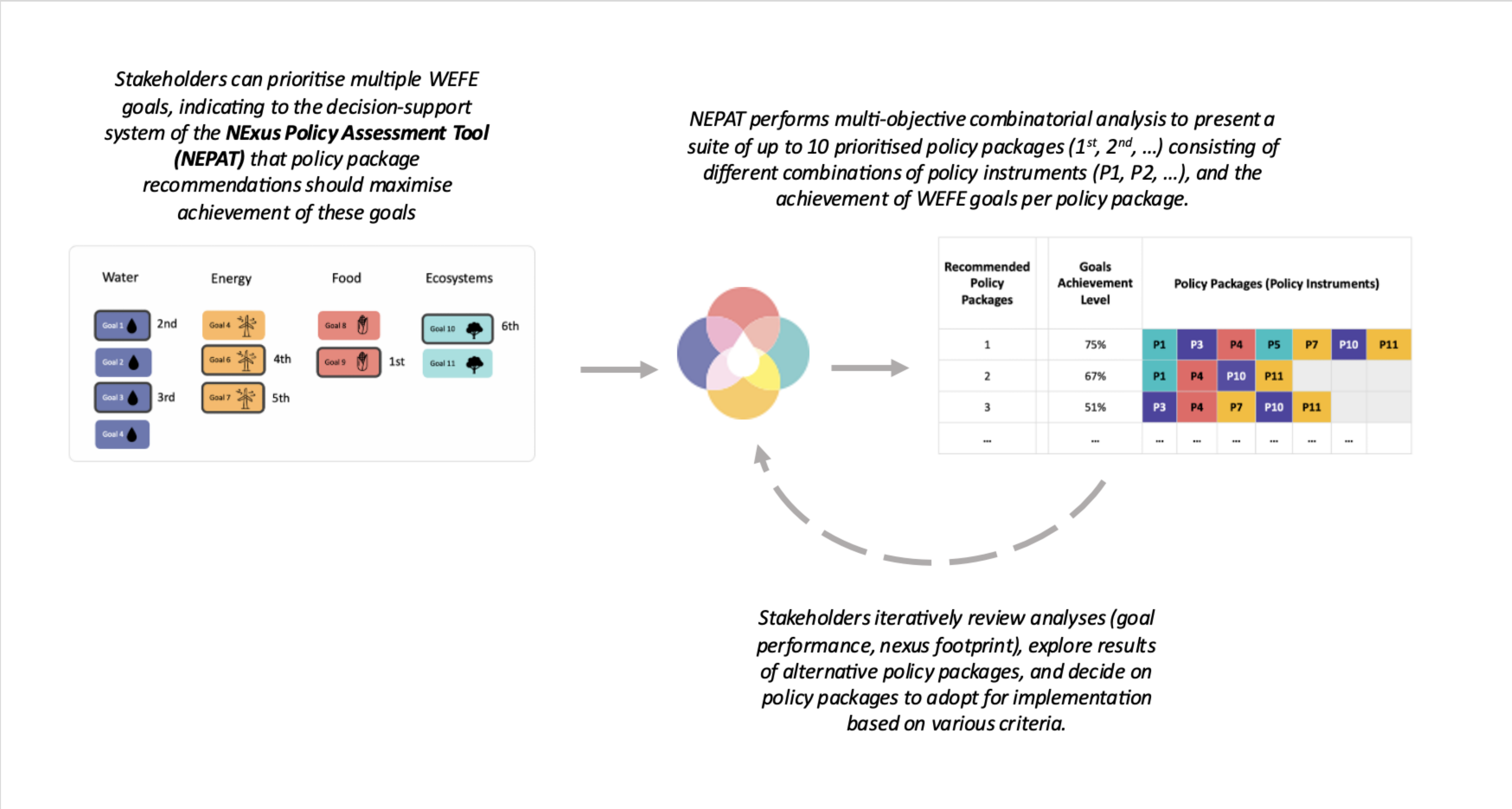

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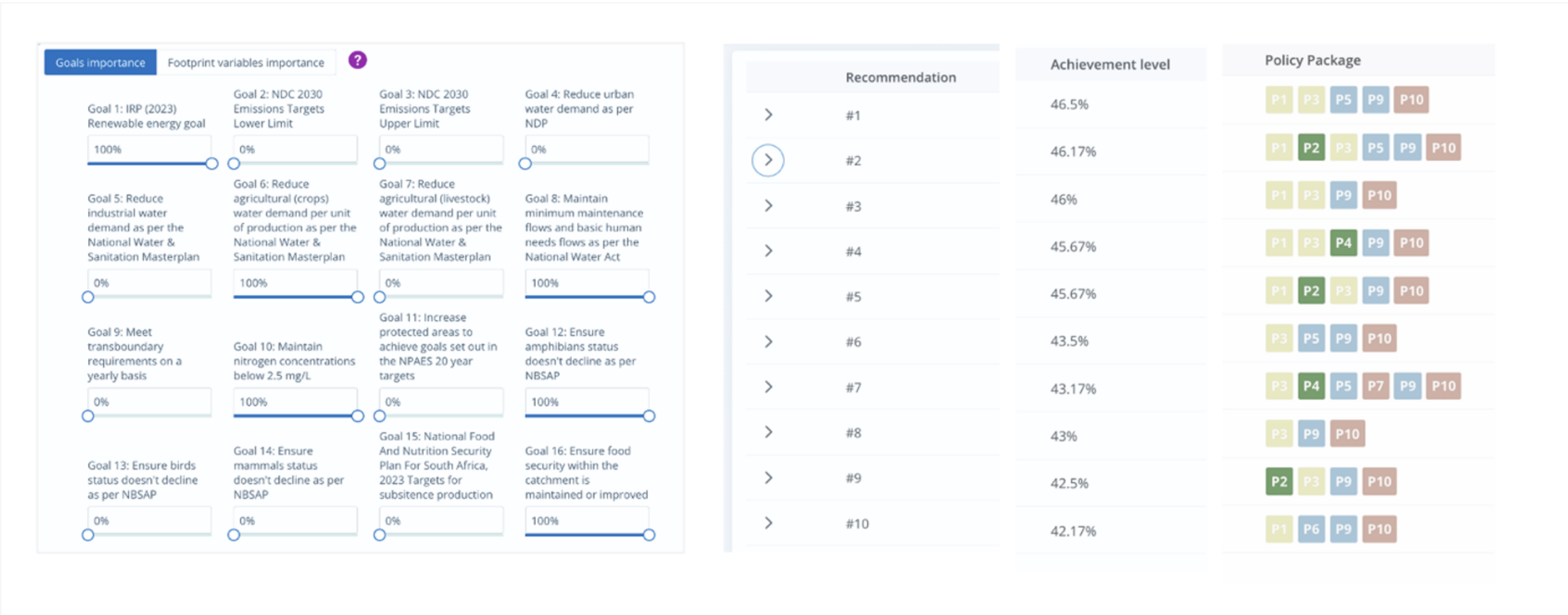
Figure 35. Sample policy package recommendations from NEPAT's Decision Support System. *Packages of policy instruments that are recommended to best achieve the prioritise Policy Goals #1, 6, 8, 10, 12 and 16. (as visualised in the NExus Policy Assessment Tool, Eurecat 2025).*



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Step 4 Validation of policy packages: Eventually, stakeholders arrive to an agreement on preferred and acceptable policy package(s) for implementation. These are called **stakeholder validated policy packages (SVPP).** A variety of criteria can be used evaluate and arrive at the optimal policy package (see Box 3).

Box 3: Criteria to support design of optimal policy packages. *A variety of criteria that can be used evaluate policy package recommendations from the NExus Policy Assessment Tool – NEPAT and narrow down to arrive at a stakeholder validated policy package. [Source: Adapted from Morrison, J. (no date), with additional criteria by Sabina J. Khan, Helmholtz Centre for Environmental Research UFZ, NEXOGENESIS project, 2025]*

- **Robustness:** Which policy packages perform the best across all future RCP+SSP scenarios (i.e., "no regrets" policies)
- **Priorities:** Which policy packages align best with international and national policy agendas or established / rising societal momentum towards change?
- **Trade-offs:** Which policy packages have serious unacceptable trade-offs to one or more stakeholder groups (e.g., human rights violations) or lowest social acceptance?
- **Levers:** Which policy packages may act as a leverage for cascading systemic change? Which policy package facilitates more multi-sector engagement or acts as an entry point for engaging a particularly reluctant sector?
- **Coordination:** Which policy packages might require complex coordination mechanisms or high transaction costs for marginally improved achievement of goals vs. a less complicated coordination constellation?
- **Costs:** Which policy packages have high implementation costs? (e.g., requires investments in expensive technology and infrastructure for which funding sources are inaccessible at the moment)
- **Feasibility:** Which policy packages have high / low technical feasibility (i.e., knowledge and skills capacity of stakeholders to implement)
- **Political feasibility:** Which policy packages already have political will backing or face an uphill battle to implement because there are countervailing trends?
- **Risk:** Which policy package, if even slightly ineffectively implemented, may have irreversible negative consequences for nature or society?
- **Impact:** Which policy packages have additional strengths of evidence (not already accounted for in NEPAT analysis) that they will provide big gains?
- **Leading edge:** Which policy packages are particularly innovative and impactful and would be a bold step (recognized in national or international arenas) in piloting?

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Exploring a new Policy Portfolio

If no policy combinations produce acceptable results for stakeholders, a new Policy Portfolio will need to be developed. This means that:

a) New policies must be added (existing policies may stay as they are or be removed). New policies could be in official policy documents or "hypothetical desired policies" (i.e., policies which stakeholders would like to be introduced and adopted)

b) Existing policies may need to be reconfigured:

   - A change in the nature of a policy (e.g., change policy from "double size of all protected areas" to "restore degraded portions of all protected areas")
   - A change in the target of a policy (e.g., change "energy production increased by 30%" to "energy production increased by 20%")
   - A change in time frame of policy (e.g., change policy application period from "2025-2050" to "2025-2040")

A combination of (a) and (b) is possible. However, if policies are added or reconfigured, these changes must be reflected in the SDMs first (i.e., restructure SDMs, source data, etc.). Once the SDMs are updated, they need to be re-integrated into NEPAT, and the DSS agents must be retrained to account for the modified policy space. This requires a full update cycle (model changes, NEPAT integration, and DSS retraining). After these updates, a validation step is essential to ensure the simulation results (across the Results View, Goals View, and Footprint Index View) and DSS recommendations align with expectations.

MORE RESOURCES ON NEPAT

- **SPF Core Service**: The Artificial Intelligence core of NEPAT, linking all the different modules.
- **NEPAT Step-by-Step User Guide (Eurecat 2025)**: *https://nexogenesis.eu/wp-content/uploads/2025/04/NEPAT-User-Guide.pdf*
- **NEPAT Teaching Guide**: The teaching guide demonstrates how scaffolding strategies can structure NEPAT-based learning, enabling students to tackle complex policy challenges while building analytical and collaborative skills. *[link to be inserted soon]*
- **Graphical User Interface (UI)**: The dashboard linked to the core of the self-learning engine of NEPAT. It enables users to interact with the self-learning engine to explore nexus dynamics, conduct in-depth analysis of policy packages configurations and understand the footprint on the WEFE nexus. It is integrated with SPF Web Service API. *https://nepat.nexogenesis.eu/#/* (use "Guest Login" to explore the tool)
- **REpresentational State Transfer Application Protocol Interface (REST API):** Acts as a bridge between the user interface and the Artificial Intelligence core of NEPAT, facilitating communication and enabling the authentication system. *https://nepat.nexogenesis.eu/api/* or *https://slnae.nexogenesis.eu/api/* or *https://nepat.nexogenesis.eu/api/docs* (documentation of the API methods)

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- **Systems Dynamic Models Translator & Systems Dynamic Models Manager:** The SDM Translator converts the System Dynamic Models from STELLA into Python, allowing them to be executed by the NEPAT backend. Once translated, the SDM Manager takes charge of running these SDMs. It selects the appropriate translated SDM script, runs it with the specified policies, and delivers the results to the Web Service API for return to the user.

- **NEXOGENESIS Data Lake / Data Sharing Tools:** Allows communication between all stakeholders in the sense of data and model sharing, and to automate the updating of models and shared data that are used in NEPAT. Users will need to develop a protocol to manage the process to upload new data versions to the platform (e.g., file versioning and folder structure) and notifying stakeholders in the workflow

    - **Nexogenesis Semantic Repository (external data publication and nexus knowledge sharing).**

        - Nexogenesis Nexus Ontology: *https://nepat-dev.nexogenesis.eu/ontology/webvowl/index.html*

        - Nexogenesis Semantic Repository: *https://nepat-dev.nexogenesis.eu/semanticRepository/*

        - Nexogenesis Data Explorer and Visualizer: https://nepat.nexogenesis.eu/visualizer/

- **Project Data Management:**

    - **Online Zenodo space** - Datasets: *https://zenodo.org/communities/nexognesis/*

    - **Online Argos space- DMP**: *https://argos.openaire.eu/explore-plans/overview/public/99b7e81a-38cb-46e2-a42f-8eed4f10fd42*

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4.4 Section 4: Co-develop phase

This phase centres on the joint development and evaluation of solutions —such as policy packages, governance roadmaps and stakeholder agreements —with the objective of enabling long-term, whole-of-society shifts towards improved WEFE nexus governance. Stakeholders engage in collaborative decision-making to identify preferred options, co-design innovative approaches, and define implementation strategies. The co-development phase prepares stakeholders to take ownership of a project's main outputs for policy-making.

4.4.1 Chapter 6 - Governance Roadmaps & Stakeholder Agreements

Governance roadmaps are pathways towards adoption and implementation of the stakeholder validated policy packages expected to achieve policy goals (as input into the NEPAT) for the governance landscape of the case-study area (e.g., a river basin). They support policy reform and adoption by outlining pathways for mainstreaming options co-developed with stakeholders, including addressing diplomacy, transboundary, and scale-related challenges. This involves plotting pathways toward the adoption or improved implementation of policies within the SVPP. A stakeholder agreement complements the roadmap by formalising stakeholder commitment to implement the agreed reforms within and beyond the project's end. Together, these tools close the loop in outlining how support the integration of water-related policies into the broader nexus

GOVERNANCE ROADMAPS

A theory of change (ToC) approach is applied to develop a governance roadmap. The ToC clarifies assumptions about how we expect the world to change as a result of our interventions (Foundations of Success 2009). A 'results chain' is an analytical tool that visually maps out a logical flow of these expected changes in the governance landscape (outcomes) in a causal "if…then" fashion. It maps out the pathway to change and associated actions to realise that change. It provides a structured framework outlining the necessary preconditions, interventions, and assumptions.

In this sense, a roadmap shows what needs to change in the governance landscape to adopt or implement the stakeholder validated policy packages. The **components of a results chain** for a roadmap are shown in **Figure 36** and are described as follows:

- **Goal:** These are the improvements in the socio-ecological system that the SVPP is meant to achieve. For example, reduced pollution, increased biodiversity, increased water conservation, increased food security, etc. These have already been defined and inputted into NEPAT .

- **Ultimate outcome:** The adoption and implementation of one policy within a SVPP

- **Intermediary Outcomes:** Key changes in the political, economic, social and cultural system (or behaviour of stakeholders in the systems) to achieve the adoption and implementation of a policy (towards the achievement of the ultimate outcome).

- **Local Actions:** Key strategies or activities that can be taken by stakeholders (by themselves or in collaboration with others) to achieve one or more intermediary outcomes.

- **Arrows:** These indicate an 'influence' relationship. Influence may be uni- or bi-directional.

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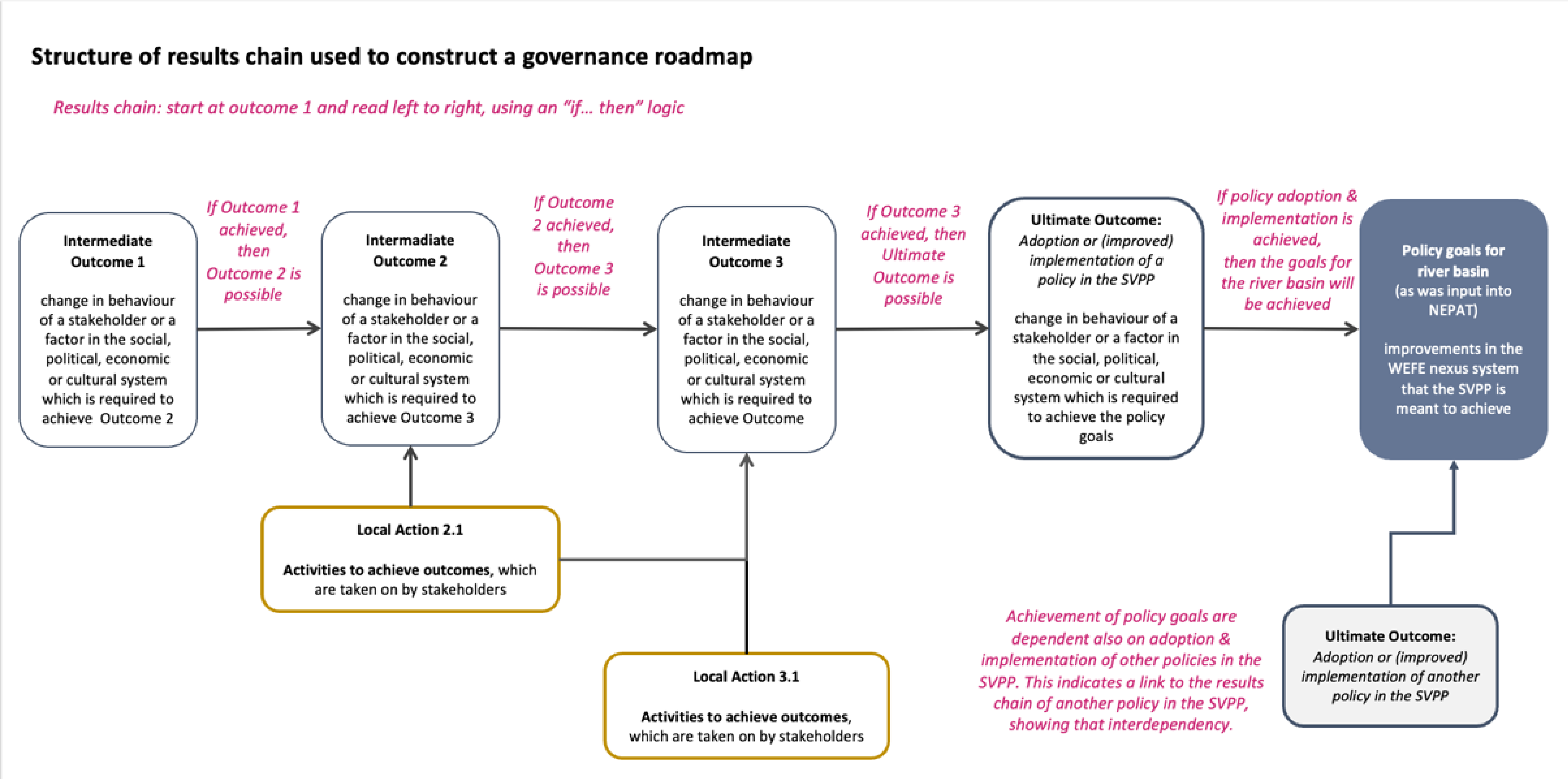
Figure 36 Structure of a results chain. *Components of results chain (as an analytical and visualization tool of the theory of change method) are used to produce governance roadmaps. (Adapted from: Margoluis et al. 2013). See also: Mooren at al. 2025a – NXG D1.4 Governance roadmaps and building blocks of a river contract in case-studies [link to be uploaded in October 2025]*



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Steps 1 -6 below required to create a governance roadmap using the template and instruction in **Figure 34** (also described in *Mooren at al. 2025a – NXG D1.4 Governance roadmaps and building blocks of a river contract in case-studies [link to be uploaded in October 2025]*

Step 1: Illustrate the goals for the river basin

Create a box and write the goals for the river basin for which the SVPP will achieve if implemented. The goals are those that were input into NEPAT and used to model how the policies perform.

Step 2: Illustrate the ultimate outcome (a policy in the SVPP)

Choose one policy within the SVPP, this is the starting point for the results chain. Create a box and place this on the right of the slide -- to the left of the 'goals for the river basin' boxes. Create an arrow from left-to-right to show that the policy helps to achieve the goals for the river basin.

Step 3: Identify and illustrate the intermediate outcomes

Create boxes that describe the discrete factors in the political, economic, social and cultural system, or behaviour of actors[4] that need to be changed in order to reach the ultimate outcome (i.e., the adoption and implementation of the policy under analysis). Arrange the boxes in a logical sequence (from left to right) such that one outcome is the precondition for the next outcome (on its right) to be achieved. Use arrows to show the causal relationships and flow between each outcome (flowing left-to-right, one outcome leads to achieving the next outcome).

Rules for each intermediary outcome box:

- Simple: one outcome per box and one stakeholder per box (unless multiple stakeholders can, already do or must achieve it together)
- Specific: Clearly defined so that all stakeholders involved have the same understanding of the factor (outcome or activity)
- Results-oriented: Specifies an outcome (e.g., reduction of water use, improved coordination mechanism, increased adoption of technology) and not activity (e.g., conduct a study, organise events, write a policy brief)
- Demonstrates change: Describes how a factor will change (e.g., improved, increased, decreased, developed, implemented). This can be defined in relation to a standard scale (numbers, percentage, all/nothing states). This is linked to the results-oriented outcome in the above point.

To brainstorm intermediary outcomes:

- Use insights from the Nexus Governance Assessment and Policy Coherence Assessment (Section 1, Chapter 2) and Stakeholder Power-Interest Assessment and Actor-Linkage Matrix (Section 1, Chapter 1).
- Use existing information from local knowledge (e.g., how others have attempted to intervene in similar situations and whether those interventions succeeded or failed and

[4] *This may be changes in actors' knowledge, awareness, attitudes, skills, aspirations and motivations.*

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why). Alternatively, use theoretical models and expert input, where appropriate and available. This can be obtained from a literature review, bilateral interviews, focus groups and workshops with stakeholders.

- Understand current or baseline conditions to determine how much change is needed to progress along the results chain from outcome to outcome.

- Examples of intermediary outcomes:

  - Enabling conditions (e.g., improved knowledge and evidence base, improved institutional and human resources, cultural acceptance of technology)

  - Behavioural changes (e.g., legislators include nexus indicators in monitoring frameworks, river basin authorities use integrated modelling in planning, ministries adopt cross-sector consultation procedures)

  - Relationship/networks (e.g., established cross-sectoral working groups, community of practice established, increased engagement of marginalized or underrepresented groups)

Step 4: Check the logic of the results chain

As new outcomes are added, check the chain to ensure there are no "leaps of faith" in the logic (missing outcomes) and clarify how much change in the governance system is need to achieve to see results

- Check the logic by reading the results chain from left to right: "*if* a particular result (change in the system / change in stakeholder behaviour) is achieved, *then* it will enable the achievement to the next result (change in the system / change in stakeholder behaviour)

- Check the logic by reading the results chain from right to left: "*if* this result (change in the system / change in stakeholder behaviour) is to be achieve, *then* what result (change in the system / change in stakeholder behaviour) must be achieved to enable that?

Note that there is a temporal component to the results chain: you cannot achieve an outcome further down a results chain (towards the right of the results chain) if earlier outcomes (towards the left of the results chain) have not yet been achieved. However, the *linkages should focus on causality not chronology.*

Step 5: Identify local actions to support achievement of outcomes

For each outcome, identify strategies or activities that will achieve it. These are actions stakeholders need to / can / or are already undertaking to affect change in the system. Use arrows to show the relationships and flow between sets of actions (e.g., one set of actions could support the achievement of two outcomes). Some questions that can be asked to brainstorm actions:

- What are stakeholders already doing to achieve the outcomes? (mapping what has been achieved, who is currently working on what)
- What do stakeholders need to do further to achieve the outcomes?

The inclusion of an action in the results chain does not imply that it is the only action needed to realise an outcome. The results chain can include all actions necessary or only a select few key

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actions (e.g., which stakeholders can agree on). One rule of thumb is to show only those actions that help clarify the if-then logic of the results chain. Too many actions can make it difficult to follow (visually), thereby losing the simplicity and communication value. Examples of actions:

- Capacity Building (e.g., technical assistance for data management, training workshops for policymakers)
- Stakeholder Engagement (e.g., convening multi-sectoral stakeholder meetings)
- Knowledge generation and sharing (e.g., baseline study, policy briefings, pilot projects)
- Communication and awareness raising (e.g., policy briefs, media engagement, direct lobbying)

Stakeholders may have to make strategic choices on what actions to take, and – just as important – what not to do. In building the results chain with stakeholders, some criteria that could be used in this decision-making process are (adapted from the *"Conservation Strategy Ranking Tool" developed by John Morrison, World Wildlife Fund, no date*).

- Feasibility (technical, political, cultural acceptance, time constraints)
- Cost or ability to leverage funding for implementation
- Leverage point/lever that has system-wide effects
- Novel approach, or fills niche or gap, or acts on unique windows of opportunity
- Potential to build stakeholder support or optimise diverse interests
- Potential to limit conflicts or reduce risks of failure ("no regrets")

Stakeholders may weight some criteria more heavily than others. Most likely, decisions about trade-offs are required, as it is difficult for all actions to score high on all criteria or meet all stakeholders' interests and level of acceptance.

Step 6: Create the timeline

Indicate the years by which outcomes and activities need to be achieved to meet the policy goal (which has a target year associated with it in the NEPAT). This is based on a mix of:

- What needs to be achieved by when (e.g., considers the rhythm of the policy cycle and deadlines for revision of policies, or considers when socio-ecological systems and indicators need to show a change – the goals for the river basin)
- What can be achieved by when from a practical perspective.

Step 7: Re-check the logic of the results chain:

Apply the "if … then" logical causality exercise, reading left to right on the results chain. Check for the following: Are there missing outcomes or key activities? Do the outcomes and activities meet best practice? Is the timeline correct and realistic?

Step 8: Identify assumptions

Be aware of the most critical uncertainties and risk factors (usually beyond the influence of the group of stakeholders in a case-study) that could affect the achievement of (1) intermediary outcomes; (2) the ultimate outcome (the adoption and implementation of the policy); and (3) the goals for the river basin. Examples:

- Macro-economic factors: economic recession, changes in cost of living (e.g., fuel, food)
- Governance factors: changes in income tax laws, strong political opposition, budget constraints
- Wider social trends and norms: greater acceptability of certain political ideologies
- Key events: elections, natural disasters, military aggression

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There are other basic assumptions associated with each outcome in a results chain. These should also be discussed, made explicit, and included in a monitoring strategy to determine if the local actions are effective. Examples:

- Assumption: Public awareness will lead to increased pressure on policymakers.
- Assumption: Policymakers are open to evidence-based recommendations.
- Assumption: Advocacy coalitions will effectively influence policy decisions.

Step 9: Consult stakeholders

Validate and refine the ToC with different groups of stakeholders to ensure it is comprehensive and robust. Table 20 provides some questions to vet the results chains. Do this with groups of the same interests and stakes (to tease out expert details) and with groups of mixed interests and stakes (to tease out potential conflicts). But first, ensure that the framing of outcomes and activities is diplomatic and therefore, does not risk the integrity of a relationship with a stakeholder group.

Table 20: Criteria of a good results chain for a governance roadmap. *Sample of questions that can be explored to vet that a results chain (and by extension, the governance roadmap) is comprehensive and robust. (Adapted from Foundations of Success 2009)*

Criteria	Questions
Gaps in Logic	Are there leaps in logic (i.e., missing outcomes or activities)? Are the links between each statement logical and reasonable? Will the achievement of one outcome help support the attainment of the next outcome? What are the connections and influence of outcomes from the results chain of another policy (within the SVPP)?
Clarity	Are the outcome statements clear and unambiguous? Is the detail adequate so that changes at each outcome are easily understood, including who or what is expected to change and the direction of the change?
Simplicity	Is the overall structure a simple, robust, clear version of reality? If it is too complicated, it might be less useful for providing direction to subsequent steps.
Impact & efficiency	To what extent will these actions directly or indirectly achieve the intermediary outcomes and the goals? Are the most effective and efficient strategies/actions chosen? Are resources being used efficiently to achieve outcomes and goals?
Risks	Are there hidden assumptions or missing critical uncertainties and risks that need to be accounted for?

Figure 35 below presents a governance roadmap developed for Inkomati-Usuthu case-study in the NXG project. The roadmap addresses two policies in the SVPP that are interconnected (from a planning and implementation perspective) within the governance landscape: Water Supply & Wastewater Treatment Systems.

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Step 10: Create the action plan

Number the outcomes and their associated activities in a logical manner and transfer this information to the “Action Plan for Roadmap” (see **Appendix 5**). The action plan is essentially a Gantt chart which specifies the intermediate outcomes and supporting local actions, the stakeholders who are currently implementing the actions (or who could / should / implement them), the approximate timeframe for implementation and indicative costs.

Step 11: Monitor, evaluate, learn & adapt

Regularly review and update the ToC based on new information, feedback, and changing circumstances to keep it relevant and accurate. It would be helpful to define indicators for a select few key outcomes to track progress, demonstrate success and avoid getting side-tracked.

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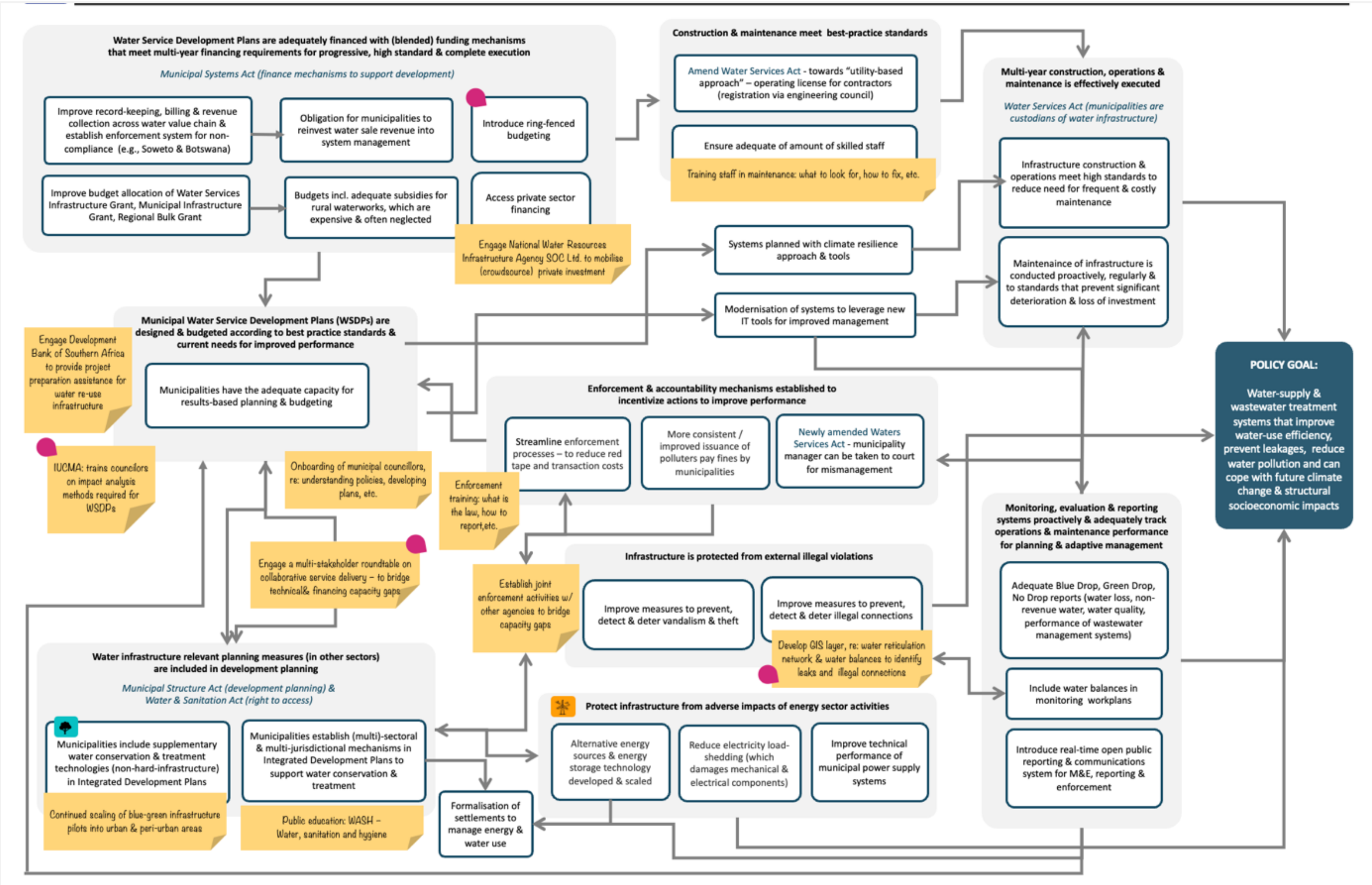
Figure 36: Governance Roadmap Water Supply & Wastewater Treatment Systems for Inkomati-Usuthu case-study. *Governance roadmap for two connected stakeholder validated policies. Changes in governance landscape (blue boxes) are supported by actions (yellow boxes). Also indicated are stakeholder agreements opportunities (pink dots) and WEFE nexus connections (icons). [Citation: Sabina J. Khan (Helmholtz Centre for Environmental Research - UFZ), Daniella Kristensen (Jones & Wagener), Blaine Haupt (Jones & Wagener), Alice Harvey (Jones & Wagener), Inkomati-Usuthu Catchment Management Agency, Tamara Avellan (Allevan Consulting), and NEXOGENESIS Project South* Africa January 2025 workshop participants*]. See also: Mooren at al. 2025a – NXG D1.4 Governance roadmaps and building blocks of a river contract in case-studies [link to be uploaded in October 2025*



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STAKEHOLDER AGREEMENT

A stakeholder agreement is defined as a voluntary, stakeholder co-created and negotiated commitment to jointly work on pathways, outcomes or actions for improved WEFE nexus management via the stakeholder validated policy packages. They encourage stakeholders to sustain working together towards achieving wider policy impact beyond the defined project timeline.

Some options for a voluntary commitment are:

- Continue the co-creation process by exploring other potential policy package options (reiterating back to the co-design phase if this is desired or deemed necessary)

- Continue the co-creation process beyond the planned project timeline by:
  - Continued developing of the governance roadmap
  - Endorsing the governance roadmap; and/or
  - Working towards achieving outcomes of the governance roadmap; and/or
  - Undertaking local actions within the governance roadmap.

- Continue the co-creation process via informal discussions aimed towards relationship and trust-building

These commitments may be in a variety of forms (see **Table 21**). Stakeholders agree on a format that is credible, legitimate, relevant and within their mandate, resources and comfort level (desired) to engage in under the situational nuance, wider political context, institutional constraints, etc. It is important to start early in thinking about what may be enabling conditions to facilitate the agreement? What would help to set the right tone, make it the right conditions, the needed context?

Table 21: Examples of stakeholder commitments. *Examples of stakeholder commitments which are formal or informal. Some commitments may already be elements of a governance roadmap, as a local action or intermediary outcome. In other cases, commitments may be outside the scope of the roadmap. (Source: OpenAI 2025).*

Type of stakeholder commitment	Description of elements of stakeholder commitment
Cooperation Agreements	Formal agreements specifying roles, responsibilities, timelines, and resource contributions.
Cross-border monitoring agreements	Arrangements to jointly collect, share, or recognise environmental data across jurisdictions.
Declarations of Cooperation	Public or semi-public expressions of intent to collaborate, usually signed but not enforceable.
Endorsement of Plans	Formal stakeholder support for river basin plans, typically via signatures or council votes.
Gentlemen’s Agreements	Verbal communication or handshake deals which rely heavily on mutual trust, goodwill, integrity and cooperation
Informal Coordination Groups	Ad hoc working arrangements used to share information or coordinate action during a crisis.
Joint Declarations	Collective public statements expressing shared positions or policy goals.

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Joint Funding Applications	Co-application for external funding, implying mutual interest and collaboration.
Joint Project Implementation (Informal)	Stakeholders contribute to shared actions without formal contracts, often based on trust or meeting notes.
Letters of Support / Endorsement	Non-binding written expressions of support for an initiative or funding application, which may also carry political or social weight.
Memorandum of Understanding (MoU)	Non-binding agreement expressing intent to collaborate on defined topics or actions.
Mutual Recognition Agreements	Non-binding agreements acknowledging each other's data, knowledge, or mandates.
Participatory Modelling Agreements	Informal commitments to co-develop and use models to support joint decision-making.
Position Papers	Written expressions of shared concerns, interests, or goals, without binding commitments. Example: press release, opinion paper.
Principles / Codes of Conduct	Shared behavioural norms or ethical guidelines developed to govern stakeholder interactions.
Public-Private Partnership	Contractual agreement between public & private entities to share risk and responsibility.
Reciprocal Commitments	Informal mutual arrangements where each party takes action conditional on the other's behaviour.
River Basin Commissions	Institutional bodies created by formal agreement to coordinate planning, data sharing, and policy implementation.
Shared Vision or Agenda Documents	Collaborative documents aligning strategies or priorities across stakeholder groups.
Shared Vision Planning	Collaborative decision-making process using participatory models and consensus building.
Stakeholder Manifestos / Charters	Co-developed documents expressing shared values and commitments to stewardship or action.
Treaties / Legal Compacts	Legally binding agreements between countries or jurisdictions outlining water-sharing or governance rules.

Once a stakeholder agreement is reached, practical implementation requires each party to carry out their committed tasks. Common challenges during implementation include delays due to technical, political, or financial issues, and the risk of stakeholders withdrawing if they perceive a lack of commitment from others.

For sustained engagement, the governance roadmap and accompanying action plan ideally would define responsibilities, including appointing a coordinating body with allocated resources. Depending on the context, some level of 'formalization' of these elements may also be required to secure stakeholder commitment and ensure consistent allocation of the necessary resources. Additionally, also depending on the local context, community-based citizen observatories may be introduced as an accountability mechanism to track progress towards meeting goals.

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Part 5. Guidelines for Outscaling

Through its application in diverse case-study contexts, the consolidated Co-creation Framework for Nexus Governance (CFNG) has been validated for encouraging more integrated nexus governance thinking. While the phases, methods, and workflow of the CFNG can be maintained, the approach is sufficiently flexible to accommodate context-specific adaptations in new case studies or regions, ensuring methodological soundness without sacrificing local relevance. This underscores the dynamic and context-sensitive nature of the co-creation process.

Part 5 provides overarching, synthesized, high-level guidance for the adoption and outscaling of the CFNG, derived from cumulative insights. The advice is intended to inform practice broadly and is aimed at water management organizations, including river basin authorities (both national and transboundary), as well as water and environment ministries and utilities.

5.1 Contextualisation & Modularity

The CFNG is a modular approach. This means that each phase (co-explore, co-design, and co-develop) and components of each phase (stakeholder engagement, data analysis, modelling, policy analysis) can be treated as a module that can be used, transferred into another process or modified independently of the others. Therefore, an all-or-nothing adoption is not necessary. The 'co-creation phases' structure breaks down an extensive process into manageable parts and consistently brings systems-thinking into the forefront of policy design and implementation.

This modularity enables the outscaling of the CFNG in a few ways:

- A project team can start with the co-creation phase or activity that is most useful for their immediate needs and tasks at hand. For example, if a government agency already has SDMs of the nexus system of interest, they can simply 'start' the co-creation process from the co-develop phase of translating the SDMs into NEPAT, etc.

- At the same time, it can be implemented by a team of consultants hired by, for example, a government ministry, to launch and steward a process of policy development.

- It can be anchored into existing policy institutions and their planning processes because useful aspects can be taken to complement existing processes, without requiring a complete overhaul of institutional infrastructures.

- It can be adapted and applied to any constellation of nexus issues, for example, land-energy, biodiversity-water-health, etc. The policy analysis that NEPAT performs is simply dependent on the configuration of the SDMs; any suite of policies across any number of domains can be analysed.

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5.2 Institutional Anchoring

Embedding the CFNG within existing governance processes and institutions significantly enhances its credibility, relevance and legitimacy and therefore, also the likelihood of widespread adoption and long-term policy impact (Klessova 2025a). When embedded within the architecture of the existing policy landscape, the CFNG can leverage established administrative routines and tap into stable funding streams, stakeholder networks, data and knowledge repositories, access to influential decision-making forums, and domain expertise.

In practical terms, anchoring may look like co-locating stakeholder engagement and use of the NEPAT with existing working groups, technical committees or regional development working groups (Mooren et al. 2025a). It is also worth exploring options to cluster with related non-governmental nexus projects in a specific area, to harmonise efforts, avoid duplication, share resources and reduce stakeholder fatigue and achieve collective impact (Glass et al. 2025).

Impact can be amplified if these have formal feedback loops linking national and local actors, translating local realities into regional and national policy-relevant insights. This would reinforce the CFNG approach of strengthening vertical coherence and stakeholder relationships. Intermediary institutions, like river basin authorities, are well-placed to facilitate this exchange.

In some cases, moments of crisis, such as severe droughts, floods, or cross-border tensions, create windows of opportunity for institutional anchoring. These situations tend to expose limitations in existing governance arrangements and catalyse a willingness to cooperate across sectors or jurisdictions. This heightened urgency to act may also create a ‘lower barrier to entry’ for the CFNG, if presented as a tested approach to generating durable solutions. However, strategic efforts should be made to sustain the CFNG’s use beyond the immediate aftermath of the crisis, for example, through the arrangement of cross-sectoral task forces or shared data platforms.

Institutional anchoring would benefit from:

- Framing the CFNG as an enabling process to realise broader (cross-cutting) sustainability agendas (e.g., climate adaptation); and
- Looking beyond a purely water-centric framing of WEFE nexus issues (e.g., framing through an energy lens, e.g., Just Transition, National Energy and Climate Plans) (Klessova 2025a).

The NXG experience shows that the energy and agriculture sectors were difficult to engage, until nexus dialogues were linked to topics that these sectors already prioritise, such as energy grid resilience, renewable revenue models, soil health, or job creation. When framed as a means to assert mandates, meet international commitments, set new standards or deliver on strategic objectives, the framework is far more likely to resonate with high-level decision-makers. Within each sector, it is useful to identify and empower ‘champions’ - professionals with technical expertise and internal credibility - who can advocate for nexus approaches among their peers. Equipping these champions with tailored tools, an evidence-base, and context-specific narratives helps them translate the CFNG’s value in ways that resonate within their domain.

A scoping exercise and a horizon scanning exercise can help identify entry points within national and sub-national policy landscapes (priority-setting forums, policy processes). To complement this, stakeholder engagement should include an assessment of sectoral motivations, capacities, and incentives (Klessova 2025a). Identifying what drives participation (e.g., compliance with regulations, access to data or funding, reputational considerations) (Klessova 2025a) enables more effective design of outreach messages, workshops and tools.

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5.3 Commitment & Capacity for Transdisciplinarity

The potential for replication and outscaling has been observed across all work packages (i.e., all components of the CFNG), but such efforts must be supported by adequate planning for transdisciplinary capacity in a project team. For the CFNG, as it was applied in NXG, this includes expertise in data, modelling, policy, stakeholder engagement, communications and facilitation.

There is value to widen the breadth of domain experts to be involved in a project team. Current reflections in sustainability science recognize the missed potential of integrating arts and humanities into this work. A project team would benefit from including economists, lawyers, educational psychologists, service design experts, political strategists, management scientists, cultural anthropologists, and so on. Start by asking: What capacities is the team missing to effectively implement shifts towards improved nexus governance? (Avellán et al. 2025b). It is particularly important to understand if team members have limited power to influence policy or engage directly with high-level decision-makers. If so, the team's collective capacity and network alliances will need to be leveraged.

We have reflected that the application of organisational theory and contingency theory (from the management sciences domain) would have been useful in some aspects of project design (Klessova 2025a). Particularly, by engaging in on-going deliberative dialogue to refine our understanding of why environmental interventions succeed in some contexts but not others (e.g., due to technical limitations or organisational and coordination issues), we could have used those insights to adapt stakeholder engagement strategies and focus the policy and institutional analysis (George, Schillebeeck & Liak 2015).

Teams must also embrace working with multiple knowledge systems (science, practice, indigenous and local knowledge, etc.) and be prepared to embed co-creation mechanisms (e.g., feedback loops amongst domain experts, with stakeholders, etc.) within their standard internal workflows. Speaking to the latter, in NXG, we discovered that there were struggles with integration even across those WPs with relatively similar or linked domain knowledge (data and modelling, or governance and stakeholder engagement, or stakeholder engagement and communications). In these instances, co-creation was hindered by communication gaps, limited time for iterative feedback and parallel workflows – resulting in redundant outputs, missed opportunities, and increased transaction costs. Therefore, projects should plan explicitly for regular team "co-creation moments" (as we did in NXG) - integration periods and deep reflective workshops to build a common working language, support mutual understanding of methods and encourage empathy and joint problem-solving. Use these exchanges to support collective sense-making, strengthen coordination, and build the trust needed to address challenges effectively (Avellán et al. 2025b).

Finally, assumptions should not be made about which team members (domain experts) hold the 'expertise' or 'authority' on designing and facilitating the co-creation processes. Often social scientists on a project team are thought to be the natural stewards of the process, with the full breadth of skills and mindset. However, any team member from any discipline can be a champion and expert in co-creation and space for such distributed leadership should be available for all.

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5.4 Trade-offs in scaling: multiple case-study initiatives

Applying the CFNG across multiple case studies, or across several sites within a single region, presents both opportunities and limitations. Multi-case study projects can generate comparative insights, support improved replicability to other contexts and broaden the scope of policy relevance (i.e., generate results that expand to a larger governance landscape). However, the intensity of co-creation required for each site should not be underestimated. Engaging a large number of case studies can overstretch the capacity of domain experts, dilute the level of iterative engagement required for developing credible outputs, and increase coordination costs. As such, outscaling should be approached conservatively, with attention to resource allocation, team capacity, and process integrity.

Before launching a multi-site application, particularly when there is a research component in the project, it is advisable to first clarify the overarching cross-case research questions. What comparative insights are being sought? For example, insights might be sought regarding how improved nexus governance can be achieved under similar socio-/geo-political contexts or nexus challenges. Alternatively, insights may be sought regarding the achievement of improved nexus governance using different nexus entry points (water vs. energy). Case studies can then be strategically selected to support a robust comparative analysis (see Eisenhardt 1991). This upfront framing helps ensure that scaling up does not come at the cost of analytical clarity or stakeholder relevance.

One of the major benefits of a multi-case initiative is the potential for horizontal learning, cross-case fertilisation and innovation, that would not emerge from single-site approaches. Case studies can actively learn from one another, either asynchronously (i.e., frontrunner cases share lessons learned and accompanying strategies with others at earlier phases), or synchronously (i.e., co-development of approaches to shared challenges contemporarily). For example, a stakeholder strategy that increased energy sector participation in one case can be adapted and tested in another case facing the similar challenge of underrepresentation. Case studies can evolve in parallel and enrich each other's problem framing, strategies, or technical innovations.

To fully realise these types of benefits, project teams might consider planning in moments and mechanisms for peer exchange, such as cross-case workshops, peer review of outputs, or even exchange visits between stakeholders (decision-makers) facing the same challenges. These can enhance the technical capacity of both a project team and the local stakeholders and possibly also plant the seeds for a community of practice that can sustain engagement and innovation beyond the project's formal lifecycle.

Multi-case CFNG projects are platforms for systemic insight, but only when structured intentionally. They should not aim to replicate processes identically across locations, but rather to anchor a consistent methodological spine that supports meaningful local variation. Cross-case comparability is only possible if case studies share common (harmonized and open) datasets and modelling assumptions (Roson et al. 2023, Rossi et a. 2023, Trabucco et al. 2023, 2023, 2024). Harmonisation (e.g., of temporal resolution, variable definitions, or scenarios) enables meaningful aggregation of findings and technical exchange. At the same time, there must be space for including the specificity and legitimacy of local data and knowledge systems.

A central coordination infrastructure (dedicated personnel, resources and coordination time for facilitation and administration) is necessary to implement the CFNG in both single and multi-case

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study initiatives. However, for the latter scenario, if it is a particularly large 'programmatic' initiative across a wider region, a dedicated project team and coordination infrastructure may be worthwhile per site or case-study. In NXG, this was partially applied (e.g., the modelling team was divided by case-study, but the stakeholder engagement and policy teams worked across the board). The learning lesson was that expertise was stretched too thin and the consequence was that the time for feedback loops amongst team members and between stakeholders and domain experts was insufficient. Scaling to multiple sites increases the diversity of insights but reduces the bandwidth for deep engagement in any one location. Project teams must consciously manage this trade-off, prioritising where intensity of engagement or technical rigour is most needed.

5.5 Use Open & Interoperable Tools

The use of harmonised datasets and open-access platforms is essential in ensuring consistency and comparability across case studies (Roson et al. 2023, Rossi et a. 2023, Trabucco et al. 2023, 2023, 2024). These platforms deliver data in standardised formats, enabling different project teams to work with a shared set of assumptions and methodologies while remaining responsive to their regional contexts. This standardisation is not only instrumental for internal coherence across multi-site initiatives, but also forms the backbone of reproducibility and outscaling to new locations.

Open data practices also enable and ease collaboration across disciplines, institutions, and countries—especially in transboundary or multi-level governance contexts. By lowering barriers to entry and enabling a shared interpretation of results, open and standardised data accelerate knowledge transfer and scaling (Trabucco 2023). In this sense, data transparency and harmonisation are not merely technical preferences—they are strategic prerequisites for replicability and transferability.

Furthermore, tools such as NEPAT and the SDMs can be reused or adapted in new contexts if the input data is well-structured, well-documented, and aligned with open data principles. This means providing not only the data itself, but also accompanying metadata, defined assumptions, units of measurement, sources, and user guidance, so that others can apply region-specific inputs without needing to rebuild the tools from scratch.

Finally, the use of open datasets also enables the long-term viability and relevance of tools, especially in cases where ongoing stakeholder engagement and data updates are necessary post-project. Stakeholders who have invested in the process have a clear preference for tools that could be modified or updated locally - highlighting the importance of user ownership, flexibility, and post-project functionality. The project team should consider issues such as data rights, licensing and platform ownership from the outset. Strategic stakeholder engagement also plays a critical role here: co-investment models may be promising avenues to maintain both the technical tools and the stakeholder networks needed to keep them operational. This can take the form of agricultural insurers supporting the development of climate-resilient irrigation modules in the SDMs or energy companies funding transboundary data platforms (Glass et al. 2025). However, projects need the legal expertise onboard to skilfully manage discussions around open data, ownership, intellectual property rights, etc. (Glass et al. 2025).

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5.6 Amplify with capacity-building

The potential for replication and outscaling of the CFNG can be significantly enhanced if there is a deliberate and directed focus on capacity-building. This particularly refers to equipping participants with the practical skills, confidence, and tools needed to engage skillfully in any other co-creation or decision-making processes long after the project ends.

Throughout the project lifecycle, stakeholders should not only deepen their understanding of the WEFE nexus and its challenges but also learn how to apply technical tools and methods. This may include developing skills in interpreting data, using modelling outputs, understanding scenario development or using digital platforms for collaborative planning.

In addition to technical competencies, a project should absolutely aim to support stakeholders in developing science communication skills - especially when it comes to sector-specific ideas and knowledge – in order to understand and correctly evaluate cross-sector interlinkages and influences (Glass et al. 2025). Other crucial skills and competencies: participatory facilitation, dialogue, mediation, conflict resolution and negotiation – all of which are especially relevant in contexts involving diverse interests, transboundary cooperation (water diplomacy) or policy reform. These are the skills that help stakeholders cope with challenging situations in policy-making arenas.

Effective capacity-building also requires adaptability. Not all stakeholders start from the same baseline of experience or expertise, and capacity-building should be responsive to this diversity. Projects should systematically assess and segment stakeholders by both influence and capacity, then design engagement activities accordingly (Glass et al. 2025). It should also offer opportunities for informal learning, peer exchange, and hands-on practice, alongside more formal training where appropriate. A training of trainers approach or program could also be invested in. Impact can be structural and wide-scale if nexus thinking is embedded in training-of-trainers curricula for policymakers who design and implement overarching policy objectives (e.g., climate change adaptation) which have cross-sectoral implications (Mooren et al. 2025a). This establishes ‘champions’ who can drive nexus engagement across the board and especially with reluctant sectors.

Ultimately, capacity-building should aim to leave behind more than just co-created knowledge and tools. It should foster leadership competencies and empower stakeholders to continue collaborative processes on their own terms (Avellán et al. 2025b).

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Part 6. Conclusion

The NXG project has demonstrated that the Co-Creation Framework for Nexus Governance is a methodologically sound, practical and adaptable approach to fostering integrated governance. The project applied a transdisciplinary approach of disentangling complex nexus dynamics underpinning resource management, exploring optimised policy solutions that could not otherwise be computationally handled without advanced tools such as artificial intelligence, understanding trade-offs, synergies and risks associated with policy decisions, and designing governance pathways towards improved nexus governance. Through application in five diverse river basins, the CFNG has proven its capacity to co-create knowledge and solutions across science, policy, practice and society through structured collaboration processes in which stakeholders play a central role in co-producing outputs and outcomes. Implemented over four years in five river basins across Europe and Africa (Adige, Inkomati-Usuthu, Jiu, Lielupe, and Nestos/Mesta), it has also proven to be replicable in and has generated valuable insights for outscaling to wider socio-ecological contexts.

The methodological steps (stakeholder engagement, governance analysis, system dynamics modelling, multi-objective policy optimization using artificial intelligence and governance roadmaps) were coherently linked in a pipeline workflow, with iterative co-creation moments, for continuous improvement by integrating stakeholder feedback and preferences. Furthermore, each step provided an opportunity for both stakeholders and researchers to improve systemic thinking about nexus issues. This was the original conception of the CFNG and subsequently rolled-out delivering relatively successful results.

A particularly useful design aspect for outscaling is the CFNG's modular design which allows adaptation to diverse contexts, enabling users to select methods and co-creation phases (co-explore, co-design, co-develop) according to the decision-making processes and needs of the local context. That is, the modularity lends well to the CFNG to be 'institutionally anchored' within existing governance processes, policy forums, and related initiatives to harmonize efforts and resources for collective impact, reduce duplication and leverage stakeholder networks. It also lends well to being adopted to tackle different constellation of nexus issues (i.e., other than WEFE). The NXG experience brought to light that this strategy would amplify the legitimacy and impact of the CFNG.

The NXG experience also highlights that the CFNG can benefit from strategic framing of nexus dialogues around priorities of non-water sectors and cross-sectoral policy imperatives, more capacity for and strategy in targeted stakeholder engagement to high-level policymakers, expanded transdisciplinary capacity by including a wider breadth of social sciences and humanities and more capacity-building for stakeholders to skillfully tackle inter-sectoral knowledge co-production, facilitation, negotiation and deliberation tasks that the CFNG relies upon.

The CFNG is a tested and evolving approach that supports inclusive decision-making and systemic thinking to address the complex interdependencies of the WEFE nexus.

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Part 7. REFERENCES

Amorocho-Daza, H., van der Zaag, P., & Sušnik, J. (2023). Ethical considerations of using system dynamics in participatory settings: A social-ecological-systems perspective*. System Dynamics Review, 40(2)*, Article e1755. *https://doi.org/10.1002/sdr.1755*

Amorocho-Daza, H., Sušnik, J., van der Zaag, P., & Slinger, J. H. (2024). A model-based policy analysis framework for social-ecological systems: Integrating uncertainty and participation in system dynamics modelling. *Ecological Modelling, 499*, Article 110943. https://doi.org/10.1016/j.ecolmodel.2024.110943

Avellan, T. (2023). Deliverable 6.11: Policy Impact Strategy. NEXOGENESIS Project. *https://nexogenesis.eu/wp-content/uploads/2023/10/NEXOGENESIS_D6.11-Policy-Impact-Strategy-20230414_rev.pdf*

Avellán, T., Müller, A. B., Kristensen, D., Papadopoulou, C.-A., Papadopoulou, M. P., Bremere, I., Munaretto, S., Nanu, F., & Blicharska, M. (2025a). Impact of explicit consent to data protection rules on the stakeholder landscape in transdisciplinary nexus research projects. *Environmental Science & Policy, 166*, 104029. *https://doi.org/10.1016/j.envsci.2025.104029*

Avellán, T., Müller, A., Ryfisch, S., Mooren, C., Munaretto, S., Papadopoulou, C.-A., Papadopoulou, M. P., Brēmere, I., Indriksone, D., Nanu, F., Cocuccioni, S., Kristensen, D., Haupt, B., & Harvey, A. (2025b). *Deliverable 5.1: Report on Stakeholder Engagement.* NEXOGENESIS Project. [link to be provided in October 2025]

Bernard, H.R. (2011). Research methods in anthropology: qualitative and quantitative approaches. Bloomsbury Publishing PLC.

Blicharska, M., Smithers, R. J., Kuchler, M., Munaretto, S., van den Heuvel, L., & Teutschbein, C. (2024). The water–energy–food–land–climate nexus: Policy coherence for sustainable resource management in Sweden. *Environmental Policy and Governance, 34*(2), 207–220.

Bojovic, D., St. Clair, A. L., Christel, I., Terrado, M., Stanzel, P., Gonzalez, P., & Palin, E. J. (2021). Engagement, involvement and empowerment: Three realms of a coproduction framework for climate services. *Global Environmental Change, 68*, 102271. *https://doi.org/10.1016/j.gloenvcha.2021.102271*

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., Reinert, F., Abson, D. J., & von Wehrden, H. (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics, 92*, 1–15. *https://doi.org/10.1016/j.ecolecon.2013.04.008*

Brandsen, T., & Honingh, M. (2018). Definitions of co-production and co-creation. In *Co-production and co-creation*. Routledge.

Bressers, H., & Kuks, S. (Eds.). (2004). Integrated governance and water basin management. In *Integrated governance and water basin management, Environment & Policy, 41,* 247–265. Dordrecht: Springer.

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

Bressers, H. (2009). From public administration to policy networks: Contextual interaction analysis. In N. Stephane & F. Varone (Eds.), *Rediscovering public law and public administration in comparative policy analysis: A tribute to Peter Knoepfel* (pp. 123–142). Lausanne: Presses Polytechniques.

Bressers, H., Bressers, N., Browne, A., Furusho, C., La Jeunesse, I., Larrue, C., Özerol, G., Ramos, M.-H., Stein, U., Tröltzsch, J., & Vidaurre, R. (2015). *Governance assessment guide: Adapt to drought and water scarcity.* https://hal.inrae.fr/hal-02602379

Britz, W., & Roson, R. (2018). G-RDEM: A GTAP-based recursive dynamic CGE model for long-term baseline generation and analysis**.** *SSRN Electronic Journal.* https://doi.org/10.2139/ssrn.3167781

Brombal, D., Niu, Y., Pizzol, L., Moriggi, A., Wang, J., Critto, A., Jiang, X., Liu, B., & Marcomini, A. (2018). A participatory sustainability assessment for integrated watershed management in urban China. *Environmental Science & Policy, 85*, 54–63. https://doi.org/10.1016/j.envsci.2018.03.020

Charpentier, L., Avellán, T., Nanu, F., Munaretto, S., Trabucco, A., Papadopoulou, M. P., Papadopoulou, C.-A., Kristensen, D., Haupt, B., Bremere, I., Indriksone, D., & Khan, S. J. (2025a). *Deliverable 6.13. NEXOGENESIS Policy Brief: Contribution on the WEFE nexus to the Water Resilience Strategy*.

Charpentier, L., Avellán, T., Nanu, F., Munaretto, S., Trabucco, A., Papadopoulou, M. P., Papadopoulou, C.-A., Kristensen, D., Haupt, B., Bremere, I., Indriksone, D., & Khan, S. J. (2025b). *Deliverable 6.14. NEXOGENESIS Policy Brief: Lessons from 5 case studies to scale-up Smart WEFE Nexus Policies for a green and digital world.*

Chambers, J. M., Wyborn, C., Ryan, M. E., Reid, R. S., Riechers, M., Serban, A., Bennett, N. J., et al. (2021). Six modes of co-production for sustainability. *Nature Sustainability, 4*(11), 983–996. https://doi.org/10.1038/s41893-021-00755-x

de Vente, J., Reed, M. S., Stringer, L. C., Valente, S., & Newig, J. (2016). How does the context and design of participatory decision-making processes affect their outcomes? Evidence from sustainable land management in global drylands. *Ecology and Society, 21*(2), art. 24. https://doi.org/10.5751/ES-08053-210224

Diogo, V., Hennen, W., Verma, M., Oudendag, D., & Kuiper, M. (2020). MagnetGrid: Model description and user guide (Report 2020-004). Wageningen Economic Research. https://edepot.wur.nl/512146

Drew, D. R. (1995). *System dynamics: Modeling and applications*. ENGR 5104 Study Notes.

Echeverria, L., Nievas, N., & Pijuan, J. (2022). *Deliverable 4.1 Self-learning nexus engine specifications and technical design. NEXOGENESIS Project.* https://nexogenesis.eu/wp-content/uploads/2023/10/D4.1.-Self-learning-nexus-engine-specifications-and-technical-design.pdf

Echeverria, L., Dkouk, C., & Nievas, N. (2024). *Deliverable* 4.3 Simulation policy framework. *NEXOGENESIS Project*. https://nexogenesis.eu/wp-content/uploads/2025/03/D4.3-Simulation-policy-framework.pdf

Echeverria, L., Dkouk, C., & Nievas, N. (2024). *Deliverable 4.4 Core Module of the self-learning nexus engine. NEXOGENESIS Project*. https://nexogenesis.eu/wp-content/uploads/2025/03/D4.4-Core-module-of-the-NEPAT.pdf

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

Eisenhardt, K. M. (1991). Better stories and better constructs: The case for rigor and comparative logic. Academy of Management Review, 16(3), 620–627. https://doi.org/10.5465/amr.1991.4279492

Eurecat. (2025). User Guide: NExus Policy Assessment Tool – NEPAT. NEXOGENESIS Project. *https://nexogenesis.eu/wp-content/uploads/2025/04/NEPAT-User-Guide.pdf*

George, G., Schillebeeckx, S. J. D., & Liak, T. L. (2015). The management of natural resources: An overview and research agenda. *Academy of Management Journal, 58*(6), 1595–1613.

Glass, J., Dupont, G., Blicharska, M., Avellan, T., Ryfisch, S., Klessova, S., Papadopoulou, C.-A., Papadopoulou, M. P., Bremere, I., Indriksone, D., Khan, S. J., Mooren, C., Nanu, F., Carnelli, F., Cocuccioni, S., Terzi, S., Haupt, B., & Kristensen, D. (2025). *Deliverable 5.7. Recommendations, experience, lessons learned from all case-studies.* NEXOGENESIS Project. [will be uploaded to the NXG website on October 2025 *https://nexogenesis.eu/downloads/*]

Ford, A. (2009). *Modeling the environment* (2nd ed.). Island Press. https://doi.org/10.5822/978-1-59726-473-0

Forrester, J. W. (1992). Policies, decisions and information sources for modeling. *European Journal of Operational Research, 59*(1), 42–63. https://doi.org/10.1016/0377-2217(92)90006-U

Forrester, J. W. (1997). Industrial dynamics. *Journal of the Operational Research Society, 48*(10), 1037–1041. https://doi.org/10.1057/palgrave.jors.2600946

Forrester, J. W. (2009). *Some basic concepts in system dynamics*. Sloan School of Management. https://web.mit.edu/jforrest/www/SDIntro.pdf

Foundations of Success. (2009). Using results chains to improve strategy effectiveness: an FOS how-to guide. Foundations of Success, Bethesda, Maryland, USA. *https://fosonline.org/wp-content/uploads/2019/11/FOS_Results_Chain_Guide_2007-05.pdf*

Freebairn, L., Atkinson, J. A., Osgood, N. D., Kelly, P. M., McDonnell, G., & Rychetnik, L. (2019). Turning conceptual systems maps into dynamic simulation models: An Australian case study for diabetes in pregnancy. *PLoS ONE, 14*(6), e0218875. *https://doi.org/10.1371/journal.pone.0218875*

Haupt, B., Dkouk, C., & Simpson, G. (2024). *Deliverable 3.7 - Final report on the WEFE Nexus Index methodology and visualisation*. NEXOGENESIS Project. *https://nexogenesis.eu/wp-content/uploads/2025/03/D3.7-Final-report-on-the-WEFE-Nexus-Index-methodology-and-visualisation.pdf*

Hayes, C. F., et al. (2022). A practical guide to multi-objective reinforcement learning and planning. *Autonomous Agents and Multi-Agent Systems, 36*(1), 26. https://doi.org/10.1007/s10458-021-09514-4

Hüesker, F., Sievers, E., Mooren, C., Munaretto, S., Canovas, I., La Jeunesse, I., Cirelli, C., Mounir, K., Madrigal, J., Schmeier, S., Müller, A., & Avellan, T. (2022). *Deliverable 1.1 - Stakeholders' co-creation approach for WEFE nexus governance.* NEXOGENESIS Project. *https://nexogenesis.eu/wp-content/uploads/2023/10/Nexogenesis-Project-Deliverable-1.1-August-2022-1.pdf*

IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core

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

Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647
https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf

International Association for Public Participation. (2018). *IAP2 spectrum of public participation*. https://cdn.ymaws.com/www.iap2.org/resource/resmgr/pillars/Spectrum_8.5x11_Print.pdf

Ioannou, A. E., & Laspidou, C. S. (2022). *Resilience analysis framework for a water–energy–food nexus system under climate change*. *Frontiers in Environmental Science, 10*, Article 820125. https://doi.org/10.3389/fenvs.2022.820125

JRC-COIN. (2019). *10-step pocket guide to composite indicators and scoreboards*. Publications Office of the European Union. https://knowledge4policy.ec.europa.eu/sites/default/files/10-step-pocket-guide-to-composite-indicators-and-scoreboards.pdf

Klessova, S. (2025a). From "The Trinity of the Nexus” to “Beyond Water” to “The Nexus of Engagement”: Multiple cross-case study analysis of NEXOGENESIS case studies’ journeys. (internal NEXOGENESIS project document)

Klessova, S. (2025b).“Beyond water”: Beyond water-centric approaches to holistic nexus planning. NEXOGENESIS external exploitation workshop. (internal NEXOGENESIS project document)

Klessova, S., Blicharska, M., & Papadopoulou, M. P. (2025, July 4). Beyond water: Rethinking nexus integration through climate planning [NEXOGENESIS General Assembly presentation]. Jurmala, Latvia. (internal NEXOGENESIS project document)

La Jeunesse, I., Cirelli, C., Canovas, I., Mooren, C. E., Sievers, E., Munaretto, S., & Hüesker, F. (2023). *D1.2 Governance and policy assessment in case studies. NEXOGENESIS Project.* https://nexogenesis.eu/wp-content/uploads/2025/03/D1.2-Governance-and-policy-assessment-in-case-studies.pdf

La Jeunesse, I., Mooren, C. E., Munaretto, S., Cirelli, E., Sievers, C., Canovas, I., & Hüesker, F. (Forthcoming). A water–energy–food–ecosystem nexus approach to assess the cross-sectoral orientation of resource governance systems [Unpublished manuscript]. University of Tours.

La Jeunesse, I., Mooren, C. E., Munaretto, S., Cirelli, C., Sievers, E. M., Canovas, I., & Huesker, F. (under review). A water–energy–food–ecosystem nexus approach to assess the cross-sectoral orientation of resource governance systems. University of Tours.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: practice,principles, and challenges. Sustainability Science, 7(SUPPL. 1), 25-43. https://doi.org/10.1007/s11625-011-0149-x

Laspidou, C., Spyropoulou, A., Ioannou, A., Kofinas, D., Mellios, N., & Ziliaskopoulos, K. (2023). *D3.2 - Final report on the complexity science and integration methodologies.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D3.2-Final-report-on-the-complexity-science-and-integration-methodologies.pdf

Laspidou, C., Spyropoulou, A., Mellios, N., Kofinas, D., Ioannou, A., Ziliaskopoulos, K., Sušnik, J., Masia, S., Amorocho Daza, H., Papadopoulou, M., Tsihrintzis, V., Indriksone, D., Bremere, I., Nanu, F., Groza, I., Terzi, S., Sambo, B., Haupt, B., Kristensen, D., Simpson, G., Trabucco, A., Roson, R., & Nega,

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

F. (2023). *D3.4 Complexity science models implemented for all the Case Studies: Prototypes and explanatory report/manual for each CS methodology*. NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D3.4-Complexity-science-models-implemented-for-all-the-Case-studies-Prototypes-and-explanatory-report-manual-for.pdf

Laspidou, C., Sušnik, J., Masia, S., Amorocho Daza, H., Spyropoulou, A., Kofinas, D., Mellios, N., Ziliaskopoulos, K., Papadopoulou, M., Papadopoulou, C., Indriksone, D., Bremere, I., Nanu, F., Terzi, S., Cocuccioni, S., Sambo, B., Carnelli, F., Simpson, G., Kristensen, D., & Haupt, B. (2023). D3.1 - Conceptual models completed for all the case studies. NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2023/10/NEXOGENESIS-D3.1-v2-Final.pdf

Laspidou, C., Sušnik, J., Spyropoulou, A., Kofinas, D., Mellios, N., Ioannou, A., Ziliaskopoulos, K., Papadopoulou, M., Tsihrintzis, V., Kourtis, G., Masia, S., Amorocho Daza, H., Bremere, I., Indriksone, D., Nanu, F., Terzi, S., Shresta, S., Sambo, B., Kristensen, D., & Haupt, B. (2023). D3.3 - Final report on the application of biophysical models and stakeholder recommendations. NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D3.3-Final-report-on-the-application-of-biophysical-models-and-stakeholder-recommendations.pdf

Mainar-Causapé, A. J., Ferrari, E., & McDonald, S. (2018). Social accounting matrices: Basic aspects and main steps for estimation (EUR 29297 EN). JRC Technical Reports, Publications Office of the European Union. https://doi.org/10.2760/010600

Margoluis, R., Stem, C., Salafsky, N., & Brown, M. (2013). Results chains: A tool for conservation action design, management, and evaluation. *Ecology and Society, 18*(3). https://doi.org/10.5751/ES-05610-180322

Masia, S., Trabucco, A., Spano, D., Snyder, R., Sušnik, J., & Marras, S. (2021). A modelling platform for climate change impact on local and regional crop water requirements**.** *Agricultural Water Management, 255,* 107005. https://doi.org/10.1016/j.agwat.2021.107005

Mooren, C. E., Munaretto, S., Hegger, D. L., Driessen, P. P., & La Jeunesse, I. (2024). Towards transboundary water–energy–food–ecosystem nexus governance: A comparative governance assessment of the Lielupe and Mesta-Nestos river basins. *Journal of Environmental Policy & Planning, 26*(6), 623–642.

Mooren, C. E., Munaretto, S., Khan, S. J., Huësker, F., Papadopoulou, C.-A., Papadopoulou, M., Bremere, I., Indriksone, D., Nanu, F., Cocuccioni, S., Carnelli, F., Terzi, S., Kristensen, D., Haupt, B., & Harvey, A. (2025a). *D1.4 governance roadmaps and building blocks of a river contract in case-studies* NEXOGENESIS Project. [link to be provided in October 2025]

Mooren, C. E., Munaretto, S., La Jeunesse, I., Sievers, E., Hegger, D. L. T., Driessen, P. P. J., & Madrigal, J. G. (2025b). Water–energy–food–ecosystem nexus: How to frame and how to govern. *Sustainability Science,* 1–22.

Mooren, C., Munaretto, S., Papadopoulou, C.-A., Papadopoulou, M., Bremere, I., Indriksone, D., Nanu, F., Carnelli, F., Terzi, S., Cocuccioni, S., Sambo, B., Bertoldi, G., Egarter Vigl, L., Kristensen, D., & Haupt, B. (2023). D1.3 - Policies for the Self Learning Nexus Assessment Engine (SLNAE). [will be uploaded to the NXG website on October 2025 https://nexogenesis.eu/downloads/]

Mooren, C. E., Papadopoulou, C. A., Munaretto, S., Levedi, K., & Papadopoulou, M. P. (2025c). A methodological framework for assessing the coherence of water–energy–food–ecosystem nexus

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

policies: Illustration and application at the river basin level. *Environmental Science & Policy, 170,* 104113.

Morrison, J. (no date). *"Conservation Strategy Ranking Tool."* World Wildlife Fund.

Moser, S. C. (2016). Can science on transformation transform science? Lessons from co-design. *Current Opinion in Environmental Sustainability, 20*, 106–115. *https://doi.org/10.1016/j.cosust.2016.10.007*

Moss, R. et al. (2008). Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies. Intergovernmental Panel on Climate Change, Geneva, 132 pp. *https://www.ipcc.ch/site/assets/uploads/2018/03/doc8-6.pdf*

Munaretto, S., & Witmer, M. (2017). Water–land–energy–food–climate nexus: Policies and policy coherence at European and international scale: Deliverable 2.1 SIM4NEXUS project–Horizon 2020 689150.

Nievas, N., Dkouk, C. & Echeverria, L. (2024). *D4.5 Final version of the self-assessment nexus engine with the corresponding validation*. NEXOGENESIS Project. *https://nexogenesis.eu/wp-content/uploads/2025/08/D4.5.-Final-version-of-the-self-assessment-nexus-engine-with-the-corresponding-validation_r.pdf*

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

OpenAI. (2025). ChatGPT (August 7, 2025 version) [Large language model]. *https://chat.openai.com/chat*

Papadopoulou, C. A., Kourtis, I. M., Laspidou, C., Tsihrintzis, V. A., & Papadopoulou, M. P. (2025). An integrated methodology for systematic stakeholder engagement in environmental decision-making under the water–energy–food–ecosystems nexus framework. *Environmental Development, 101268.*

Papadopoulou, C. A., Papadopoulou, M. P., Laspidou, C., Munaretto, S., & Brouwer, F. (2020). Towards a low-carbon economy: A nexus-oriented policy coherence analysis in Greece. *Sustainability, 12*(1), 373.

Papadopoulou, C.-A., Kourtis, I. M., Laspidou, C., Tsihrintzis, V. A., & Papadopoulou, M. (2025). An integrated methodology for systematic stakeholder engagement in environmental decision-making under the Water-Energy-Food-Ecosystems nexus framework*. Environmental Development, 56*, Article 101268. *https://doi.org/10.1016/j.envdev.2025.101268*

Portmann, F. T., Döll, P., Eisner, S., & Flörke, M. (2013). Impact of climate change on renewable groundwater resources: Assessing the benefits of avoided greenhouse gas emissions using selected CMIP5 climate projections. *Environmental Research Letters, 8*(2), 024023. *https://doi.org/10.1088/1748-9326/8/2/024023*

Pahl-Wostl, C. (2019). Governance of the water–energy–food security nexus: A multi-level coordination challenge. *Environmental Science & Policy, 92*, 356–367. https://doi.org/10.1016/j.envsci.2017.07.017

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

Pourcher, L. & Klessova, S. (2023). *D6.8 - Internal and external exploitation workshop (first report).* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D6.8-Internal-and-external-exploitation-workshop-first-report.pdf

Pourcher, L., Olivier, N., & Klessova, S. (2024). *D6.9 - Internal and external exploitation workshop (second report).* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D6.9-Internal-and-external-exploitation-workshop-second-report.pdf

ProClim – Forum for Climate and Global Change. (1997). *Research on sustainability and global change – Visions in science policy by Swiss researchers.*

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., & Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management, 90*(5), 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001

Roson, R., Nega, F. M., Rossi Cervi, W., Linderhof, V., & Oudendag, D. (2023). D2.3 - *Nexus data vector of Socioeconomic data for each case study.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D2.3-Nexus-data-vector-of-socio-economic-data-for-each-case-study.pdf

Rossi Cervi, W., Oudendag, D., Hennen, W., & Linderhof, V. (2023). *D2.4 - Socioeconomic data at grid level.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D2.4-Grid-level-socio-economic-data-set.pdf

Scholz, R., & Steiner, G. (2015). The real type and ideal type of transdisciplinary processes: Part I—Theoretical foundations. *Sustainability Science, 10*(4), 527–544. https://doi.org/10.1007/s11625-015-0326-4

Sievers, E., Canovas, I., Kristensen, D., & Hüesker, F. (2025). Assessing to act: A water–energy–food–ecosystem (WEFE) nexus governance assessment for the Inkomati-Usuthu river basin in South Africa. *Environmental Science & Policy, 164,* 103986.

Stakeholder engagement: A good practice handbook for companies doing business in emerging markets. (n.d.). https://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/Sustainability-At-IFC/Publications/Publications_Handbook_StakeholderEngagement__WCI__1319577185063

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. McGraw-Hill.

Sušnik, J., Masia, S., Indriksone, D., Brēmere, I., & Vamvakeridou-Lydroudia, L. (2021). System dynamics modelling to explore the impacts of policies on the water–energy–food–land–climate nexus in Latvia. *Science of the Total Environment, 775*, 145827. https://doi.org/10.1016/j.scitotenv.2021.145827

Sušnik, J. (2022). *Terminology on modelling in NEXOGENESIS*. (internal document of Work Package 3 - Nexus System Thinking and Integration, of the NEXOGENESIS Project).

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

Sušnik, J., Masia, S., Jewitt, G. et al. (2021). *Guidance for Case Studies: getting started, and mapping and understanding the nexus issues in a local context.* Internal document of Work Package 3 - Nexus System Thinking and Integration, of the NEXOGENESIS Project.

Sušnik, J., Masia, S., Amorocho Daza, H., Mellios, N., Kourtis, G., & Terzi, S. (2024). *D3.6 Sensitivity/Uncertainty Analysis Report.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D3.6-Sensitivity-and-uncertainty-analysis-report.pdf

Sušnik, J., Masia, S., Amorocho Daza, H., Trabucco, A., Roson, R., & Nega, F. (2024). *D3.5 - Sensitivity and uncertainty analysis.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D3.5-Sensitivity-and-uncertainty-analysis.pdf

Sušnik, J., & Mellios, N. (2025). The historical role of system dynamics modelling in understanding and supporting integrated natural resource management. *Cambridge Prisms: Water, 3*, 1–32. https://doi.org/10.1017/wat.2025.10002

Sutton, R. S., & Barto, A. G. (2018). *Reinforcement learning: An introduction* (2nd ed.). MIT Press.

Trabucco, A., Roson, R., & Masia, S. (2022a). *M7. Delivery of documentation reporting data and information available to specific Nexus dimension.* NEXOGENESIS Project.

Trabucco, A., Roson, R., Masia, S., Heredia-Arribas, R., Rossi Cervi, W., & Linderhof, V. (2022b). *D2.1 - Document information and consolidated data available according to specific Nexus dimensions from Modelling, Repository and Inter-Comparison projects.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2023/10/D2.1-WP2_NXG.pdf

Trabucco, A., Masia, S. & Faizan Aslam, M. (2023). *D2.2. Nexus data vector of biophysical data for each case study.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D2.2-Nexus-data-vector-of-biophysical-data-for-each-case-study.pdf

Trabucco, A., Rivosecchi, A., Masia, S., Aslam, M. F., Rossi Cervi, W., & Linderhof, V. (2024*). D2.5 - Future Trends and Validation of biophysical data for uncertainty assessment.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/03/D2.5-Retrospective-analysis-and-validation-of-biophysical-data-for-uncertainty-assessment.pdf

UNESCO. (2018). *UNESCO policy on engaging with indigenous peoples* (IPTF/UNESCO-POLICY/FULL_VERSION/2018). https://unesdoc.unesco.org/ark:/48223/pf0000262748

Walmsley, T., Aguiar, A., & Narayanan, B. (2012). *Introduction to the Global Trade Analysis Project and the GTAP Data Base* (GTAP Working Paper No. 67). Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP). https://doi.org/10.21642/GTAP.WP67

Water Europe. (2022). *D6.1 – Communication Strategy*. Internal confidential document of the NEXOGENESIS Project.

Water Europe. (2024a). *Policy Brief 1: Mainstreaming the WEFE Nexus into Policy Making.* NEXOGENESIS Project. https://nexogenesis.eu/wp-content/uploads/2025/01/NXG-FC1-WEFE-Nexus_.pdf

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

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

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

Part 8. APPENDIX

Appendix 1: Stakeholder categories for engagement. Classification of stakeholders, highlighting the groups to consider during identification and engagement activities (Source: *Avellán et al. 2025 - D5.1 - Report on Stakeholder Engagement – link available in October 2025)*

#	Category	Definition	Examples
1	Civil society	Individuals or organised groups (representing a specific community with a collective interest or activity), that are actively engaged (as e.g., users, protectors) to any WEFE resources	Women's groups, minorities, civil society organisations, incl. NGOs
2	Public initiatives	Leader or representative of local procedures, arrangements or organised activities carried out by the civil society that addresses interconnections between WEFE domains	Existing initiatives that the project can connect to focussing on e.g., Water-Energy, Water-Agriculture.
3	Policy makers at local level/ municipalities	Individuals or organisations with an active participation and decision-making power regarding the local management of WEFE-nexus-related resources and services (e.g., water, land, energy, agriculture, biodiversity).	Civil servants/policy makers in municipalities, regional admins, governments that work/design/ participate in discussions on WEFE issues. Politicians: mayors, local & regional councillors, etc. who can take the decisions
4	Policy makers at national level	Individuals or organisations with an active participation and decision-making power regarding the management WEFE-nexus-related resources and services (e.g., water, land, energy, agriculture)	Policy makers in municipalities, regional admins, governments that work/design/ participate in discussions on water, energy-water, agriculture-water, environment-water issues.
5	Agricultural authorities	Organisations that represent the interests of the farmers or farm managers in the case-study location(s). These organisations address from laws and policies to consultation and capacity development activities towards ensuring a good quality of agricultural activities.	- Agricultural chambers - Strategic managers that work/design/participate in discussions on agriculture and WEFE-related issues
6	Energy authorities	Organisations in charge of shaping energy policies, overseeing the implementation and enforcement of laws.	- Strategic managers that work/design/participate in discussions on energy and WEFE-related issues

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#	Category	Definition	Examples
7	Water management authorities	Organisations in charge of shaping water policies, overseeing the implementation and enforcement of laws.	- Strategic managers that work/design/participate in discussions on water and WEFE-related issues
8	River basin authorities	Organisations in charge of developing and implementing water management strategies at a river basin scale. Can include existing transboundary cooperation entities.	- Strategic managers that work/design/participate in discussions on water and WEFE-related issues
9	Environmental protection authorities	Organisations in charge of shaping and overseeing the enforcement/implementation of policies and laws.	- Strategic managers that work/design/participate in discussions on environmental protection
10	Business/private or public enterprises	Organisations providing goods and services that are actively engaged (as e.g., users, protectors) to any of the NXG resources and services of interest (water, energy, food, ecosystems - WEFE).	- Energy, water supply, mining companies
11	Media/science communicators	Individuals or organisations communicating engaged on but not limited to news transmissions, environmental topics for a general audience, or science communication.	- Newspapers - Organisations publishing informative bulletins (e.g., of water resources status)
12	Research & academia	Individuals or organisations related to the design, planning, management, and execution of research projects and/or educational and capacity building based on research.	- Research institutes - Universities
13	Other	Individuals or organisations that can have an interest on the specific CS and do not belong to any of the other categories.	

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Appendix 2. Workshop modalities for stakeholder engagement. Overview of the three workshop modalities (face-to-face, online, hybrid) and considerations regarding their advantages and limitations. (Source: *Avellán et al. 2025 - D5.1 - Report on Stakeholder Engagement – link available in October 2025)*

Workshop Modalities	Advantages for engagements & logistics	Challenges to consider in engagement & logistics
Face-to-Face	• Tends to provide a closer environment to build trust and even familiarity with other stakeholders, especially during coffee breaks which offer an opportunity for professional networking, knowledge exchange, and building personal connections that may open doors in the future. For example, in the NXG Lielupe case-study, coffee breaks were spaces where stakeholders found out about funding opportunities that they could jointly collaborate on.	• Increased preparation requirements: catering, accommodation, finding an appropriate and accessible venue to meet diversity of needs (e.g., with facilities that meet mobility needs, politically “neutral” spaces that make stakeholders from all WEFE domains feel comfortable in) • The possibility of reduced workshop length especially for transboundary case-studies (e.g., cross-border travel limitations regarding inability to stay overnight for multi-day workshops) • For international transboundary cases, may limit participation of some stakeholders due to visa requirements • Tricky to reconcile real-time language translation if this is necessary in transboundary cases (e.g., especially if high-level political stakeholders are participating or if presenters communicate best in their local language)

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Online	• Allows more participation, including partial participation when commitment to longer sessions is not feasible • Easier to record and digitally track participants as well as their comments (e.g., recordings, chat transcriptions) transcripts, intended participation (acceptance of invitation) vs. actual attendance/participation). • Enables participation of stakeholders who cannot travel to on-site venues due to constraints around distance, time, budget, limited transportation options, physical mobility difficulties, family commitments. This may be especially the case in international transboundary river basins or river basins with a particularly large geographical area. • Allows two workshops with the same agenda to be held on the same day (e.g., one in the morning, another in the afternoon), to accommodate the schedules of different stakeholders. This also allows for adaptation of the afternoon session based on feedback from the morning session. • If language translators can be organised, it facilitates real-time discussions between cross-border stakeholders within one workshop • For broad outreach or information-sharing purposes- engaging a larger and diverse group of stakeholders	• Does not facilitate further interaction between participants post-workshop or during breaks • Allows multi-tasking, thus participants may not be paying full attention. • (Access to) stable internet connection and the understanding of / ability to use virtual participation tools is a limiting participation factor for certain stakeholders • In the absence of participants' comments during discussions sessions, there are few other clues to gauge participants' interest and understanding of material, validation of results, etc.

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Hybrid	• Flexibility for attendees to still participate online if their planned in-person availability changes unexpectedly on short notice • More inclusive for stakeholders with different participation preferences • For broad outreach or information-sharing purposes- engaging a larger and diverse group of stakeholders	• Increased preparation requirements, especially for the coordination between both modalities (e.g., ensuring equal participation opportunities of people on site and in online platform) • In some cases, requires sufficient technical capacity (e.g., speakers and microphones for in-person / online attendees to hear each other, stable internet connection)

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Appendix 3. Template for evaluating the effectiveness of knowledge co-production at workshops. *Template designed to assess stakeholders' perception of the effectiveness of workshops in co-producing system, target and transformation knowledge. The template can also be adapted and used for other engagement activities (e.g., focus groups) and even as a high-level evaluation of the entire project at its conclusion (e.g., with adjusted wording "to what degree did the project help you understand the current state of the…?" (Source: Tamara Avellan (AVA) & Simon Ryfisch (Uppsala University), NEXOGENESIS Project, 2021)*

<table>
<tr><td colspan="8">Biophysical System
(Biological and physiochemical components like the effect of precipitation on water flows)</td><td colspan="8">Socio-Economic System
(Social and economic components like the effect of employment rates on GDP)</td><td colspan="8">WEFE-Nexus
(Interlinkages across Nexus aspects and the overall footprint)</td><td colspan="8">Stakeholder Landscape
(The classification of stakeholders, their relationship towards each other and for the problem & solution)</td><td colspan="8">Policy Landscape
(The classification of policies, their relation to the WEFE Nexus aspects and their role in solving Nexus problems)</td></tr>
<tr><td colspan="8">System Knowledge:</td><td colspan="32">To what degree did the workshop help you understand the current state of the …?</td></tr>
<tr><td colspan="8">Biophysical System</td><td colspan="8">Socio-Economic System</td><td colspan="8">WEFE-Nexus</td><td colspan="8">Stakeholder Landscape</td><td colspan="8">Policy Landscape</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td></tr>
<tr><td colspan="40">Target Knowledge: To what degree did the workshop help you understand the desired state of the …?</td></tr>
<tr><td colspan="8">Biophysical System</td><td colspan="8">Socio-Economic System</td><td colspan="8">WEFE-Nexus</td><td colspan="8">Stakeholder Landscape</td><td colspan="8">Policy Landscape</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td></tr>
<tr><td colspan="40">Transformation Knowledge: To what degree did the workshop help you understand how to influence the …?</td></tr>
<tr><td colspan="8">Biophysical System</td><td colspan="8">Socio-Economic System</td><td colspan="8">WEFE-Nexus</td><td colspan="8">Stakeholder Landscape</td><td colspan="8">Policy Landscape</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>N/A</td></tr>
</table>

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Appendix 4: Methodological matrix of the Nexus Governance Assessment Tool *(La Jeunesse et al., 2023).* The NXGAT helps stakeholders understand the governance system surrounding the WEFE nexus interlinkages and identify entry points for change towards more WEFE nexus governance [Huesker et al. 2022; La Jeunesse et al (under review)].

	Quality of WEFE nexus governance system (very low / low / high / very high)				
Governance dimensions	**Comprehensiveness** *Degree to which current governance system* ***includes*** *relevant WEFE nexus elements*	**Coherence** *Degree to which elements of the governance system are strengthening rather weakening each other*	**Flexibility** *Capacity of current governance system to provide different pathways towards WEFE nexus governance*	**Intensity of action** *Capacity of current governance system to urge more WEFE nexus-oriented actions*	**Fit** *Degree to which current governance system matches ecosystems properties & functions*
Actors and networks	To what degree are relevant actors and networks affected by or affecting WEFE nexus domains involved? **Very high:** All relevant actors and networks affected by or affecting WEFE nexus domains are involved. **High:** The majority of relevant actors and networks affected by or affecting WEFE nexus domains is involved. **Low:** A limited number of relevant actors and networks affected by or affecting WEFE nexus domains are involved. **Very low:** The relevant actors and networks affected by or affecting WEFE nexus domains are not involved.	To what degree are interactions of relevant actors and networks across WEFE nexus domains cooperative, solid and based on trust? **Very high:** Interactions of relevant actors and networks across WEFE nexus domains are fully cooperative, solid and based on trust. **High:** Interactions of relevant actors and networks across WEFE nexus domains are mostly cooperative and solid and based on trust. **Low:** Interactions of relevant actors and networks across WEFE domains are little cooperative, solid or based on trust. **Very low:** Interactions of relevant actors and networks across WEFE nexus domains are neither cooperative nor solid and also not based on trust.	To what degree does the governance system allow to include new actors or shift the lead from one actor to another when needed? **Very high:** The governance system easily allows to include new actors or shift the lead from one actor to another when needed. **High:** The governance system allows to include new actors or shift the lead from one actor to another when needed in some situations. **Low:** The governance system makes it difficult to include new actors or shift the lead from one actor to another when needed. **Very low:** The governance system does not allow to include new actors or shift the lead from one actor to another when needed.	To what degree is there pressure from a relevant actor or actor coalition across WEFE nexus domains towards behavioral change or management reform? **Very high:** There is very strong pressure from a relevant actor or actor coalition across WEFE nexus domains towards behavioral change or management reform. **High:** There is strong pressure from a relevant actor or actor coalition across WEFE nexus domains towards behavioral change or management reform. **Low:** There is weak pressure from a relevant actor or actor coalition across WEFE nexus domains towards behavioral change or management reform. **Very low:** There is no pressure from any relevant actor or actor coalition across WEFE nexus	To what degree are relevant actors and networks across WEFE nexus domains appropriate to deal with ecosystem properties and functions? **Very high:** Relevant actors and networks across WEFE nexus domains are appropriate to deal with ecosystem properties and functions. **High:** Relevant actors and networks across WEFE nexus domains are appropriate to deal with/manage ecosystem properties and functions in some situations. **Low:** Relevant actors and networks across WEFE nexus domains are little appropriate to deal with ecosystem properties and functions. **Very low:** Relevant actors and networks across WEFE nexus domains are inappropriate to

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				domains towards behavioral change or management reform.	deal with ecosystem properties and dynamics.

	Comprehensiveness *The degree to which the current governance system **includes** relevant WEFE nexus elements*	**Coherence** *The degree to which the elements of the governance system are strengthening rather weakening each other*	**Flexibility** *The capacity of the current governance system to provide different pathways towards WEFE nexus governance*	**Intensity of action** *The capacity of the current governance system to urge more WEFE nexus-oriented actions*	**Fit** *The degree to which the current governance system matches ecosystems properties and functions*
Levels and scales	To what degree are relevant levels and scales across WEFE nexus domains involved? **Very high:** All relevant levels and scales across WEFE nexus domains are involved. **High:** The majority of relevant levels and scales across WEFE nexus domains are involved. **Low:** A limited number of relevant levels and scales across WEFE nexus domains are involved. **Very low:** The relevant levels and scales across WEFE nexus domains are not involved.	To what degree do relevant levels and scales across WEFE nexus domains work together, acknowledging interdependencies and trusting each other? **Very high:** Relevant levels and scales across WEFE nexus domains always work together acknowledging interdependencies and trust each other. **High:** Relevant levels and scales across WEFE nexus domains most of the time work together, acknowledge interdependencies and trust each other. **Low:** Relevant levels and scales across WEFE nexus domains rarely work together, rarely acknowledge interdependencies and have little trust on each other. **Very low:** Relevant levels and scales across WEFE nexus domains do not work together, do not acknowledge interdependencies and/ or do not trust each other.	To what degree does the governance system allow to change levels and/or scales at which WEFE nexus issues are addressed? **Very high:** The governance system easily allows to change levels and/or scales at which WEFE nexus issues are addressed. **High:** The governance system allows to change levels and/or scales at which WEFE nexus issues are addressed in some situations. **Low:** The governance system makes it difficult to change levels and/or scales at which WEFE nexus issues are addressed. **Very low:** The governance system does not allow to change levels and/or scales at which WEFE nexus issues are addressed.	To what degree is there pressure from relevant levels and/or scales across WEFE nexus domains towards behavioral change or management reform? **Very high:** There is very strong pressure from the relevant levels and/or scales across WEFE nexus domains towards behavioral change or management reform. **High:** There is strong pressure from relevant levels and/or scales across the WEFE nexus domains towards behavioral change or management reform. **Low:** There is a weak pressure from relevant levels and/or scales across the WEFE nexus domains towards behavioral change or management reform. **Very low:** There is no pressure from relevant levels and/or scales across the WEFE nexus domains towards behavioral change or management reform.	To what degree do relevant levels and scales of the governance system match ecosystem properties and functions? **Very high:** Relevant levels and scales of the governance system fully match ecosystem properties and functions. **High:** Relevant levels and scales of the governance system mostly match ecosystem properties and functions. **Low:** Relevant levels and scales of the governance system hardly match ecosystem properties and functions. **Very low:** Relevant levels and scales of the governance system do not match ecosystem properties and functions.

NEXOGENESIS STREAMLINING WATER RELATED POLICIES

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	Comprehensiveness *The degree to which the current governance system **includes** relevant WEFE nexus elements*	**Coherence** *The degree to which the elements of the governance system are strengthening rather weakening each other*	**Flexibility** *The capacity of the current governance system to provide different pathways towards WEFE nexus governance*	**Intensity of action** *The capacity of the current governance system to urge more WEFE nexus-oriented actions*	**Fit** *The degree to which the current governance system matches ecosystems properties and functions*
Problem perspectives and goal ambitions	To what degree are various problem perspectives and goal ambitions across WEFE nexus domains taken into account? **Very high:** All problem perspectives across WEFE nexus domains are taken into account and are translated into WEFE nexus goal ambitions. **High:** The majority of problem perspectives across WEFE nexus domains are taken into account and most of them are translated into WEFE nexus goal ambitions. **Low:** A limited number of problem perspectives across WEFE nexus domains are taken into account and only a few are translated into WEFE nexus goal ambition. **Very low:** Problem perspectives across WEFE nexus domains are not taken into account and there is no WEFE nexus goal ambitions.	To what degree are problem perspectives and goal ambitions across WEFE nexus domains mutually reinforcing? **Very high:** Problem perspectives and goal ambitions across WEFE nexus mutually always reinforce each other. **High:** Problem perspectives and goal ambitions across WEFE nexus most of the time mutually reinforce each other. **Low:** Problem perspectives and goal ambitions across WEFE nexus rarely mutually reinforce each other. **Very low:** Problem perspectives and goal ambitions across WEFE nexus never mutually reinforce each other.	To what degree does the governance system allow to re-assess goals across WEFE nexus domains and combine multiple goals in package deals as needed? **Very high:** The governance system easily allows to re-assess goals across WEFE nexus domains and combine multiple goals in package deals as needed. **High:** The governance system allows to re-assess goals across WEFE nexus domains and combine multiple goals in package deals as needed in some situations. **Low:** The governance system makes it difficult to re-assess goals across WEFE nexus domains and combine multiple goals in package deals as needed. **Very low:** The governance system does not allow to re-assess goals across WEFE nexus domains, and combine multiple goals in package deals as needed.	To what degree do problem perspectives and goal ambitions across WEFE nexus domains urge for WEFE nexus orientation? **Very high:** Problem perspectives and goal ambitions across WEFE nexus domains very strongly urge nexus orientation. **High:** Problem perspectives and goal ambitions across WEFE nexus domains urge nexus orientation. **Low:** Problem perspectives and goal ambitions across WEFE nexus domains weakly urge nexus orientation. **Very low:** Problem perspectives and goal ambitions across WEFE nexus domains do not urge nexus orientation.	To what degree do problem perspectives and goal ambitions across WEFE nexus domains take into account ecosystem properties and functions? **Very high:** Problem perspectives and goal ambitions across WEFE nexus domains always take into account ecosystem properties and functions. **High:** Problem perspectives and goal ambitions across WEFE nexus domains most of the time take into account ecosystem properties and functions. **Low:** Problem perspectives and goal ambitions across WEFE nexus domains rarely take into account ecosystem properties and functions. **Very low:** Problem perspectives and goal ambitions across WEFE nexus domains never take into account ecosystem properties and functions.

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	Comprehensiveness *The degree to which the current governance system **includes** relevant WEFE nexus elements*	**Coherence** *The degree to which the elements of the governance system are strengthening rather weakening each other*	**Flexibility** *The capacity of the current governance system to provide different pathways towards WEFE nexus governance*	**Intensity of action** *The capacity of the current governance system to urge more WEFE nexus-oriented actions*	**Fit** *The degree to which the current governance system matches ecosystems properties and functions*
Strategies and instruments	To what degree do relevant strategies and instruments include WEFE nexus orientation? **Very high:** All relevant strategies and instruments include WEFE orientation. **High:** The majority of relevant strategies and instruments include WEFE orientation. **Low:** A limited number of relevant strategies and instruments include WEFE orientation. **Very low:** Relevant strategies and instruments do not include WEFE nexus orientation.	To what degree are relevant strategies and instruments across WEFE nexus domains mutually reinforcing? **Very high:** Relevant strategies and instruments across WEFE nexus domains always reinforce each other. **High:** Relevant strategies and instruments across WEFE nexus domains most of the time reinforce each other. **Low:** Relevant strategies and instruments across WEFE nexus domains rarely reinforce each other. **Very low:** Relevant strategies and instruments across WEFE nexus domains never reinforce each other.	To what degree does the governance system allow to combine or make use of different strategies and types of instruments across WEFE nexus domains? **Very high:** The governance system easily allows to combine or make use of different strategies and types of instruments across WEFE nexus domains. **High:** The governance system allows to combine or make use of different strategies and types of instruments across WEFE nexus domains in some situations. **Low:** The governance system makes it difficult to combine or make use of different strategies and types of instruments across WEFE nexus domains. **Very low:** The governance system does not allow to combine or make use of different strategies and types of instruments across WEFE nexus domains.	To what degree do relevant strategies and instruments across WEFE nexus domains urge WEFE nexus-oriented behavior or management reform? **Very high:** Relevant strategies and instruments across WEFE nexus domains strongly urge WEFE nexus-oriented behavior or management reform. **High:** Relevant strategies and instruments across WEFE nexus domains urge WEFE nexus-oriented behavior or management reform. **Low:** Relevant strategies and instruments across WEFE nexus domains weakly urge WEFE nexus-oriented behavior or management reform. **Very low:** Relevant strategies and instruments across WEFE nexus domains do not urge WEFE nexus-oriented behavior or management reform.	To what degree do relevant strategies and instruments across WEFE nexus domains take into account ecosystem properties and functions? **Very high:** Relevant strategies and instruments across WEFE nexus domains always take into account ecosystem properties and functions. **High:** Relevant strategies and instruments across WEFE nexus domains most of the time take into account ecosystem properties and functions. **Low:** Relevant strategies and instruments across WEFE nexus domains rarely take into account ecosystem properties and functions. **Very low:** Relevant strategies and instruments across WEFE nexus domains never take into account ecosystem properties and functions.

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	Comprehensiveness *The degree to which the current governance system **includes** relevant WEFE nexus elements*	**Coherence** *The degree to which the elements of the governance system are strengthening rather weakening each other*	**Flexibility** *The capacity of the current governance system to provide different pathways towards WEFE nexus governance*	**Intensity of action** *The capacity of the current governance system to urge more WEFE nexus-oriented actions*	**Fit** *The degree to which the current governance system matches ecosystems properties and functions*
Responsibilities and resources	To what degree are responsibilities and resources across WEFE domains clearly assigned to support WEFE nexus-oriented management? **Very high:** Responsibilities are clearly assigned across WEFE nexus domains and fully supported with resources to allow WEFE nexus management. **High:** The majority of responsibilities are clearly assigned and sufficient resources are allocated across WEFE nexus domains to support WEFE nexus management. **Low:** Few responsibilities are clearly assigned and only limited resources are allocated across WEFE nexus domains to support WEFE nexus management. **Very low:** Responsibilities are unclear across WEFE nexus domains and resources are insufficient to support WEFE nexus management.	To what degree do responsibilities and resources across WEFE nexus domains lead to cooperation among these domains? **Very high:** Responsibilities and resources across WEFE nexus domains always lead to cooperation among these domains. **High:** Responsibilities and resources across WEFE nexus domains most of the time lead to cooperation among these domains. **Low:** Responsibilities and resources across WEFE nexus domains rarely lead to cooperation among these domains. **Very low:** Responsibilities and resources across WEFE nexus domains do never lead to cooperation among these domains.	To what degree does the governance system allow to pool assigned responsibilities and resources across WEFE nexus domains without compromising accountability and transparency? **Very high:** The governance system easily allows to pool assigned responsibilities and resources across WEFE domains without compromising accountability and transparency. **High:** The governance system allows to pool assigned responsibilities and resources across WEFE domains without compromising accountability and transparency in some situations. **Low:** The governance system makes it difficult to pool assigned responsibilities and resources across WEFE domains without compromising accountability and transparency.	To what degree do responsibilities and resources across WEFE nexus domains urge implementation of WEFE nexus-oriented actions? **Very high:** Responsibilities and resources across WEFE nexus domains very strongly urge implementation of WEFE nexus-oriented actions. **High:** Responsibilities and resources across WEFE nexus domains strongly urge implementation of WEFE nexus-oriented actions. **Low:** Responsibilities and resources across WEFE nexus domains weakly urge implementation of WEFE nexus-oriented actions. **Very low:** Responsibilities and resources across WEFE nexus domains do not urge implementation of WEFE nexus-oriented actions.	To what degree are assigned responsibilities and allocated resources across WEFE nexus domains appropriate to deal with ecosystem properties and functions? **Very high:** Responsibilities and resources across WEFE nexus are always appropriate to deal with ecosystem properties and functions. **High:** Responsibilities and resources across WEFE nexus domains are most of the time appropriate to deal with ecosystem properties and functions. **Low:** Responsibilities and resources across WEFE nexus domains are rarely appropriate to deal with ecosystem properties and functions. **Very low:** Responsibilities and resources across WEFE nexus domains are never appropriate to deal with ecosystem properties and functions.

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			Very low: The governance system does not allow to pool assigned responsibilities and resources across WEFE domains without compromising accountability and transparency.		
Overall score	*[Very low / low / high / very high]*	*[Very low / low / high / very high]*	*[Very low / low / high / very high]*	*[Very low / low / high / very high]*	*[Very low / low / high / very high]*
Concluding evaluation	The current governance system is [*highly restrictive/ restrictive/moderately supportive/ supportive*] towards WEFE nexus governance: justification with barriers and leverages				

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Appendix 5: Template for action plan for governance roadmap. *Template that can be used to coordinate the implementation of the actions of the governance roadmap towards achievement of the outcomes. Roles of stakeholders and resources required can be identified. The data from the visual results chain are transferred directly to the respective columns and rows of the template. (Source: Sabina J. Khan - Helmholtz Centre for Environmental Research UFZ, as part of the NEXOGENESIS project, 2025).*

NEXOGENESIS STREAMLINING WATER RELATED POLICIES

Action Plan for Roadmap of Policy 3 of SVPP-1

NAME OF THE POLICY: *Policy 1 ....*							*CY = calendar year* *Q1 = January, February, March // Q2 = April, May, June //* *Q3 = July, August, September // Q4 = October, November, December*							
DESCRIPTION OF THE POLICY: *[briefly -- what problem the policy will solve, how it is expected the policy would work]*														
Outcomes *(blue boxes of results chain)*	**Local actions** *(yellow boxes of results chain)*	**Lead Role** (organisation or person)	**Support Roles** (organisation or person)	**Indicative Costs**	**Indicative funding sources**	**Notes** *(contingencies, risks, special requirements, etc.)*	**CY2026**				**CY2027**			
							Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
O1 *[details]*	A1.1 *[details]*	NGO *[name]*	university	10,000 Euros	research grants									
O1 *[details]*	A1.2	private sector association	corporation		corporate sponsorship	workshop requires external facilitator								
O2	A2.1	tbd	CSO *[name]*	5,000 Euros	tbd	merge with A1.1 if no lead is found by end of Q1	tbd	tbd						
O3	A3.1, A3.2, etc.	government agency 1 [name]	government agency 2	150,000 Euros	multi-lateral funds									
and so on...														

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