D1.7: PROGRESS OF THE ASSESSMENT FRAMEWORK OF THE NEXUS ESTABLISHED

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Executive summary

This deliverable presents the current version of the SIM4NEXUS nexus assessment framework. The framework is interpreted at this stage as a step-by-step methodology that describes the assessment of the nexus in the SIM4NEXUS project. Therefore, we start by summarising key steps of the framework from a processual angle. These result from the combination of activities that were and are being carried out in different work packages. In addition, and in support to the first steps of the framework, focus is given to aspects related to the independent understanding of nexus systems, with insights on how individual systems interact with other systems of the nexus of water, land, energy, food and climate. A review of integrated assessment modelling exercises is performed to explore the status-of-the-art of multi-systems assessments and what quantitative methods are used in such analyses. From the exploration of the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework it was found its usefulness for the systematization of information in each case study that enable the characterization of the nexus, identification of drivers and better understanding of impacts, responses and pressures. For this reason, the DPSIR is included in the framework as a tool for the formulation of narratives in each case study. Case study approaches in the development of their respective assessments, including stakeholder participation, is also summarised in this report. From the development of the wide range of case studies in SIM4NEXUS we aim at gain understanding of what is essential in the development of assessments of the nexus and, in this way, produce a framework which captures effectively the key elements towards the development of nexus compliant practices. Apart from the framework proposed in this deliverable, we consider an important outcome of the task T1.5 the production of a glossary of terms related to the science of the nexus. Its usefulness is supported not only by the necessity of harmonizing how different terms are understood within the project consortium and actors involved (from experts, to modellers, case study leaders, and stakeholders in general), but also as contribution to growing research community in the science of the nexus. The glossary also aims at standardizing, within the extent possible, terminology which is frequently used in resource nexus discussions and can facilitate communication with stakeholders and other audiences in contact with the work.

This deliverable is to be interpreted as a living document with the final version of the framework to be included in Deliverable 1.5 “Framework for the assessment of the Nexus”, due in month 48 of the project.

Changes with respect to the DoA

Task 1.5 was prolonged from month 30 to month 48 of the project, in order for the development of the framework to follow up and feed into the work of the case studies and of other activities in the project.

Dissemination and uptake

The deliverable is to be used by case study leaders and modelling teams working on the development of scenarios in the case studies and in the analysis of results.

Short Summary of results (<250 words)

Not applicable.

Evidence of accomplishment

The deliverable is presented in the format of a report.

Glossary

See Appendix A.

Acronyms

As the document is being written, terms and glossary will be added here as needed. Before the last version is submitted this list will be re-arranged alphabetically by the lead author.

TERM	EXPLANATION / MEANING
BEVS	BATTERY ELECTRIC VEHICLES
CCS	CARBON CAPTURE AND STORAGE
CLEWS	CLIMATE, LAND (FOOD), ENERGY AND WATER SYSTEMS
DAFNE	DECISION ANALYTICAL FRAMEWORK TO EXPLORE THE WATER-ENERGY-FOOD NEXUS IN COMPLEX TRANSBOUNDARY WATER RESOURCE SYSTEMS
DICE	DYNAMIC INTEGRATED MODEL OF CLIMATE AND THE ECONOMY
DPSIR	DRIVERS – PRESSURES – STATE – IMPACTS – RESPONSES
ETS	EMISSIONS TRADING SCHEME
FAO	FOOD AND AGRICULTURE ORGANISATION
FEW	FOOD-ENERGY-WATER
GHG	GREENHOUSE GASES
GWP	GLOBAL WARMING POTENTIAL
IAM	INTEGRATED ASSESSMENT MODEL
IMF	INTEGRATED MODELLING FRAMEWORK
ISMHS	INTEGRATED SYSTEM MODELLING HUBS
KEE	KNOWLEDGE ELICITATION ENGINE
LCA	LIFE-CYCLE ASSESSMENT
MUSIASEM	Multi-Scale Integrated Assessment of Society and Ecosystem Metabolism
PHEVS	PLUG-IN HYBRID ELECTRIC VEHICLES
PIP	PARTICIPATORY AND INTEGRATED PLANNING
PV	PHOTOVOLTAIC
RES	RENEWABLE ENERGY SOURCES
SDM	SYSTEM DYNAMICS MODEL
TPES	TOTAL PRIMARY ENERGY SUPPLY
TWW	TREATED WASTE WATER
UNECE	UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE
WEF	WATER – ENERGY – FOOD
WEFO	WATER, ENERGY AND FOOD SECURITY NEXUS OPTIMIZATION MODEL
WELF	WATER-ENERGY-LAND-FOOD
WP	WORK PACKAGE

1 Introduction

1.1 Introduction

Natural resources, meaning materials or substances occurring naturally tin the environment, are being used in a non-sustainable manner. The intensification of human activities and increasing demands, driven by population growth and economic development, adds pressure in these reserves and raise questions in regard to the impacts on the environment and the feasibility of maintaining current practice to the management of resources. This motivates the need to better understand resource systems and how these can be more efficiently managed. From this reasoning develops the idea of system thinking in which one regards the interactions between different systems and how these are interlinked and what type of dynamics govern such interactions, where conflicts and pressures could exist but also opportunities and synergies. This integrated multi-systems' thinking, or system-of-systems thinking, can be referred to as "Nexus", as the approach that seeks knowledge and understanding to systems' interactions, what factors influence them, how to recognise and assess trade-offs and synergies, and in this way reconcile the interests of the different sectors part of the domains that constitute the nexus. Trade-offs refer to the loss in quality/quantity of one resource when the quality/quantity resource increases. Synergy refers to when two or more elements, such as systems, have a greater total effect than the isolated individual contributions. By understanding how socio-economic drivers, such as population or economic growth, influence the demand for resources and goods in specific contexts, and having good knowledge of how systems interact, solutions and alternative ways of managing resources can be investigated. The Nexus approach thus allows to seek for synergies, while overcoming or minimising trade-offs. By such actions, one aims to achieve a sustainable integrated management of natural recourses.

This document describes key steps in the development of the SIM4NEXUS Nexus Framework for the assessment of the nexus in the case studies. In SIM4NEXUS, the nexus assessed is composed by the domains, and respective systems, of Climate, Land Use, Energy, Water and Food. Governance is another dimension which is key to the management of resources in the biophysical sphere. Sectoral policies and policy coherence play an important role on how resources are managed, with the risk of cross-sectoral trade-offs when planning is not performed in an integrated manner. Furthermore, the Framework developed in this context does not have the approach of resource output optimization of but resource use efficiency, meaning that what it is sought is the maximisation of outputs per unit of resource used; or minimisation of inputs for the production of the same amount of output. For instance, rather than maximising the crop production by over-exploiting water resource, i.e. higher yield for increased water supply, food is to be produced using more efficient irrigation methods, that supply water when strictly required, and thus avoiding unnecessary use of water resources. A connected concept to resource-efficiency is the concept of circular economy. Overlaps in the approaches clearly exist, especially in the common interpretation of resources' management which should follow an integrated systems' approach.

The SIM4NEXUS framework is developed in a step-by-step approach that aims at providing the key elements in the development of an integrated nexus assessment, including the biophysical, governance and socioeconomic domains. In this way, it facilitates the processual understanding of the analysis and serves to identify where different expertise contribute to and how transdisciplinary is achieved. The ultimate goal of the nexus analysis is to inform and support decision makers in the development of Nexus-compliant strategies and planning in a way it can be incorporated in their practice; in other words, practices that cope with trade-offs between Nexus sectors and build cross-sectoral synergies. In a two-way cooperation, the 12 case studies will feed their insights to the shaping of the framework; meanwhile the framework will support the case studies in their nexus system interactions development. In a step-by-step approach, this document presents the development of the Nexus Framework of the SIM4NEXUS project up to October 2018. As a starting point, the version of the SIM4NEXUS Nexus framework builds from the Climate, Land, Water and Energy strategies (CLEWs) framework (Howells et al., 2013a). However, CLEWs does not incorporate separately "Food" dimension, as it is considered embedded in the "Land Use" system of the framework. Thus, further lessons and insights related to the "Food" dimension are drawn from the Water-Energy-Food Nexus developed by FAO (Food and Agriculture Organization of the United Nations) (FAO, 2014). The current version of the framework is updated with the tasks that have been carried out I the first two years of the SIM4NEXUS project, until the development of the baseline scenario in the case studies and preparation of the System Dynamic Models. Therefore, the framework version presented here is expected to be further expanded, final version which will be included in Deliverable D1.5 in Month 48 of the project.

1.2 Definition of Nexus in SIM4NEXUS context

The previous section introduced the reader to the concept of Nexus and the framework presented in this document. The Nexus approach developed under the scope of this study follows a set of definitions, which are separately introduced here.

First, Nexus approach is a systematic approach accounting for the implicated systems (in SIM4NEXUS: Climate, Land Use, Energy, Water and Food) and their interactions, both in qualitative and quantitative measures to better understand their relationship. Nexus interlinkage corresponds to the interconnected elements within the same or different domains, where the elements can be a physical link linked to a resource. From these interlinkages, nexus challenges can be derived. A nexus-induced challenge is complex task or combination of factors that for not having an upfront or obvious solution requires a Nexus approach, i.e. one solution could benefit one sector but exacerbate negative impacts on another. The issues can be derived from one nexus domain, but poising the actual challenge(s) in other systems, and also possibly trigger a feedback mechanism. Such feedbacks refer to an output that is routed back as input to the same or another nexus domain, in the former case it would be a negative feedback. Figure 1 illustrates a very simple representation of the terms defined here using the Water and Energy systems and their activities related to hydropower operation and water treatment.

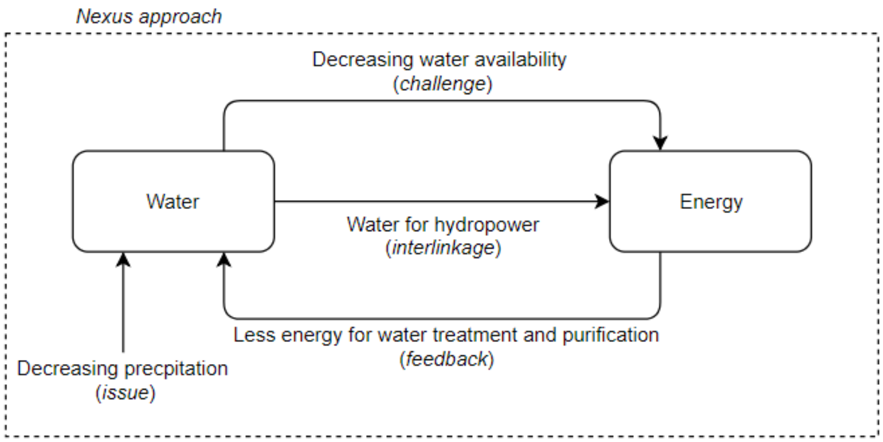

Figure 1. Visual representation of selected Nexus-related terms.

Furthermore, interlinkages occur between main natural resources domains: water, energy, food, land and climate. In principle, the assessment of the nexus spans through all these domains. With that said, another Nexus-study may incorporate other systems for interactions; however, this is up to the scope of the study. Nexus domains are composed by systems, which in turn can include activities of different sectors. Domains hold a system, which in its turn hold sectors, and the latter two is where interactions occur. This is further elaborated in the report.

In order to support the definitions used within this report and in the SIM4NEXUS project, a glossary of terms has been established (see Appendix A – SIM4NEXUS Glossary of Terms). This effort is motivated by the need of clarifying the interpretation of nexus related terms, not only limited to this project but the Nexus-arena in general. The glossary is a work in progress and is to be updated throughout the SIM4NEXUS project. In its final version it will correspond to a comprehensive glossary of terms and definitions commonly used related to the Nexus. The glossary aims at bringing coherency to all users and actors that take part in a nexus study.

1.3 Objective and foreseen outcomes

This report aims at to presenting a first version of the Nexus Framework of SIM4NEXUS, based on the development of the case studies up to Month 28 (October 2018) of the project. The final version of the assessment framework will be included in Deliverable 1.5 in month 48. The report informs on the main methodological steps in the development of a nexus assessment in the SIM4NEXUS project. It results from a combination of activities in different project tasks, and on the comparative analysis of the case studies' progress towards the development of the SDM and the *Serious* Game. Ultimately, the current version of the framework already provides significant insights on how a nexus assessment can be performed and what the key methodological steps of the process are.

The aforementioned is done by breaking down the steps of the framework and providing in-depth knowledge through:

a) Outlining the framework developed in SIM4NEXUS;
b) Presenting the systems included and how these work in order to identify nexus interlinkages;
c) Exploring methods for the development of narratives that can characterize the case studies and pathways/scenarios under analysis (in this version we introduce the DPSIR framework as an approach that can assist with the formulation of nexus storylines for the case-studies, facilitate nexus dialogues and incorporate feedback from multiple sources);
d) Literature review of existing integrated assessment modelling frameworks to collect insights on key elements, identify gaps in the nexus research field that could be addressed in SIM4NEXUS;
e) Summarising and comparing how the Nexus assessments in the 12 case studies;
f) Identify next steps in the development and improvement of the Framework.

1.4 Adopted approach

The work presented here is highly dependent on the progress of the entire SIM4NEXUS project; thus, correspondence and interactions with other WP are necessary. Further, since the 12 case studies are meant to help guide the Framework development, the progress and result of each of the case studies feed in as valuable, and critical, insights. As was mentioned in section 1.1, the framework development under SIM4NEXUS draws from the CLEWs framework (Howells et al., 2013a), and is complemented by the Food system from the WEF-Nexus by FAO (FAO, 2014).

1.5 Structure of the document

This report is structured in eight Chapters and two Appendices as follows. Chapter 2 provides an overview of the most important interactions between Task 1.5 "SIM4NEXUS Framework for the Assessment of the Nexus in Case Studies" and other tasks in the Work Package 1, and with other tasks from different work packages. Chapter 3 introduces the SIM4NEXUS framework as a draft methodology for the development of nexus assessments, next steps in the framework development, and a reflection on its current limitations. This is followed by Chapter 4 that details the main elements in each resource system and how the different systems interact. An analysis of the added value of the Drivers-Pressures-State-Impacts-Responses for the assessment of the nexus is introduced in Chapter 5. In Chapter 6, a review of integrated assessment modelling initiatives is presented so to inform on the state-of-the art of this field of research. Chapter 7 compiles information from the development of the 12 case studies in SIM4NEXUS and identifies common methodological steps in the nexus analysis, and how these were considered in the framework development. Finally, in Chapter 8, findings from the development of the task are presented along with the next steps in the finalization of the framework for the assessment of the nexus. The Glossary of Terms is presented in Appendix A.

2 Interactions with other Work Packages

The Framework for the assessment of the nexus in the case studies has multiples interactions with several activities in different work packages of the project. As defined in the Grant Agreement, it plays an important role for the understanding of the nexus dimensions under focus in SIM4NEXUS via a schematic scrutiny of each dimension in collaboration with Work Package 5, and also in the identification of the thematic models best suited to represent and inform on the interactions between the nexus dimensions, interacting with Work Package 3. These interactions are an iterative process. Figure 2 summarizes the interconnections between WP1 tasks and efforts in other Work Packages of the project.

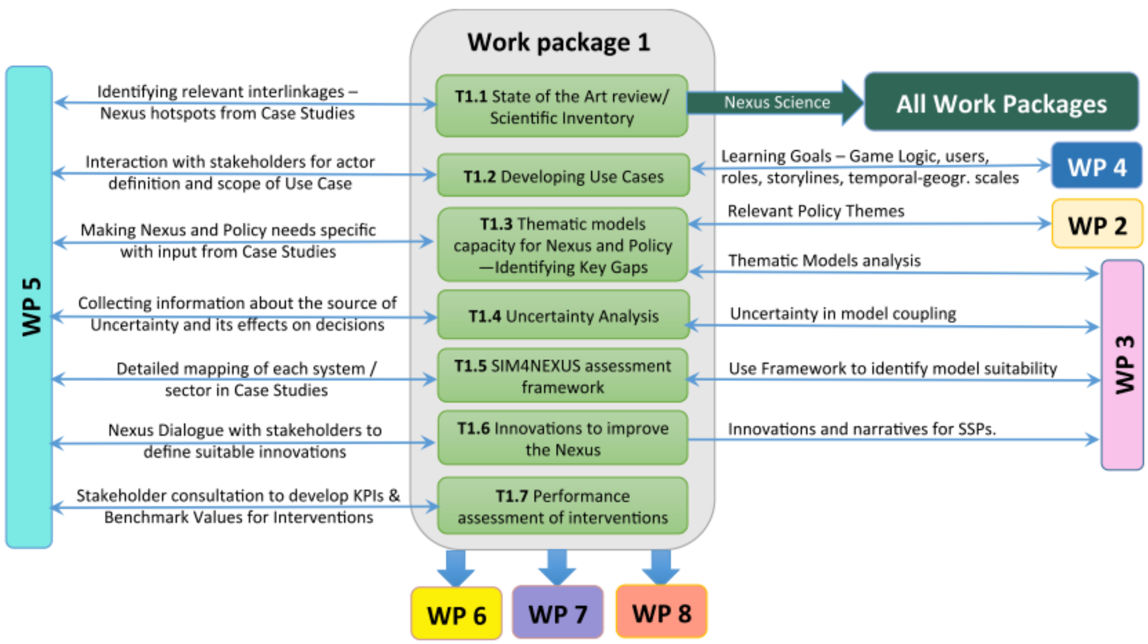

Figure 2. Task by Task diagram of Work Package 1 and interactions with other Work Packages in the project as established in the SIM4NEXUS Grant Agreement.

2.1 Interactions within WP1

Within WP1 tasks, the preparation of the Framework is informed by task 1.1 "scientific Inventory of the Nexus" (months 1 – 9). Identification of interactions between systems is a key step in the development of a nexus analysis. Also inputs from Task 1.3 "Thematic models capacity for Nexus and Policy" (months 1 – 12) are considered in the choice of modelling tools, which is an element of the framework. Task 1.5 is linked to Task 1.6 "Innovations to improve the Nexus in the case studies" as it provides information on the interactions between nexus domains via the intersectoral mapping exercise. The Framework will also identify the space for the definition of benchmark values to characterise the performance of nexus interventions, in result of the data collection methodological step.

2.2 Interactions with WP2

Activities in Task 2.1 “Identification of policy areas” (months 3 – 12) directly link to efforts in WP1 via the identification of relevant Policy Themes, which is done in collaboration with Task 1.3, as represented in Figure 2. An implicit link also exists with Task 2.2 “review of nexus-related policies for each national and regional SIM4NEXUS case study” (months 9 – 26).

2.3 Interactions with WP3

A two-way interaction between WP1 and Task 3.3 “Thematic models implementation to case studies under different scenarios” indicated via the “use of the framework to identify model suitability”, which relates to activities in Task 1.5. This was particularly relevant for D3.1 “Report on “first run” simulation results of the thematic models: Identifying key gaps”, on Month 12. The preparation of this deliverable required the development of models using the different modelling tools in each case study. This meant that the modelling tools had to be chosen at a very early stage in the development of the case studies. In Task 1.5, we derive insights from the selection of tools in the case studies

The implementation of the thematic models for each case study for specific scenarios, as foreseen in item *c* of task 3.3 (month 13 – month 24), is partly related to the choice of tools informed also by Task 1.5, i.e. if these have the capacity to explore scenarios of interest; but primarily from Task 1.3.

2.4 Interactions with WP5

It is with WP5 activities Task 1.5 interacts the most, as WP5 is the work package assisting the case studies in the development of their assessments. Interactions are bi-directional with the framework both supporting and deriving insights from the progress of the work.

3 The SIM4NEXUS assessment framework

3.1 Reviewing the nexus concept

The term “nexus” relates to the approach of assessing interactions between different entities (Liu et al., 2018). In its application to the analysis of resource systems, it gained momentum with the Bonn Nexus conference (Hoff, 2011), although the importance of assessing cross-sectoral challenges was highlighted in the Global risks report 2011 (World Economic Forum, 2011), and the importance of the quantitative investigation of interactions by (Bazilian et al., 2011; IAEA, 2009).

As covered in the introduction, an important output of the SIM4NEXUS project, specifically related to Task 1.5 activities, is the formulation of the nexus concept in line with the project aims. In the proposal stage, the nexus concept is defined as the model-based analysis of the Nexus of water, land use, climate, energy, and food domains to assess the society-wide impacts of resource use and of sectoral policies on the sectors of agriculture, water, biodiversity and ecosystem services. The quantification approach aims at representing the interactions between nexus domains and used to investigate their dynamic response to the influence of drivers e.g. economic growth, demographics, policies, governance, technological and social innovations and social cohesion.

Embedded in the nexus approach in SIM4NEXUS is the investigation of trade-offs from the interactions between nexus systems with the aim of identifying and maximising synergies. The focus is not to so much of optimising resource output, but rather to balance the output of the different resources. Maximising food consumption will likely cause trade-offs with other natural resources (e.g. water). Largely because trade-offs occur with inadequately priced scarce resources (e.g. water). In SIM4NEXUS the motivation is the sustainable and integrated management of natural resources. The latter is not possible with the lack of policy integration and coherence, thus governance is a pivotal component in the nexus approach.

3.2 Main methodological steps of the scientific policy-relevant nexus framework

The current version of the SIM4NEXUS Nexus Framework is based in the activities of the case studies and tasks in the project until October 2018. It is illustrated in Figure 8. Six main steps aggregate activities that are developed to produce outputs that feed subsequent steps.

3.2.1 Step 1 – Development of Nexus knowledge

A key step when performing a nexus assessment is the familiarization of expert teams initiating the analysis with nexus thinking and the science of the nexus. This is critical when starting any nexus assessment to understand the complexity of the analysis as well as to facilitate the clear communication with stakeholders, and at a later stage, when communicating the assessment outcomes to different audiences.

a) **Building the Nexus knowledge**: The analysts build their knowledge on the Nexus concept and identify which are the critical Nexus components for the case study and thoroughly investigate in literature all the generic (not case specific) possible nexus component interlinkages.
b) **Screening of modelling tools and quantification approaches to assess the nexus.** State-of-the-art of tools used in nexus analysis (Chapter 6). Comparison of modelling tools and their capacity of covering the different domains of the nexus.
c) **Preparation of the background knowledge on the nexus**: the inventory of systems interactions. An inventory of all these interlinkages is created, a list of all the possible pathways that a shift in one nexus component can cause a shift in any other. The pathways are initially direct and bidirectional, from component A to B, and from B to A. The elaboration of the inventory of nexus interlinkages advances the knowledge of the nexus systems, and because of this, a bi-directional interaction is considered.

Key Outputs: Inventory of nexus interlinkages, review of modelling tools and integrated assessments.

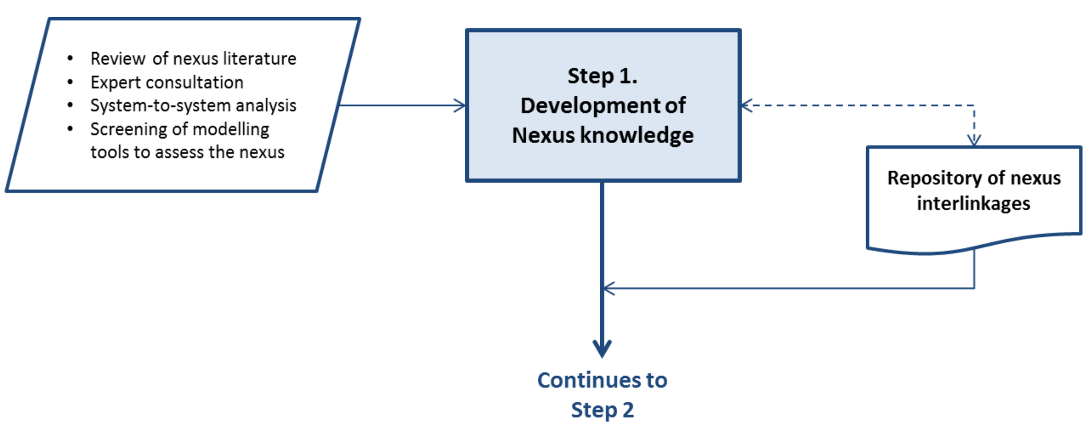

Figure 3. Step 1 in the SIM4NEXUS Nexus Assessment Framework.

3.2.2 Step 2 – Profiling of the nexus domains

The second step corresponds to the assessment of individual domains of the nexus, their trends, status of sectors, and identification of sectoral challenges. This step, which diagram we present in **Error! Reference source not found.**, combines a series of efforts and is majorly performed by the expert teams. Main tasks of Step 2 are described below.

a) **Characterization of the nexus domains**: characterization of the nexus dimensions, their systems and sectors, in the case study using publicly available sources and expert knowledge. Take for example the case of the water domain. This step corresponds to the development of understanding of what characterizes this nexus domain in the context of the case study in terms of natural availability of resources and how these are used. The latter relates to the sectors that directly depend on water as a primary nexus resource essential for the function of the sector. Sectors in the water demand can include water purification and supply systems; another sector could be just the waste water treatment. This step includes drafting the systems' conceptual maps of each nexus domain, which can be used later in the first consultation workshop.
b) **Policy and governance analysis:** Inventory of policies, strategies and plans implemented or to be implemented in the near future per nexus domain at all scale levels (regional, national, continental, global);
c) **Collection of data:** Distinguish qualitative and quantitative. Data collection and sorting. Raw data (original from the source, not stored in a harmonized format yet) and thematic models data (assessment of available modelled data for the case study, from existing scenario runs, identified in the first step) if necessary are collected. The data may refer to resource uses, stresses, availability, spatial and temporal distributions, etc.
d) **Mapping of stakeholders and key actors, and first stakeholders' consultations:** The key players are identified in this step and the stakeholder engagement process initiates. At the same time, some first impression of the stakeholders on what shapes the nexus map regarding resources, sectors and processes hotspots is recorded. The latter is done mostly via unilateral consultations. This step relates to activities in WP5 and Deliverable 5.1 "Common application and evaluation framework for SIM4NEXUS tools defined".
e) **Identification of sectoral challenges:** Inputs from points a) - e) result in the identification of sectoral challenges, which can be operational and/or at institutional level. An attempt of identifying the challenge-implicated interactions in the systems' diagram should be performed. The DPSIR framework can be applied in this step to assist in the structuring and interpretation of the information collected, from a single-system perspective.
f) Assessment of thematic models outputs as data sources (this is done to assess the potential use of data for gap filling).

Key outputs: sectoral assessments and nexus domains diagrams; policy analysis; stakeholder mapping; identification of main and/or potential data sources, and identification of the case study profound hotspots regarding processes and resources.

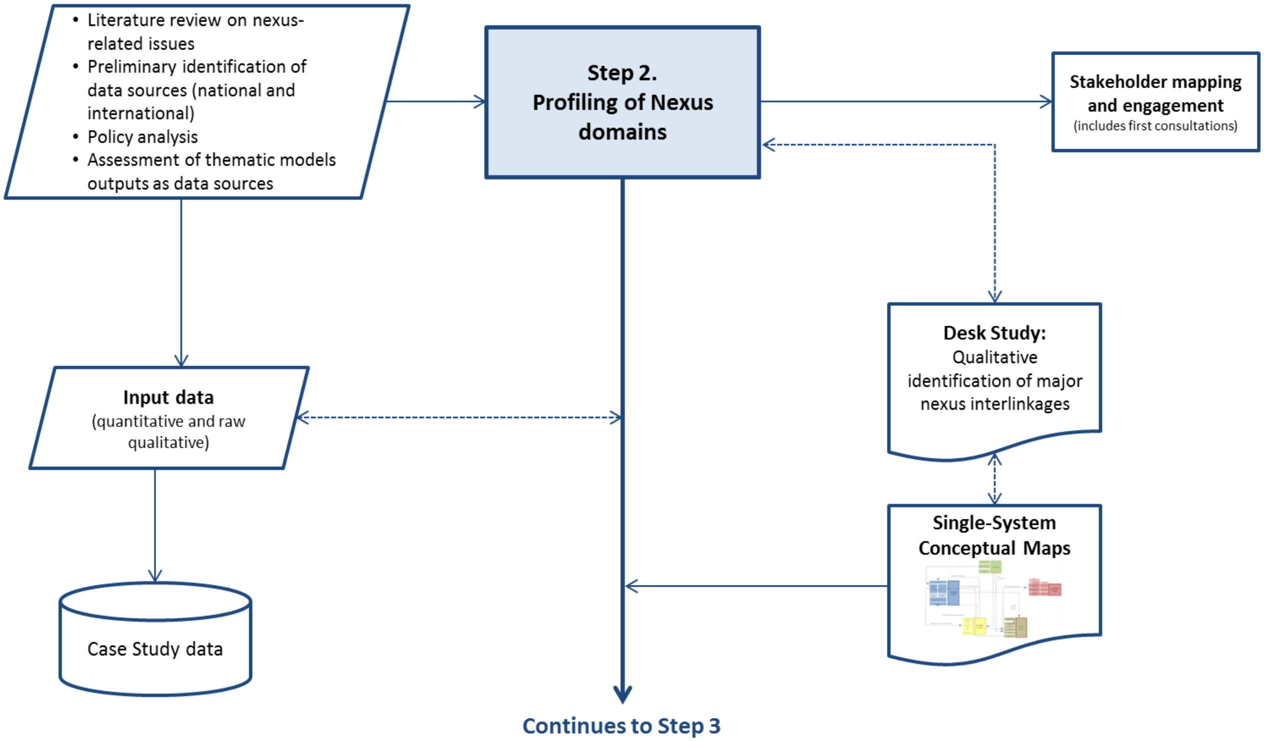

Figure 4. Step 2 of the SIM4NEXUS Nexus assessment framework.

3.2.3 Step 3 – Preliminary nexus assessment

This step develops from the outputs of Step 2, such as the desk—study and the single-system's conceptual maps, which are analysed in an integrated manner following the sub-steps described below. The diagram for this step is shown in **Error! Reference source not found.**.

a) **Comparison of systems for the identification of nexus interlinkages.** The inventory of interlinkages (i.e. SIM4NEXUS Deliverable 1.1) produced in Step 1 will be necessary in this step;
b) **Preliminary estimation of the interlinkages significance.** The data collected are used for a first estimation of the most relevant interlinkages from the perspective of each system, based on the magnitude of their interactions. The share of resources uses and their flow from sector to sector is quantified. This quantification may serves to filter the relevant interlinkages through the rejection of interlinkages noted in the first step but found to result in little impact to the systems' dynamic interaction. On the other hand, this analysis may reveal some important hidden interlinkages that were not perceived as critical, if numbers had not been compared. This preliminary nexus quantification will also reveal the comparative spatial and temporal distributions of uses, processes and availability of resources and will help define the proper time step and granularity of the following modelling exercise according to the uniformity of the distributions.
c) **Development of the first version of the nexus conceptual model** – representing in a single diagram how the different systems depend on each other. This is complemented by nexus systems-specific

diagrams that indicate in more detail how a main system interacts with the other domains of the nexus;

d) **Consolidated identification of critical interlinkages**. Comparison of (outputs from Step 1, such as sectoral challenges, preliminary interlinkages, policy analysis) and sub-steps a) – c) (assessment of the significance of interlinkages, and conceptual maps) for a consolidated identification of critical interactions, and by doing so, of nexus-induced challenges;

e) **First consultation workshop** for stakeholder input and opinion on the status of the systems, sectors and challenges. Validation and/or identification of critical interactions (consolidated in d)) making use of the previous resources developed (conceptual maps, sectoral briefs, policy analysis summary, etc). Implementation of the Drivers – Pressures – Status – Impacts Response (DPSIR) framework for a more structured collection of inputs;

f) **Formulation of the baseline narrative (or storyline) and identification of pathways that could be of interest to analyze**. Formulation of "raw" narrative that characterizes the baseline case (or business-as-usual) related to how stakeholders perceive the development of the different sectors following current or expected trends. This is an important step to be used as a benchmark for pathways or scenarios of interest.

g) **Definition of the modelling approach strategy (e.g. selection of thematic models)**. This step builds on the previous steps and the consequent refinement of nexus challenges and critical interactions. Thematic models, and other quantification methods are identified based on their ability to cover the nexus systems and, most importantly, to capture the cross-system dynamics related to the critical challenges identified in each case study. It will be important to assess data availability and access at this stage.

Key outputs: Identification of nexus interactions and challenges; definition of pathways; first modelling requirements (what systems should be covered and with what level of detail); preliminary identification/selection of modelling tools, first version of the narrative (storyline) for the baseline case of the case study.

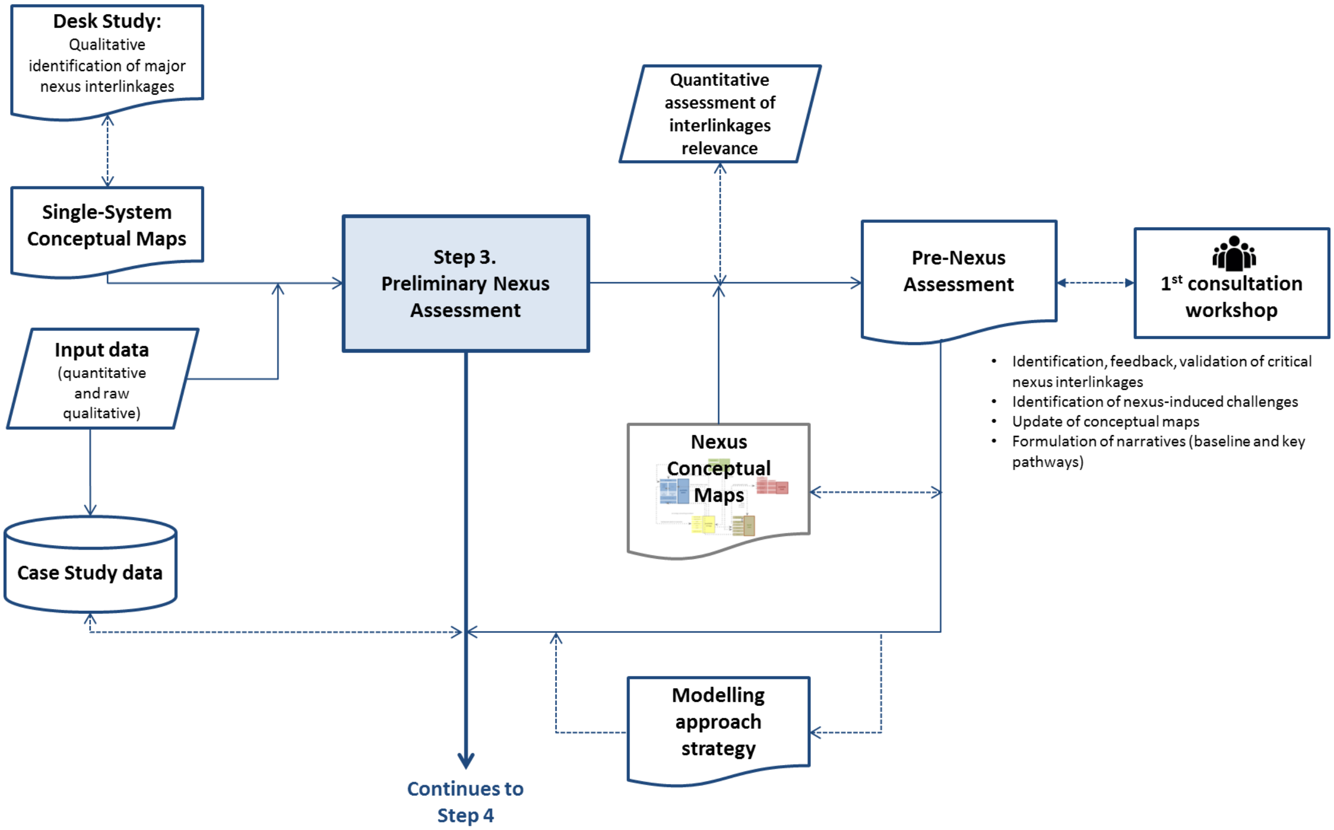

Figure 5. Step 3 of the SIM4NEXUS Nexus assessment framework.

3.2.4 Step 4 – Model development

The fourth step in the framework is related to the quantification analysis and the definition of how the qualitative information and elements gathered in the previous steps will be translated into numbers. An illustration of this step is shown in Figure 6. Main sub-steps include:

a) **Analysis of the information available for quantification**: In this step, analysts compare inputs from the previous tasks, in particular related to the nexus interactions, pathways and conceptual maps.
b) **Implementation and development of the modelling approach strategy.** The selection of modelling tools, suggested in Step 2, is evaluated and (re)defined (decided). The choice of thematic models is also based on data availability and formulation gaps within the SDM. Inputs and outputs of models are compared; and harmonization of input data is performed to the extent possible.
c) **Literature review regarding the overall and in-parts model structure.** The whole modeling approach integrates thematic models were needed and links them with all relevant variables through commonly accepted formulations. The equations used must not be complex so that the final outcome is kept as simple as possible, taken that the final target model already involves parameters from many different processes.
d) **Characterisation of the baseline in quantitative terms:** Drivers and narrative elements are analyzed for their representation in the models, and to guide the definition of assumptions coherent with the baseline and across modeling tools. Since the thematic models will unlikely cover all nexus

systems with equivalent level of detail, it will be important that the detailed narrative that is produced as a starting point, covers plausibly the evolution of the nexus systems so that "baseline" dynamics across systems are well understood (step 3.f). This is an important step prior to the definition of scenarios.

e) **Data requirements are assessed and data availability evaluated**, in order to prepare baseline models for the case study. Modelling teams clarify the type of interactions and components of the narrative they could inform about.
f) **Data preparation and model development.** Data is collected and prepared to be used in the thematic models. Baseline of the models is prepared. Models are run and results analyzed. Depending on results, models may require to be improved to ensure the adequate representation of the functioning of the dynamics they represent. An important step in the modelling work is the analysis of the baseline results, represented separately in the diagram. Nexus trade-offs are identified as well as potential synergies across sectors and systems. Once the baseline is prepared, scenario development and implementation can follow.
g) **Building the policy scenarios**. Policy scenarios are built according to the policy papers review and stakeholder participation.
h) **Preparation of the SDM structure (complexity science tools).** Once the conceptual maps are revised, based on activities in 3. a – f, the structure of the SDM is prepared. Data requirements of the SDM are mapped against models inputs and outputs, and other relevant data available. The policy scenarios and the narratives shape up the SDM structure and flows from inputs to outputs.
i) **Iterative model calibration and validation.** The SDM runs indicate the major model bugs. The runs will be used for calibration and validation. An iterative process between the SDM building (including thematic models) and the SDM runs lead to its structural improvement. Sensitivity analysis of the SDM completes the SDM building.
j) **The 2nd stakeholder workshop** takes place for stakeholders to be informed on the outputs of the modelling exercise and discussion of first results. This may require updates or other iteration of the models. The workshop is also used to further discuss pathways and scenarios. The latter is done based on the selection of policies to be studied in combination with stakeholder input and feedback. Application of the DPSIR to test how the systems' dynamics would be affected in different pathways and / or from the implementation of selected policies measures and/or instruments.

Key outputs: Sectoral and/or multi-systems models; repository of input and output data (referred to in Step 4 diagram as "case study data"); documentation of modelling assumptions in relation to the characterization of the baseline, SDM.

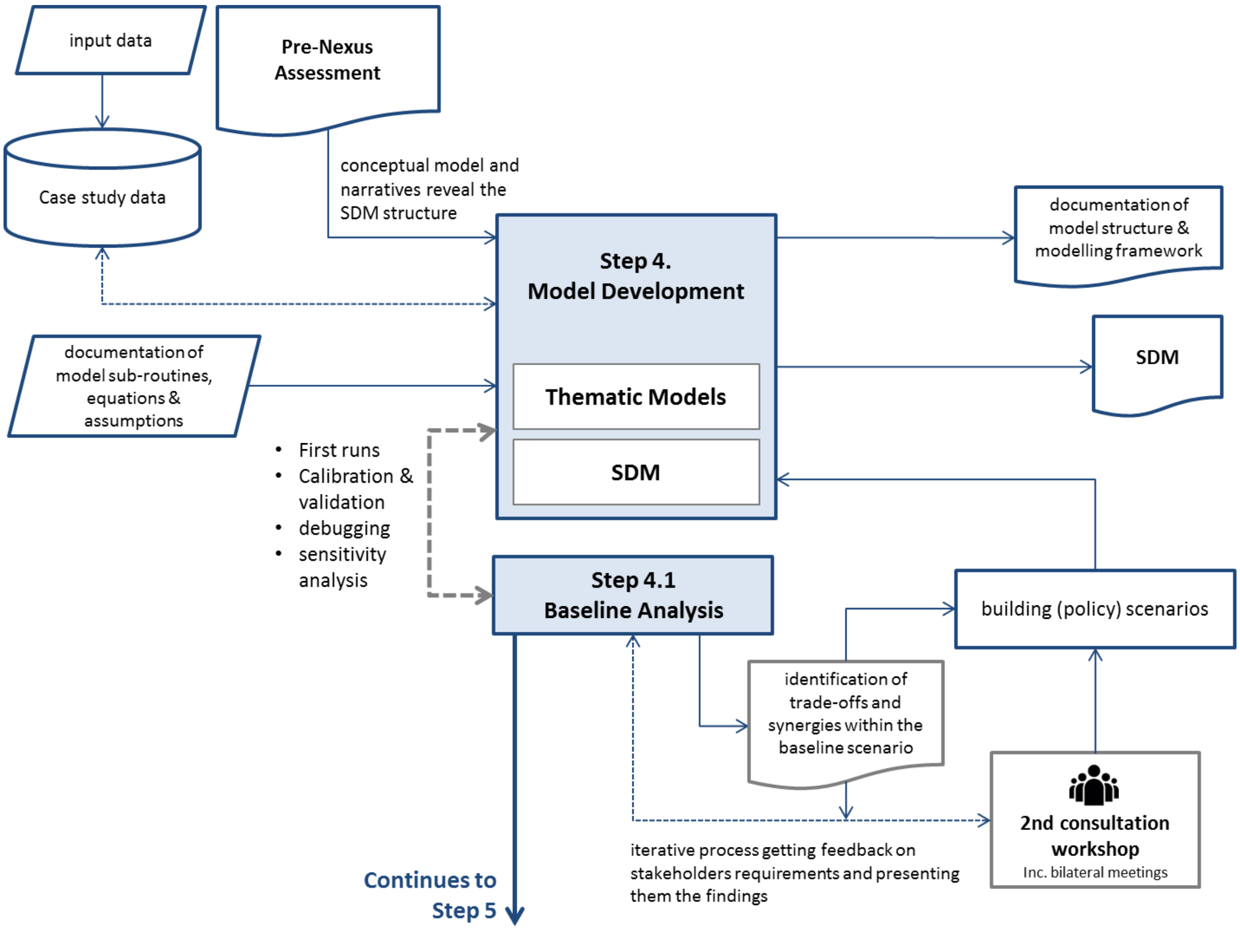

Figure 6. Step 4 of the SIM4NEXUS Nexus assessment framework.

3.2.5 Step 5 – Science-Policy interface

For results to be within reach of a variety of audiences (policy makers and other actors of decision, in public and private institutions, academia, civil society, NGOs, etc), they need to be packaged in a way which is simple and intuitive to interpret. In SIM4NEXUS this is achieved with the Knowledge Elicitation Engine in the format of a Serious Game, which combines all efforts from the previous steps condensing them in an interface in the format of a game. The Serious Game bridges the domains of science and policy, making the analysis accessible to a wider audience. In this way, users of the game do not require to have particular expertise or knowledge in any of the main components of the studies, but will acquire knowledge on the nexus by playing the Serious Game. Tasks related to the development of the game, illustrated in Figure 7, include:

a) Development of the Knowledge Elicitation Engine (KEE) is the inference engine of an expert system (the Serious Game in SIM4NEXUS);
b) The development of Use Cases for the game and creation of the Semantic repository;
c) Definition of indicators to illustrate the performance of the nexus systems to be displayed in the game. These are designed to facilitate the understanding of the nexus systems responses and the evaluation of the policies in respect to the SDGs and to the Nexus coherency.

d) Development of the visualization interface;
e) Instructions of how to play the game.
f) A 3rd consultation workshop to present the game in the stakeholder group for feedback.

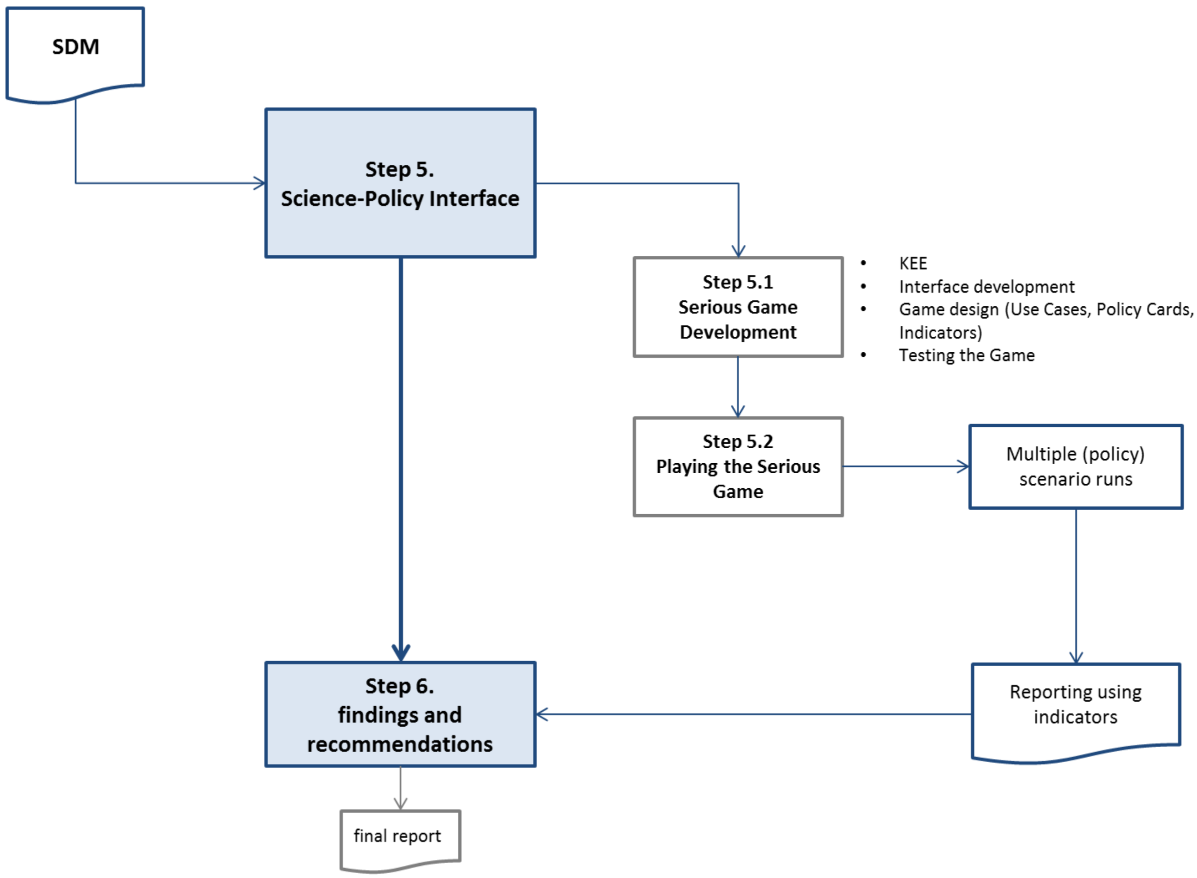

Figure 7. Steps 5 and 6 of the SIM4NEXUS Nexus assessment framework.

3.2.6 Step 6 – Conclusions, findings and recommendations

Interpretation of results and identification of key messages based on the objectives of the pathways and scenarios in each case study. This step puts in practical terms all the analysis conducted in the development of the case studies and of the project. Once the players play the game, they can manipulate the systems to explore different futures and collect messages that are specific to their choices. They will be able to infer on the coherency of policies based on the quantification analysis; the role of innovations; identification of trade-offs and synergies in the different scenarios; assess potential solutions at sectoral and cross-sectoral level. This step can include the presentation of the Serious Game in a 3rd / 4th stakeholder consultation Serious Game, for the final version of the game. Other game dissemination activities include its application at universities and schools.

Key outputs: Dissemination reports, Serious Games for the case studies (game interface, manuals, tutorials, factsheets).

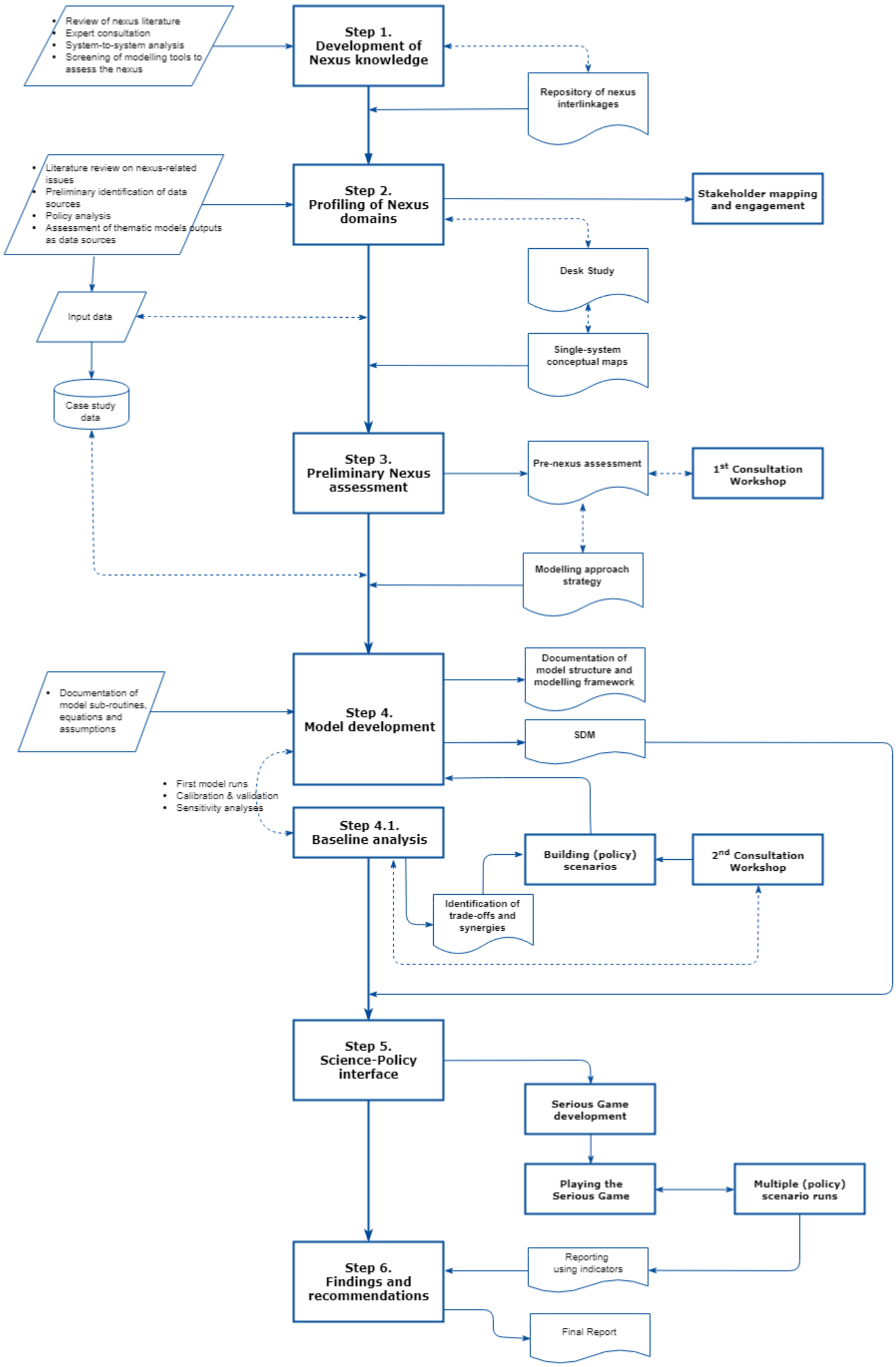

Figure 8. Diagram of the SIM4NEXUS Nexus assessment framework.

3.3 SIM4NEXUS framework from the perspective of decision-making

An important, and necessary, contribution to the science of the Nexus from SIM4NEXUS is the focus given to making the findings from a nexus assessment reachable by different audiences. This value is added with the SDM and the development of case-specific Serious Game for each case study. The Serious Game establishes the bridge between the scientific analysis and the variety of audiences, as it was explored in the previous sub-section, in Step 5. In a simplified manner, the outcome of each assessment will be seen in the format of an interface that enables the players to explore the nexus in each case study, and learn from their experience using the game. A framework based on the perspective of the player (e.g. decision-maker) would follow the next key-steps:

1. Problem definition
2. Problem analysis
3. Game development
4. Playing the game
5. Conclusions

In such case, the framework can be understood as a procedure to provide support and/or tools to improve decision-making by finding compromises for water-energy-land-food-climate nexus relevant problems. This concept will be further explored in the coming months of the project.

4 Systems' mapping

4.1 Introduction

This chapter aims to guide the reader through the theory and ideas behind mapping the system of each of the nexus domains that are considered in the SIM4NEXUS Nexus assessment frameworks: Water, Land, Energy, Food and Climate. The insights gained from this chapter can feed into the work of conceptualising ones system's interactions. Specifically, it is important, and valuable, for the SIM4NEXUS's 12 case studies and their Conceptual mapping as part of the Conceptual Complexity Science, feeding the development of the System Dynamics Model (SDM) (WP3). From the systems mapping presented in this chapter, each case study can gain knowledge on how the systems are build, and ideas on possible interactions. Within the overall Nexus Framework developed for the SIM4NEXUS project, this chapter feeds well into the Step 3 "Preliminary nexus assessment", aiming to first understand the systems and then possible interactions.

Beginning with the definition of system mapping, system is defined as a set of things that works together as parts of a mechanism or an interconnecting network (Oxford dictionaries, 2018b); mapping is the operation that associates each element of a given set (the domain) with one or more elements of a second set "the range" (Oxford dictionaries, 2018a). Different disciplines use system mapping in different way, but all usually share the common way of linking elements to each other. For instance, one can outline, or map, the electrical grid in order to find nodes or intersections; or one may map the occurrence of certain species at one location to link their breeding pattern to the months. In sense of the nexus framework developed under this scope, we regard system mapping as the association of different elements in terms of their resources[1] for each nexus domain in relation to either other nexus domains. It is important to distinguish between domain, system and sector when discussing about nexus. One can define it as each nexus domain contains, or holds, a system, which in its turn contains a sector. The important difference is that the domain is simply the residency for the system, and it is between a system and/or its sector that interactions occur. Therefore, for each SIM4NEXUS domain, there will be a system which can interact with other systems of other domains. Additionally, a system does not have to be limited to one sector or resource, and this is where one can expect to find interactions between systems. For instance, the water domain may regard the treatment of wastewater within the water system; however, this system also requires energy for treatment plants which comes from the energy sector. Thus, the discussion may become complex and confusing; nonetheless, Figure 9 shows a simple representation of the hierarchy of the three categories commonly defined in this document.

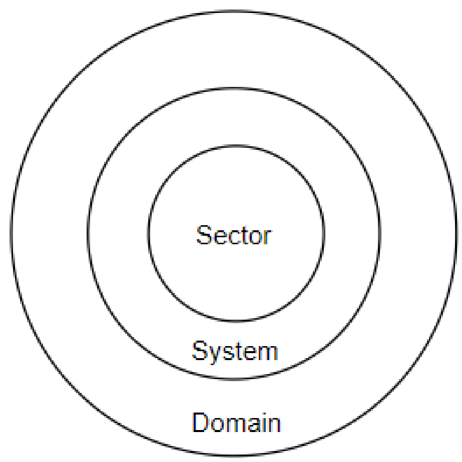

Figure 9. The nexus boundaries' hierarchy.

Table 1 provides the definitions and boundaries of the domains in SIM4NEXUS framework which are applied to the development of the system's mapping in this chapter. These are important in order to understand the system boundaries of the systems that each domain holds. Note the difference between Land Use and Food when regarding agriculture; the former is defined as the land use that agriculture consist of, whereas the latter is the activities and outputs of the agricultural practise that ends up into food waste. Thus, Land Use is the spatial entity whereas Food is the supply chain of the resources. Further detail about the domains are found in Laspidou et al (2017) as well as Munaretto and Witmer (2017).

[1] Resource refers to a physical object such as forest, water, crops or oil and as a physical object it can be moved in-between systems

Table 1. The five nexus domains in SIM4NEXUS with their definition and boundaries.

Domain	Definition
Water	Hydrological cycle and water demand (human, animals, nature) in terms of quantity & quality; thus, a resources unit
Land	Spatial entity consisting of different land cover and land-uses; thus, a resources unit Agriculture is considered to be part of land in terms of its land occupation; activities are, on the other hand, related to the Food domain In this chapter, ecosystem is also presented under land though it is highly coupled to the Water domain as well
Energy	Supply chain of energy (resources-conversion-demand)
Food	Supply chain of food (resources-processing-packaging-transport-demand-waste) Food is considered the activities and output of agricultural practise; and the food demand that drives the agricultural production
Climate	Long-term pattern of the weather

What all the five nexus systems have in common is that they contain a set of resources that are either constrained or affected by activities related to a sector, which activities may span two or more systems. However, there are dimensions in a nexus framework which are regarded in the nexus framework development which are non-resources orientated. These can be directed to the socio-economic perspective and regards health, economy, well-being and others of the society.

Figure 10 presents a general mapping of the interactions between all five nexus systems included in SIM4NEXUS domains. This is to display the 1st degree interactions and can be connected to Step 2 in Figure 8 that can lie the foundation of the interactions they ought to focus on more. A system-by-system analysis can be seen as a means of supporting both finding the initial interactions (Figure 10 below) and then further investigate each system (see the following sections) for one's specific case study and support additional in-depth analysis. Socio-economic factors are regarded as drivers of change, thus there are no interactions with them indicated; but a driver could be increasing food demand, which would alter and intensify the interactions between the SIM4NEXUS domains and systems, e.g. land requirements for agricultural practises. Lastly, the interaction here are not limited to these, rather endless ones can appear, but as mentioned earlier this figure is meant to display how a nexus mapping case look like.

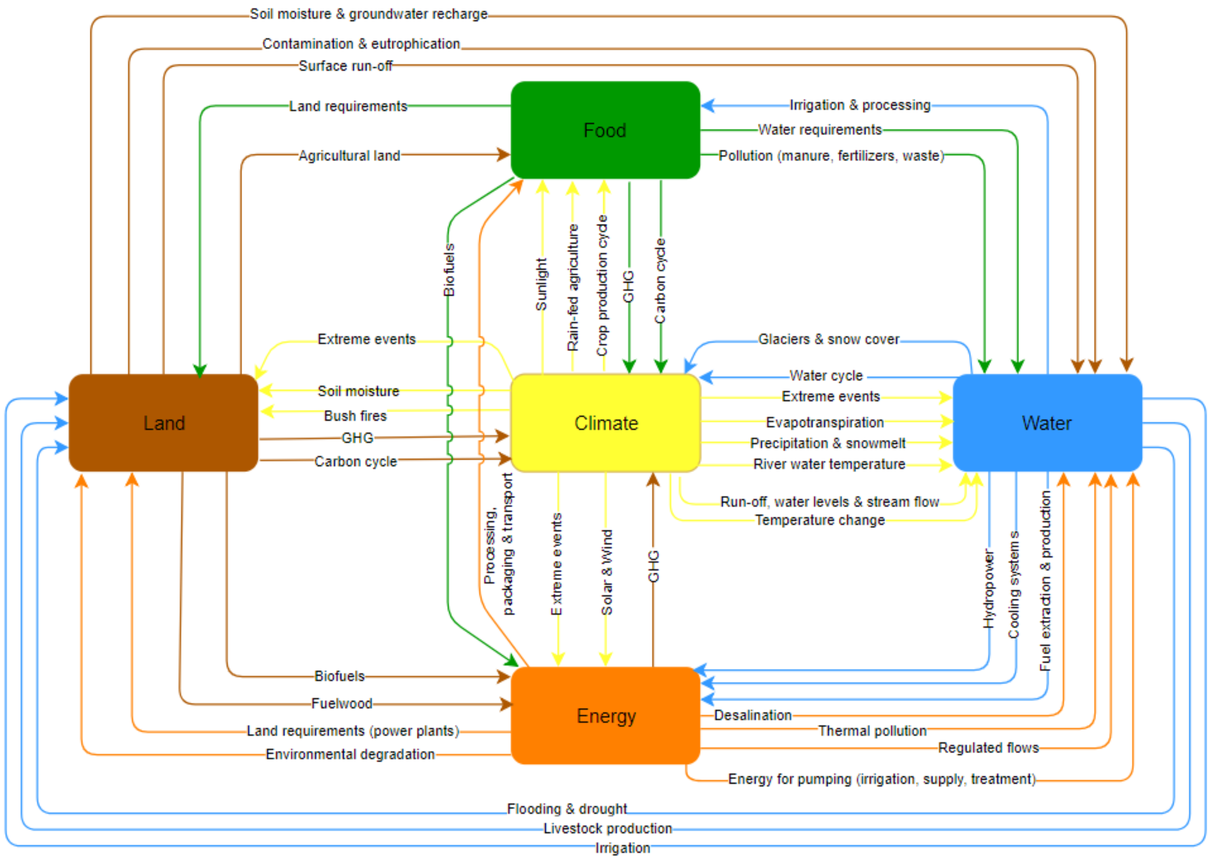

Figure 10. Overall water, land, energy, food and climate nexus Diagram representing the five nexus systems considered in SIM4NEXUS.

There is also a need to understand why one aspires to map the nexus system. In terms of the systems chosen for this project, one could argue that the mapping is done in order to identify hot spots, or pressure points, where one would expect to find clashing interest or trade-offs. For instance, an increase in temperature (climate) may increase the evaporation from water bodies and affect the hydrological cycle (water). However, these overlapping or crossing are not limited to negative effects; instead, one could also experience synergies, where another example could be the practise of livestock (food) that provide open landscape (land). Furthermore, mapping does not imply that there has to be one direct link; rather one could potentially see a domino effect in which one effect in one system will affect a third part indirectly or as a by-effect. For instance, as the example above, an increase in temperature (climate) may increase evaporation from water bodies (water) and hence affect irrigation potential in agricultural practices (food). These interlinkages are in Laspidou et al (2017) referred to as different degree of interlinkages and are discussed later in this chapter. A further important definition is that the relationship between the nexus systems are bilateral, meaning that an interaction between A -> B is different from an interaction between B -> A. In this sense, one could have a positive effect in one direction, but an adverse effect if one moves in the other direction.

The remaining of this chapter will introduce each of the SIM4NEXUS domains and their systems in section 4.2. Further, Section 4.3 discusses the non-resource system of socio-economy and its part as a driver of change within the other systems. In section 4.4, the interactions between the systems are discussed in terms of its complexity and levels of degree. Lastly, section 4.5 discusses factors that shall be regarding when mappings one's system(s) such as scale of study and access to data.

4.2 Mapping of nexus domains and their systems

This section presents the systems mapping of each nexus domain separately; however, the interlinkages between different systems in different domains are presented too but with the focal point of the current system. Climate differs from the other domains as it is overarching for all domains and its systems, and does not in the same sense include sectors. Therefore, the Climate domain is mainly focusing on its system and its interlinkage with the others; whereas for water, food, land and energy, their sectors are also presented in more detail.

The reader shall note the complexity of mapping systems, for instance in terms of potential overlap but also setting the boundaries; the definition and boundaries for the mapping done here are in accordance to Table 1. The systems presented here aim to give an overview of selected activities within it that can be used to understand interactions between the systems. The resources mapped out are also not limited to the ones here, but attempting to cover them all would require a substantial work; and yet that would most likely not be enough. Therefore, the systems and their resources, activities and interactions presented below are an indicative representation working to inform the reader on a basic set of tools that can be adapted to one's own case study.

4.2.1 Climate system mapping

Before going in to details, one can start with differentiating between climate and weather: the latter typically refers to short-term changes we see in temperatures, precipitation, wind etc., whereas the first is the weather over many years in averaged terms, frequently in periods of 30 years. The weather can change over the day whereas the climate changes slowly, often in the scale of tens, hundreds or even thousands of years (MSFC, 2015).

The atmosphere is divided up into five different layers; each layer containing different characteristics in terms of density, chemical composition, movement and thermal characteristics. These are exosphere, thermosphere, mesosphere, stratosphere and troposphere; where the latter one is known as the one in which all weather occurs and is 2-20 km high. The atmosphere is composed of different particles and gases, the most abundant ones are nitrogen, oxygen, argon and carbon dioxide; together making up more than 99% of all the gases. Other gases of importance to chemical processes in the atmosphere, especially in the troposphere, are known as trace gases as they exists in much smaller amount. These correspond to, among others, water vapour (in gas state), carbon dioxide, methane and nitrous oxide and are also identified as the major greenhouse gases (GHG) (NOAA, 2017a.). In addition the aforementioned GHG, fluorinated gases are also of important since they do not have any natural sources but are related to human activities and have high energy absorption (US EPA, 2015a). Ozone and halogens are also important, in particular for processes in the stratosphere. The amount of all these gases and their abundance in different layers of the atmosphere is linked to different phenomena and effects climatic processes in different ways, as a result of the interaction with solar radiation. Gases with global warming effect have a role in regulating the temperature in the troposphere and in the earth's surface, by absorbing long infrared radiation reflected by the Earth's surface, and by emitting infrared radiation in all directions radiation – that as a thermal effect. A higher concentration of these gases and particles, such as aerosols, could lead to more thermal radiation being reflected in the troposphere, giving rise to higher temperature which directly or indirectly affects other variables in the climate (SMHI, 2016). Global warming potential is a way of measuring and comparing the different impacts different gases has on global warming; the larger value the more a gas will absorb energy of incoming radiation and warm the earth. Table 2 shows different gases along with their global warming potential (GWP) and main origins from the fifth IPCC assessment report (Myhre et al., 2013) with complementing information of origins from EPA (US EPA, 2015a). Note, the values of the GWP does not account for any climate-carbon feedback; values including these would be higher. The subscript 20 and 100 refers to the time horizon in years. Further, CO_2 is not written here as it has by definition a GWP of 1 since it is being used as the reference gas when calculating the index (Myhre et al., 2013).

Table 2. Major gases in the atmosphere with the warming potential and main origins (Myhre et al., 2013; US EPA, 2015a).

Gas	Chemical Formula	Lifetime (years)	GWP_{20}	GWP_{100}	Origin
Methane	CH_4	12.4	84	28	Waste, landfills, agriculture
Nitrous oxide	N_2O	121	264	265	Agriculture, industry, biomass burning
PFC-14 (Perfluorinated compounds)	CF_4	50,000	4,880	6,630	By-products from industrial processes, e.g. aluminium production and semiconductors
CFC-11 (Chlorofluorocarbons)	CCl3F	45	6,900	4,660	Refrigerators (the precursor of PFC's)
HFC-134a (Hydrofluorocarbons)	CH_2FCF_3	13.4	3,710	1,300	Refrigerators, aerosols propellants and fire retardants

Climate changes naturally, among others due to the change in position of the Earth in the orbit around the Sun, and due to its tilt, which in turns affects how the surface of the Earth is illuminated. Because climate has a natural variability and is unpredictable in its nature, one often speaks about its variability in terms of probability or frequency changes. However, recent year's particular increase in global averaged temperature has led to the discussion on anthropogenic effects on the climate (IPCC, 2014). Many studies tend to put the responsibility on the emission of greenhouse gas from anthropogenic activities (GHG), more specifically as a result of burning fossil fuels for heat and energy and raising livestock (US EPA, 2017b).

Effects of the altering climate changes has been increasing occurrence of extreme events, such as flooding and droughts. Nonetheless, earlier, the confidence and also uncertainty varies over regions and times, mainly due to that extreme evets have been rare and thus there is limited data and measurement techniques (e.g. for flooding). Despite this, there exists agreements that there is a large likelihood that events of heavy precipitation in certain regions have increased, confidence that droughts in certain regions have been intensified and prolonged, and smaller evidence that of climate-driven changes in magnitude and frequency of flooding in certain regions have altered. On a global scale though, these patterns have been more difficult to state as confident or evident, as they are region-based and variability exists. Even so, climate change occurs both due to natural changes, which is dominating, but more evidence of anthropogenic activities also playing a cause, is appearing (IPCC, 2012).

In this section, the nexus domain of “Climate” will be mapped out, summarizing the main elements in the climate systems and how these interact with other nexus domains, such as energy, water, food, and land; and sectors of the economy. The map will first be presented and then discussed during which each of the sectors are broken down for more detailed explanation.

4.2.1.1 The Climate mapping

Figure 11 presents the Climate mapping as a nexus domain, which has developed adopting the insights from IPCC (IPCC, 2014), EPA (US EPA, 2017a; US EPA, 2015a; US EPA, 2015b), EIA (EIA, 2011) and Nieder and Benbi (Nieder and Benbi, 2008). It includes selected examples of interactions between the different components and highlights pressure points, i.e. what factors may effect one system on the other. As one can see, temperature has more interlinkages than the other variables here; that does not mean it has a larger effect than others do but it was merely the idea to point out that this one may have a more noteworthy effect on all sectors at a first glance. In addition, the climate variables presented in Figure 11 are not limited to these; instead, there are several more and are allocated among the atmosphere, ocean and land (NOAA, 2017c). However, the variables presented here presented here are ones considered under the scope of this nexus mapping.

Food refers to agricultural practices and land includes ecosystem services in general. Furthermore, a socioeconomic perspective is not included here as it is a non-resource sector and not a part of the nexus domains of SIM4NEXUS, the same applies for industry, but they are both discussed further down in the section. The greenhouse gases are in the diagram only considering CO_2, CH_4 and NO_x, and an additional arrow for the water vapour, but there are more gases that in reality are present and should be considered. However, for reasons of complexity, it is chosen to only consider the three aforementioned. The components and the flow of the diagram are explained in detail in the coming subsections.

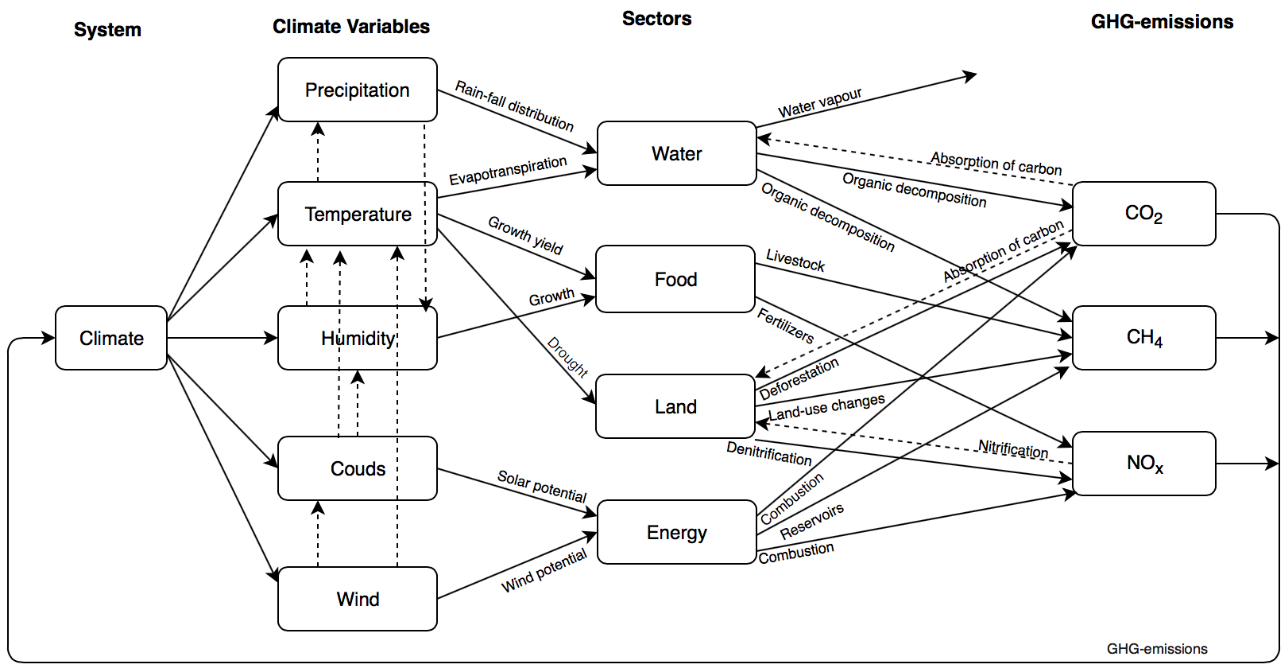

Figure 11. Mapping of the climate system.

Climate is here assumed to be represented by five major variables: precipitation, temperature, solar radiation, wind near the surface of the Earth, humidity and clouds (types and amount) (IPCC, 2001) These all have an impact or effect on the sectors described below, but they also have interlinkages between each other. Climate is a term which system covers all the five variables together, and it is important to understand that they are interacting either directly or indirectly at all times. Figure 11 indicates a few; for instance, the wind will affect the temperature and changes in precipitation may change the humidity of the air (NOAA, 2017a).

4.2.1.2 Interactions with the "Water" system

The hydrological cycle is highly dependent on the occurring climate in its region and global warming will generally lead to an acceleration in this cycle. The response to this acceleration would be that seasonal patterns change, both in terms of precipitation and temperature, resulting in changes in evaporation, as well as the intensity of these. The rainfall distribution (either more or less intensified) may affect stream flows as well as lake levels, either by flooding them or by as a result of drought events. It is expected that one will experience increase in rainfall in the tropics and higher altitude, but a decrease in the already semi-arid to arid mid-latitude; in that sense water-scarce areas are prone to become drier, and hotter with no water to cool the air (FAO, 2011).

It can be difficult to state specific activities of the water systems themselves that have a negative effect on the climate. However, as stated in the introduction, one of the major constituents of the atmosphere is water vapour. When temperature of the atmosphere rise, water from the earth's ground storages (rivers, soils etc.) will have an increased evaporation; hence, leading to a large amount of vapour in the atmosphere. Considering vapour as a greenhouse gas, an increase of it in the atmosphere will lead to more absorption of infrared energy radiated from Earth; however, as more vapour exists in the atmosphere more will condense to clouds. These two effects, together with poor measurements, have led to the issues of uncertainty of defining its importance and extent of impact (NOAA, 2017b)

Lakes have been identified to play an important role in the uptake of GHG; total carbon uptake has been estimated to be at the same magnitude as that of oceans and forests. In Lakes, particularly, CO_2 and CH_4 are mainly produces at the bottom sediment as a product of the decomposition of organic matter. Geothermal activities may also contribute to the concentration of CO_2 and CH_4. The CH_4 may however be oxidised to CO_2 by methanotrophs in the bottom sediment; the CO_2 will also be processed in the photosynthesis and not necessarily released to the atmosphere (LERNZ, n.d.). In general, if the water at the surface is supersaturated with the two gases, there will be a flux towards the atmosphere and vice versa. In the latter case, where the water would adsorb the gases, it would act as a carbon sink. What is important to understand is that the solubility of the gases depend on the temperature; lower temperature means more solubility. This implies that in warmer regions, or where temperature will increase in the future, GHG emission tends to be higher. The altitude also plays a role here, where lower altitude is said to have lower solubility. Studies shows that CH_4 dominate the emissions through bubbling; if the reservoir or lake is deep however, the bubbles may dissolved before reaching the surface. The flux of emissions from the surface tends to be of CO_2 (Kumar and Sharma, 2012). Eutrophication, as a result of overload of nutrients, is discussed in section of “Land”.

4.2.1.3 Interactions with the “Food” system

Main interaction between Food and Climate considered here is within the agricultural practise. First, activities related to the management, preparation, cultivation, tending and harvesting of the land, are affected by ambient air temperature, humidity and water availability, along with soil characteristics, in order to yield the highest crops at a minimum irrigation need. Decrease in precipitation and increase in temperature will likely have negative effect on the growth yield by causing water stress, resulting less crops to be harvested, or water availability for livestock, thus stressing the food supply chain. However, there are positive effects of an increase in temperature being observed in certain areas; one can notice an extension in growing season and a latitude threshold in the northern parts of the world (FAO, 2011).

Extreme events, change in water availability and other climatic responses, have by, among others, FAO (2016) identified to cause pests and diseases in the agronomic ecosystems, in its turn affecting the cultivation and livestock. Furthermore, in the event of increase or intensification of precipitation causing flooding or droughts, may cause the land useless for cropping or livestock maintenance (FAO, 2017).

According to IPCC (IPCC, 2017), agriculture is said to contribute to 20% of the global anthropogenic greenhouse gas emissions. Of the total CO_2, CH_4 and N_2O emissions, agriculture contributes with up to 25%, 60% and 80% respectively. The CO_2 emission are mainly associated with fossil fuels used on farms but also shift in cultivation patterns and deforestation. The CH_4 emissions can be derived to rice paddies, land use change, biomass burning and animal waste as well as enteric fermentation (digestive process of livestock). Lastly, the N_2O emissions come mainly from nitrogenous fertilizers (often synthetic) on the cultivated soils as well as animal waste. How these three emissions can, on the other hand, be absorbed by nature, is discussed under the section “Land”. In summary, there are large GHG emissions from the agricultural practise in the food supply chain; however, one shall not forget the cycle of the Food supply chain which is not limited to the production and transportation of food, but also the deposition and wastage. Waste disposal is often done through landfill, incineration or other treatments such as fermentation/composting Eurostat, 2015). The former, landfill, has the largest share of associated GHG emissions, with methane being the main gas. The incineration and fermentation/composting processes have larger overall GHG emission, and the incineration process also have the possibility of energy recover, meaning to use the waste as fuel to generate electricity or heat. Fermentation or composting may be used as a pre-step to landfill in order to reduce the methane or nitrous oxides.

Food and agricultural activities also include fisheries, where its population also tends to be sensitive to climatic changes. For instance, changes in temperature, salinity, oxygen content as well as current and hydrological characteristics may cause the shift in abundance and distribution of species or populations. This can include depletion of species or migration from warm water to colder ecosystems. Acidification has also been said to cause depletion of fishes as a result in pH changes (North Sea Foundation, 2011). On the other hand, fisheries and its activities may also cause an impact on the climate through emissions. The main source of impact comes from the fuel consumption and emitted CO_2 gases, but the impact and emission varies between different fishing gears. For instance, the passive gear such as gill-nets are more efficient in their fuel use than active gears such as trawls (Waldo and Paulrud, 2016). In addition to the fuel associated with the fishing industry, one can also associated nitrogen (and phosphorus) waste from aquaculture (fish farming) due to sources of excrement, uneaten food and other organic waste used during feeding (WRI, n.d.).

4.2.1.4 Interactions with the "Land" system

Land refers to all land-use and land-cover, but note that the agricultural activity related to food supply chain is considered under Food. Ecosystem is also presented below despite, as mentioned in the introduction, can also possible to be considered under Water. Land profile differs between regions in accordance to, among others, the climate; deserts occur where temperatures are higher and less frequent precipitation, rainforests are characterised as regions where precipitation are frequent and by the poles or at higher altitudes can find land which tolerates less humidity and lower temperatures.

Effect on land or land-use due to changes in climate can primarily be given by the example of droughts or flooding due to primarily changes in precipitation. In addition, poor water management practices with an over abstraction by upstream users is also an issues. Upstream and downstream users can be either in same nation or different; latter possibly causing transboundary issues to arise. Along with this, sea level rise is likely to cause an effect on coastal areas, among others, in terms of flooding and saltwater intrusion (FAO, 2011). Lastly, landslides are prone to occur under heavy precipitation (Crozier, 2010) and the warmer temperatures, especially in arid areas, may cause bush fires to become more frequent (Dale et al, 2001).

The land-cover itself can play an important role in terms of in interactions with the climate. Industrial, residential and commercial areas can be traced with burning fuels that causes GHG emissions, often associated to the energy sector (EPA, n.d.). Further, deforestation may cause negative effect since it is a carbon sink; hence decreasing the forest land will cause less uptake of atmospheric carbon, as well as providing cooling opportunities (Bonan, 2008). Further, changes in land-patterns, such as urbanization, preparing for agricultural land or other settlement patterns, may lead to changes in the land characteristics. These changes in land-use and land-cover, corresponding to less vegetation and low albedo values, along with increase of pollution and anthropogenic heating, has caused the temperature to rise and imposed so called urban heat islands. Not only does this impose a direct effect of human health in terms of the increasing heat; but additional health effects comes from the fact that temperature rise has also caused ground level ozone to increase which is produced from volatile organic compounds (VOC) in the presence of NOx gases. The latter is called the photochemical, as it uses the sunlight, smog mechanism (Lo and Quattrochi, 2003).

Ecosystems, and their habitats, can differ in how sensitive they are to changes in the climate. Certain ecosystems are more prone to be affected negatively, whereas other ecosystems tend to have larger spans of how much they can tolerate. One possible situation is that changes in the climate and environment may lead to a proliferation of invasive species and a change in biodiversity, threatening the original species living there. For instance, an increase in temperature may lead to the invasion of certain organisms into an ecosystem in which the current species living there are not resistant or tolerant to these new organism and their activity. From a broader ecosystem level, a change in the lower parts of the food chain, for instance the inclusion of new organisms, may disrupt the food chain higher up (US EPA, 2017b). Another threat to flora and fauna, specifically in aquatic ecosystem is the effects from eutrophication. In short, eutrophication refers to the nutrient enrichment of a water body that result in the excessive growth of phytoplankton and macrophytes. The overgrowth of aquatic plants creates a layer on top of the water that decreases the light penetration and reduces the re-oxygenation of the air current in the water. Identified climate changes effects causing the eutrophication; an increase in temperature or physio-chemical alterations may hasten direct effects whereas indirect ones are associated which extreme weather events causing, for instance, excessive nutrient load. The effects of eutrophication may be many, for instance oxygen depletion, reduction in fauna, decreased biodiversity, loss of aquatic species that have high light compensation point and shift in the species composition. In the event of increase of temperature, and thus an increase in evaporation, the latter will, by most probably means, exacerbate the eutrophication. This is due to the fact that when water evaporates, water vapour of molecules enter the atmosphere, and leaves behind salt and other contaminates which may alter the eutrophication process (Ansari et al., 2010).
Human activities on the land can emit different gases, for instance, the use of landfills for waste decomposition and treatment of wastewater will emit CH_4 gas. CH_4 will also be naturally emitted from wetlands through bacteria decomposition of organic matter. Smaller sources can be traced to oceans, sediments, volcanoes, wildfires and termites. In the same manner, the nitrogen cycle will emit nitrous oxides in various forms as a result of bacterial processes (US EPA, 2015a).

On the other hand, natural processes will help in the removal of CO_2, CH_4 and NO_x gases. For instance, deforestation was mentioned earlier to be a threat to the uptake of carbon; in other words, it acts as a carbon sink and is able to absorb the CO_2 released. In terms of CH_4 and NO_x, one can take bacterial processes as examples of uptake. Regarding the CH_4, one finds methanotrophs in the soil and in water, which will use biological decomposition to remove CH_4. The nitrogen has a natural cycle during which it takes on different forms and are absorbed from the atmosphere when it is being decomposed by bacteria (US EPA, 2015a). The nitrogen cycle is often explained by the process of nitrification and denitrification; the latter during which oxides nitrogen is reduced to, after full denitrification process, dinitrogen (Nieder and Benbi, 2008).

4.2.1.5 Interactions with the “Energy” system

Energy here refers to the production of energy in terms of using different sources. The potential of wind and solar energy is dependent on its resources and hence the flux of solar radiation, the changes in temperature and wind speed, in addition to the topographical conditions of the regions. Furthermore, hydropower production is also dependent on the water availability and hence, flooding or drought due to increase or decrease of precipitation, increase and decrease of runoff (depending on water uses and soil characteristics), may also cause problems on hydropower production by changing this availability. The water availability is also crucial for the thermoelectric power plants for cooling as well as cropping for biofuel production. When regarding oil and gas production, these are prone to be affected by extreme weather events through the disruption of production or breakdown of oil platforms (IEA, 2015).

In terms of effects from energy production on climate, the main emission is CO_2 coming from the combustion of fossil-fuels like coal, oil and sub-products, and natural gas. The construction and operation are often rarely ever carbon neutral, no matter if the technology is a renewable source or not. However, the use of fossil-fuel for energy production has a negative effect on the CO_2-emission (US EPA, 2015a); hydropower as a renewable resource may not emit emission from its operation, but storage hydropower have associated methane gas emission from its reservoir (Kumar and Sharma, 2012). In addition, a reservoir which is affected by eutrophication may have problems with the nutrient-rich water acting chemically on the turbines (Ansari et al., 2010).

New technologies using Carbon Capture Storage (CCS) allow for energy generating facilities using fossil-fuels, and hence releasing CO_2, to capture the CO_2 by decarbonisation or separation of flue gases and other gaseous mixtures and transport it through pipelines and store it in geological formations (IEA, 2010). In addition to CO_2, the energy sector is also a source of NO_x emission as a by-product of fuel combustion; both in mobile sources such as transport and stationary sources such as coal power plants (EIA, 2011).

4.2.2 Land system mapping

4.2.2.1 Introduction

Contemporary spatial systems are complex and dynamic systems consisting of several elements that interact with each other, either directly or indirectly. Spatial entities and spatial relations are strongly connected with geographical space as they have a geographical reference. In this analysis, land constitutes a natural resource that supports the production of several products/services (food, energy, etc.) while it is also related to water resources management and human residence. Threats to land may include desertification of forest or agricultural land, drought, erosion caused by intense and heavy rainfall, increase of floods and increase of forest fires.

Figure 12, present the Land Use system mapping with the main and most general land uses and possible interactions with the other nexus components are presented. These interlinkages are bilateral, for instance how land provides grassing opportunities for livestock whereas livestock may also cause desertification of the land.

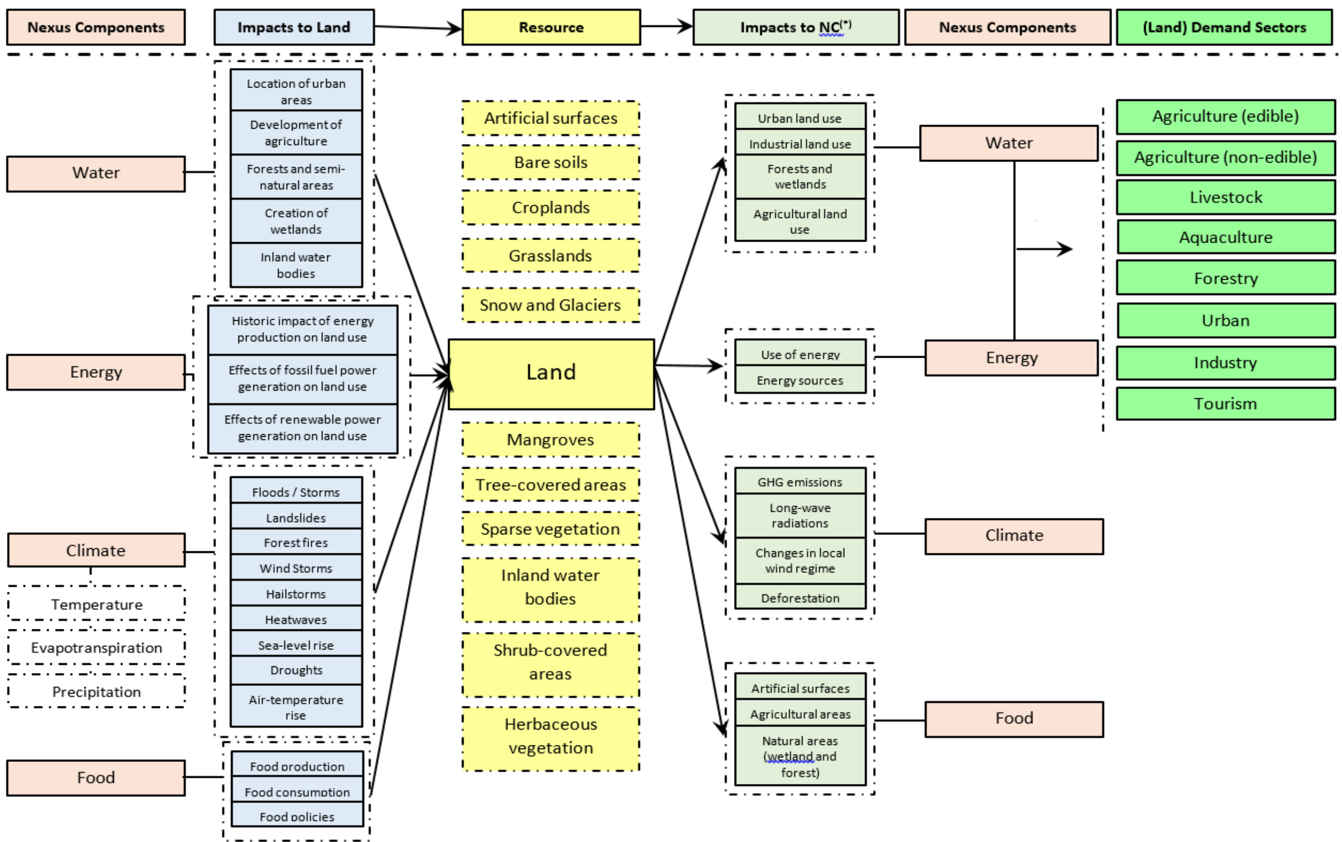

Figure 12. A proposed reference Land Use system mapping (NC refers to Nexus Components).

When discussing land, one must differ between the land-use and the land-cover: the land cover is the physical observed covers, e.g. grassland, whereas land-use is the activities performed on the land, e.g. agriculture. Depending on the depth of the study, the land cover can be represented in more or less details. In Figure 12 above, the land covers is presented under the "Resources" column, whereas land use is presented as the "(Land) Demand sectors".

The land covers seen in Figure 12 are based on the eleven global land covers to classify the land in accordingly by FAO (2014). Figure 13 shows these classification and its spatial distribution over the world.

Land Cover types	Label
Artificial Surfaces	01
Cropland	02
Grassland	03
Tree Covered Areas	04
Shrubs Covered Areas	05
Herbaceous vegetation, aquatic or regularly flooded	06
Mangroves	07
Sparse vegetation	08
Baresoil	09
Snow and glaciers	10
Water bodies	11

Table 1 – GLC-SHARE land cover legend

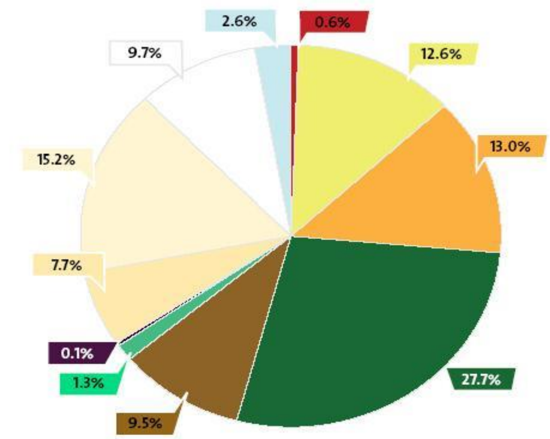

Figure 5 – GLC-SHARE distribution of land cover types

Figure 13. Global Land Cover - SHARE classification (GLC-SHARE) and worldwide distribution of land types. The classification was developed by FAO (2014).

Land use on the other hand refers to the management and practise of land, performed by human activities. For instance, residency, agriculture and forestry are three examples of land use practises induced by the humans and are not part of the cycle of land itself. In similar terms as one say that industry “consumes” energy, activities can also “consume” the land by either using the resources it inhabits or by occupying its property. In the following sub-sections, the land use sectors presented in Figure 13 are presented and discussed in more detail.

4.2.2.2 Agriculture

The agricultural sector represents one of the basic land ‘consumers’. Large areas of the available land are used for the development of several agricultural activities and the production of non-edible and edible agricultural products. Among the non-edible products are those related to energy production (energy crops, collection of agro-waste) and also several specific products such as tobacco and cotton with high added value in economy nationally. The agricultural sector is dominant in the field of food production. Considerable amounts of fruits and vegetables are produced in order to satisfy population’s nutrition needs (food security). Moreover, it has a strong relationship with the secondary sector, especially the food sector related to processing and manufacturing of agricultural products. The agricultural sector is also a highly demanding water-consumer as water resources are exploited for irrigation purposes. Agricultural sector is also directly related to the development and the promotion of agro-tourism and eco-activities taking place in rural regions as new tourist trends. It is clear that agricultural land has the potential to play a multifunctional role through the combination of pure agricultural activities with other activities such as tourism and energy production. From a policy making perspective, a legislative framework regulating land uses is of primary importance in order to protect agricultural land from other competitive uses.

4.2.2.3 Livestock

Livestock is among the basic activities of the primary sector. It plays the role of food supplier; it is interconnected with the food processing sector while it also provides raw materials to clothing and shoe industries. Livestock has also the potential to contribute to energy production through the exploitation of the waste produced by the sector's activities. The development of livestock presupposes the availability of water and food for grazing animals, but in return contribute to emissions such as CH_4.

4.2.2.4 Aquaculture

Aquaculture plays also the role of food supplier and it is an activity 'belonging' to the primary productive sector. The establishment of aquaculture activities demands land and water and as discussed in the Climate section, it puts pressure on the quality of water and air.

4.2.2.5 Forestry

Forestry activities provide raw materials (wood) to the similar industry while forest biomass has the potential to contribute to energy production by Renewable Energy Sources (RES). As a physical property, it inhabits land and acts as a natural carbon sink; however, under un-sustainable, deforestation can cause the sink to reduce and eventually disappear.

4.2.2.6 Urban

Urban land areas constitutes of several sub-areas and land uses in itself and among the main categories of urban land uses are residential use, industry, goods processing, trade, services and entertainment. Also, landfills are located nearby urban areas serving for waste disposal purposes. Due to the high rate of cities' expansion, issues concerning protection of highly productive agricultural and forest land are explored in order to attain balance between urban population's needs and the protection of natural resources.

4.2.2.7 Industry

Industrial activity is usually located at large industrial areas where several types of industrial and manufacturing, processing activities are operating. Land is the 'receptor' of such activities and the legislation of each country defines the framework under which industrial areas are operating. Industrial activities are responsible for soil pollution and other environmental impacts that should be managed.

4.2.2.8 Tourism

Tourist activities take place either in urban, sub-urban and rural environment, in the mainland or the islands, along the shoreline or at mountainous regions. Land is the 'receptor' of such activities which also demand significant amounts of water, energy and food. Each country's legislative framework 'protects' tourist land from other competitive land uses while it also regulates the perspectives and limitations under which the tourist sector will be developed in the future.

4.2.2.9 Interactions with other nexus systems

Following are a selection of interaction between Energy and the other domains/systems, based on Laspidou et al (2017).

Climate

Depending on the land cover, it can act as a carbon sink and is important for the mitigation of climate change. However, activities such as deforestation reduced the carbon uptake and may thus alter climate change. In terms of land-use, the impact on, and from, climate may vary. For instance, agriculture is a large contributor of GHG gases, specifically methane from livestock. Conventional industries may emit large quantities of emissions; similarly is the case for urban areas. Nonetheless, land is an important constituent for the climatic cycle as it is involved in and provides opportunity for, among others, the nutrient and water cycle.

Energy

Biomass found and extracted from land can be used as fuel in energy generation; in many countries, specifically those with low electrification rates, biomass remains the main source of energy. Furthermore, land provides the necessary spatial entity for energy technologies, and renewable resources such as wind and solar are dependent on the land cover.

Water

The land cover and use determines the requirements for water and its role of interplay. For instance, urbanisation causes intensification of water usage, wastewater disposal etc., that can cause troubles on water availability and its quality. Further, the land cover affects the run-off patterns as well as possibilities for groundwater infiltration, and is thus a main factor in the water balance.

Food

Land creates natural conditions for food production in terms of agricultural practises and grazing land for livestock as well as the land requirements of fisheries.

4.2.3 Energy systems mapping

4.2.3.1 Introduction

An energy system (Droste-Franke et al., 2015) is a set of components that interact in various ways with the aim to provide energy services to the end user. By energy services, we typically mean electricity, heating/cooling and transport, while the final users can be classified in the following sectors: household, industrial, commercial and agriculture. Broadly, the processes included in an energy supply chain (that provides the aforementioned services) are fuel extraction, energy conversion, storage, transmission and distribution (Bruckner et al., 2014). Figure 14 presents a general representation of an energy system including resources and extraction to generation technologies and demand sectors. Note the separation of resources between renewable and non-renewable; many times one also considers uranium to belong to a third category of “nuclear”, but here the former two are only considered. Electricity is assumed to be used in all sectors, for instance machineries in the agricultural and forestry sector can be driven by electricity; however, its oil dependency is considered to be directed to the industrial sector. The latter applies for oil in residential as well; oil for heating is as the figures indicates directed to the heat-module in the conversion box. This heating includes both centralised and decentralised, thus, oil products can be turned into heat for residential use. Further, the figure also indicates a selection of interactions with the other SIM4NEXUS domains to show case their interdependency.

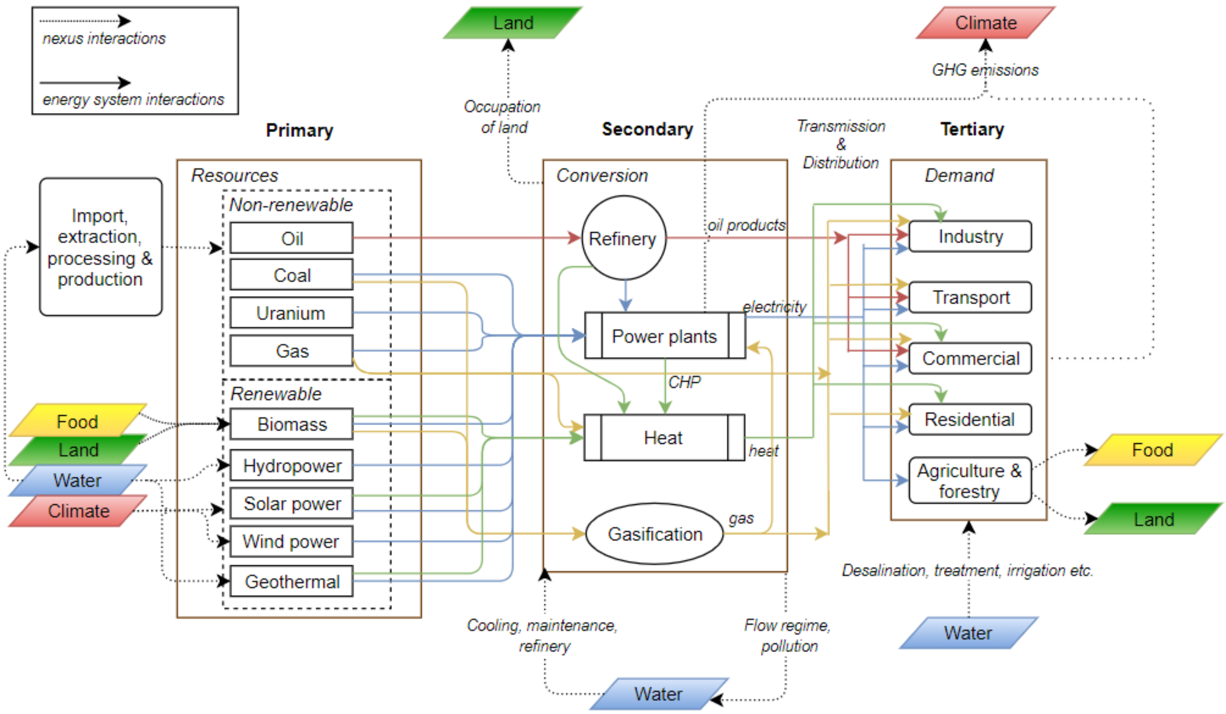

Figure 14. Energy systems mapping (produced by KTH-dESA).

Access to energy services is the cornerstone of most contemporary activities and, consequently, a well-functioning energy system constitutes the spine of economic development. GDP per capita and energy consumption per capita are strictly correlated which is a clear indication that economic growth is tailored to energy infrastructure. From buildings to factories and from hospitals to farms, every contemporary economic activity needs modern energy services. Besides economy, energy access has implications to a number of societal aspects. Educational services can be improved significantly when they are coupled with energy access (i.e. a school without electricity would not meet today's standards). The same applies to health services where energy is a fundamental resource needed for preservation of medicines, to the operation of hospital equipment.

4.2.3.2 Energy Resources

Energy resources can be broadly categorized in fossil fuels and renewables, and one can also consider nuclear as a third category. The share of use of those resources varies significantly both by country or region as well as by energy sector. On a global scale though, fossil fuels are the dominant source of the total primary energy supply (TPES), followed by renewables and lastly nuclear. Figure 15 depicts the share of each energy source in the world's TPES in 2015.

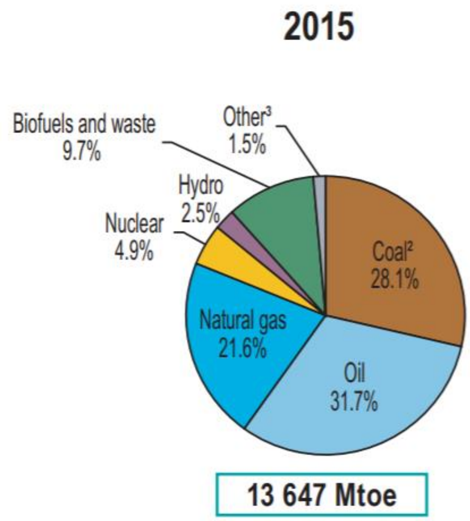

Figure 15. World's Total Primary Energy Supply, in Mtoe, in 2015 (IEA, 2017).

Fossil fuels comprise coal, oil and natural gas which can be all be further categorized into different fuel subtypes. All three types are extracted from reserve fields, transported to process facilities (e.g. oil refinery) and then redirected to the relevant spot depending on the service in need. For electricity generation, fossil fuels are used in combustion plants while for transportation and heating they are used directly by the final consumer (with the exception of district heating, to be explained below). In general, fossil fuels are relatively low-cost (compared to other resources) and the technologies that use them are well established. Nevertheless, there are a few associated disadvantages:

- They are depletable.
- They are subject to price fluctuations and if imported, have implications on energy security.
- The use of fossil fuels leads to greenhouse gas (GHG) and other pollutant emissions which lead to climate change and public health concerns respectively.
- Water may be required for cooling the power plants. This exerts stresses on the water system.

Renewable energy sources consist of solar, wind, hydro, ocean, geothermal and biomass (conditionally renewable, only when it does not lead to deforestation). All renewables can be used for electricity generation while geothermal, solar and biomass can be also used for heating. Renewable energy generation is not associated with pollutant or GHG emissions which renders it more environmentally friendly than fossil fuels and since renewable energy sources are domestic, they may increase security of supply. On the downside, renewable energy technologies are in most cases more expensive than fossil fuels and also, in the case of wind and solar power, due to their intermittent nature they are not available necessarily available when needed.

Nuclear, despite not being its own category above, is released during nuclear fusion or fission and is harnessed in reactors in order to generate electricity. It is a low cost, well established technology which can operate continuously (i.e. no intermittency issues like in the case of renewables) and it does not emit GHG or other pollutants. Nonetheless, the production of radioactive waste which along with the risk of accident which can cause large scale environmental and social impacts render nuclear a controversial energy source.

4.2.3.3 Power Plants

As we can see, power (referring to electricity) generation is based on a plethora of sources. For each of those, a number of technologies have been developed through the years. Starting with fossil fuels, the chemical energy within the fuel is converted to thermal, then kinetic and finally electrical. Two broad types of thermal power plants have emerged throughout the years, the steam cycle and the gas cycle. The former utilises steam as its working medium while the latter works with gas (natural gas in particular). Various combinations have been devised such as the combined cycle. Besides fossil fuels, steam cycle is also used in nuclear, biomass, geothermal and certain types of solar power plants. The most common way to generate electricity from solar energy though, is through photovoltaic (PV) panels that convert solar radiation directly to electricity. Wind turbines (horizontal or vertical) capture the kinetic energy in the wind and convert it electricity. A group of wind turbines in very close proximity to each other form a wind farm. Finally, ocean technologies utilise various apparatuses to convert kinetic energy to electrical.

4.2.3.4 Gasification

In most instances, raw biomass is not suitable for direct use in contemporary energy systems. Therefore, it is subject to a plethora of processes that convert it to different forms (solid, liquid or gaseous) that can be utilised by different types of burners/combustion engines. One of the most common processes is gasification, the process under which raw biomass is converted to gas. Further, also fossil fuel such as coal can be used. The process is performed in devices called “gasifiers” which can be of various types. The raw biomass -which can be solid waste, agricultural residues or similar- or fossil fuel enters the gasifier where it is heated up to very high temperatures (higher than 700 °C) reacting with a controlled quantity of steam and/or steam but with no combustion occurring. The outcome of is called syngas or production gas and is a widespread fuel.

4.2.3.5 Oil refinery

Oil is the primary source of energy that is used the most on a global basis. However, in its initial form (i.e. crude oil), the fuel is unsuitable for use in most devices and thus it requires certain processing. The latter takes place in dedicated industrial plants called oil refineries. The main process that takes place in a refinery is distillation where crude oil is transformed into various fuels and other petro-chemical products. Some of the most common output fuels are kerosene, diesel oil, light fuel oil and heavy fuel oil. Oil refineries are not necessary located nearby oil extraction fields but in many occasions, they are closer to demand sites.

4.2.3.6 Heating

Space (air) and water heating (or cooling) is an important component of an energy system. Heat can be delivered to or produced by the final user in various ways. End-use technologies such as heat pumps and electric heaters are fed with electricity to provide heating or cooling (in the case of heat pumps) while boilers run on oil or gas. Solar collectors can also deliver heat, mainly for domestic hot water. Another way of delivering heating/cooling to the point of demand is by centrally generating it and transferring it via water pipelines. In this case, the way to produce it can be either by heat pumps or furnaces/boilers. Thermal

storage is used in order to deliver heat when needed as heat generation is not instant (like in the case of electricity. Another reason for using thermal storage technologies is to produce heating or cooling when the cost is lower or when the associated technology can actually operate (e.g. solar technologies do are not available during the night). Thermal storage technologies include mostly buffer tanks filled with water or other media. Below follows a quick description of how the main heating technologies function.
Electric heater: an electrical resistor is loaded with electricity which in turn is converted completely to heat. The resistor is submerged in some type of tank that contains a heat transfer medium (in most cases water).
Heat pump: a fluid (e.g. ammonia) enters a compressor in gaseous form where its pressure rises before entering a condenser (i.e. a heat exchanger) where a large amount of its heat is released in the ambient. Then it flows through an expansion valve where its pressure drops again before entering the evaporator (also a heat exchanger) where it absorbs heat from the ambient. Whether a heat pump is used for providing heating or cooling, determines whether the condenser or the evaporator respectively is the component used to exchange heat with the space/water.
Boiler: it consists mainly of a combustion chamber where fuel is mixed with air and produces flame and a heat exchanger where water is heated by the flame.
Solar collector: an apparatus that consists mainly of a glazing frame that absorbs solar radiation and then heats a fluid that flows inside pipes situated beneath the frame.

4.2.3.7 Demand sectors

The commonly defined demand sectors of the energy systems are industry, transport, commercial, residential and agriculture/forestry; however, these can be extended or reduced depending on the scope of the study. Each of these demand sectors requires different types of energy to function, which are, as Figure 14 also indicates, the four products of electricity, heating, oil products and gas. Not all sectors demand all of them; for instance, oil may be argues to be directly used in agriculture/forestry, but rather in the machineries which are produced in the industrial sector. Below, the four forms of energy are presented and discussed in accordance to their final demand sector.

Electricity

Electricity is produced by the aforementioned three types of resources. Power plants of different scale are used to serve different levels of demand, from industries to residential areas. The electricity produced by the grid-connected power plants reaches the final consumer through a transmission or distribution system. The transmission system consists of high voltage lines and sub-stations, while the distribution system refers to those lines delivering electricity to the final consumption spot. It is worth noting though that not every power generation unit is connected to the transmission or distribution system. There are decentralized (off-grid) technologies that are linked directly to the distribution lines, while others such as roof photovoltaic (PV) panels can supply electricity directly to the final user. The services that run on electricity span from industrial machinery and pumping for agriculture to household and commercial appliances as well as transport. An important part of the electricity generation chain is storage. The latter is used primarily to balance intermittency (i.e. associated with renewables) and the main types of electricity storage are battery arrays and pumped-storage hydroelectricity stations.

Heating/cooling

Space (air) and water heating (or cooling) is an important component of an energy system. Heat can be delivered to or produced by the final user in various ways. End-use technologies such as heat pumps and electric heaters are fed with electricity to provide heating or cooling (in the case of heat pumps) while boilers run on oil or gas. Solar collectors can also deliver heat (usually for domestic hot water). Another way of delivering heating/cooling to the point of demand is by centrally generating it and transferring it via water pipelines. In this case, the way to produce it can be either by heat pumps or furnaces/boilers. Thermal storage is used in order to deliver heat when needed as heat generation is not instant (like in the case of electricity. Another reason for using thermal storage technologies is to produce heating or cooling when the cost is lower or when the associated technology can actually operate (e.g. solar technologies do are not available during the night). Thermal storage technologies include mostly buffer tanks filled with water or other media.

Oil products

After the refinery process of crude oil, petroleum products are formed to be used in its various applications. The products consist of, among others, gasoline, heavy fuel oil, distillates such as diesel fuel and heating oil (EIA, 2018). Petroleum products are used to fuel vehicles, heat buildings (industry, residential and commercial) and also to generate electricity (EIA, 2017b). Particularly, gasoline is used as a means of transportation fuel; diesel fuel as well in transportation; heating oil (fuel oil) for heating buildings and some industrial places; hydrocarbons gas liquids, for instance propane, for heating and cooking. The latter may be used as heating of livestock housing, thus petroleum products may also be considered in the agricultural sector. In addition to petroleum as a fuel, the petrochemical industry use it as a raw material in the products of for instance plastics.

Gas

Gas is considered to be used in all demand sectors expect of agriculture/forestry (EIA, 2017a). One can either consider gas as a fuel directly used from its resource, i.e. without conversion, and is then referred to as natural gas. In the case of gasification, one uses other inputs than gas itself, such as biomass and oil, and then the resultant gas is often called syngas. The syngas itself is mainly used within electricity generation, but has also has the application of lighting, cooking and to some extent heating. In the case the gasification process is using biomass as fuel input, one can consider the resultant gas can be considered renewable. Other than being a fuel input to the power plants, natural gas is used within the industrial sector in the process heating and combined heat and power systems, and also as a raw material in the production of chemicals, fertilizers, plastics and other products. Within the residential sector, natural gas is mainly used for heating and cooking; similarly for the commercial sector but also including some lighting outdoors as well as more refrigeration and cooling equipment. Combined heat and power systems may also be a part of the commercial sector’s natural gas demand. Natural gas may also be used as a fuel for transportation vehicles; nonetheless, the conventional fuel remains oil-based.

4.2.3.8 Interactions with other nexus systems

Following are a selection of interaction between Energy and the other domains/systems, based on Laspidou et al (2017).

Climate

The use of fossil fuels and non-renewable biomass leads to greenhouse gas emissions which results in a massive contribution to climate change. At the same time, climate may affect the energy sector both in terms of supply and demand. More specifically, certain renewables are directly affected by the climate (i.e. hydropower by precipitation and wind power by wind speed) while demand for heating/cooling is related to the climate pattern.

Land

The interaction between energy and land lies on the fact that energy infrastructure requires (depending on the energy source) a certain amount of land. Hereby, there is a trade-off pertaining to the allocation of land for the energy sector and other uses such as crop cultivation. On the other hand, oil, gas, electricity and other energy-related resources makes up basic need for land cultivation, preparation and maintenance.

Water

Allocation of water resources for irrigation or domestic use may hinder the generation of hydropower as the latter requires also certain quantities of river water. Therefore, there is a direct trade-off between the two that can be tackled through an overall management approach. Besides hydropower, combustion as well as solar thermal power plants require water for their energy conversion cycle, cooling of the station and fuel extraction. On the other hand, water infrastructure also needs energy for pumping, purification and desalination.

Food

Production of energy crops can occupy land areas that would be otherwise used for food production. At the same time, food production has a direct impact on energy consumption since energy (in all forms) is required throughout the various stages (e.g. from crop harvesting to packaging and preservation).

4.2.4 Water systems mapping

4.2.4.1 Introduction

The water system is in common terms referred to as the hydrological cycle. This cycle can be represented as the “Large water cycle” and “Small water cycle”, see Figure 16. The large water cycle represents the water cycle on a river catchment, from rainfall, through all water bodies, to discharge into the sea. The small water cycle focuses on the water for anthropic uses: production and distribution of drinking water, collection and treatment of wastewater, water for industry needs, etc.

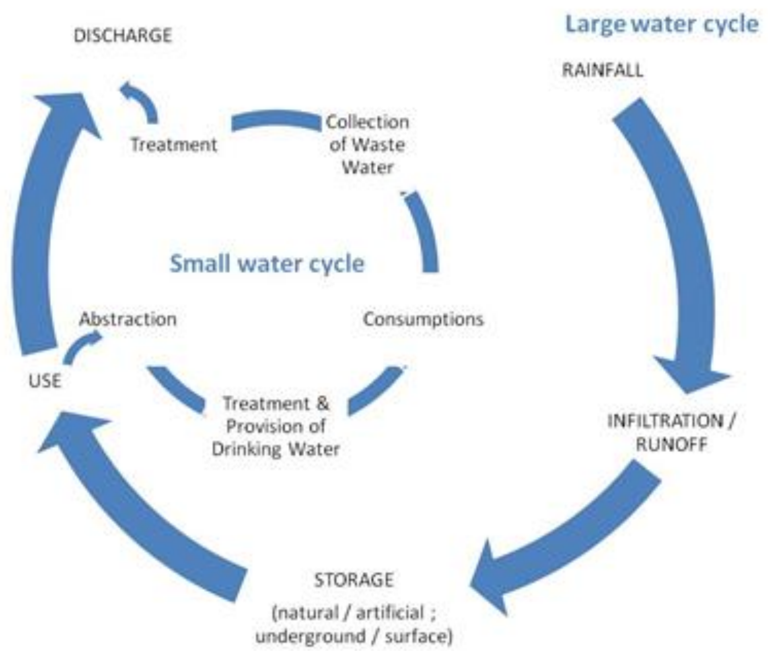

Figure 16. Synthetic representation of the large water cycle and the small water cycle (elaborated by ACTeon).

However, in order to understand the connection between the hydrological cycle and other systems, this representation has to be adapted. Figure 17 shows a system mapping where the interaction between the nexus components as well as the internal water system where both the large and small water cycle is apparent.

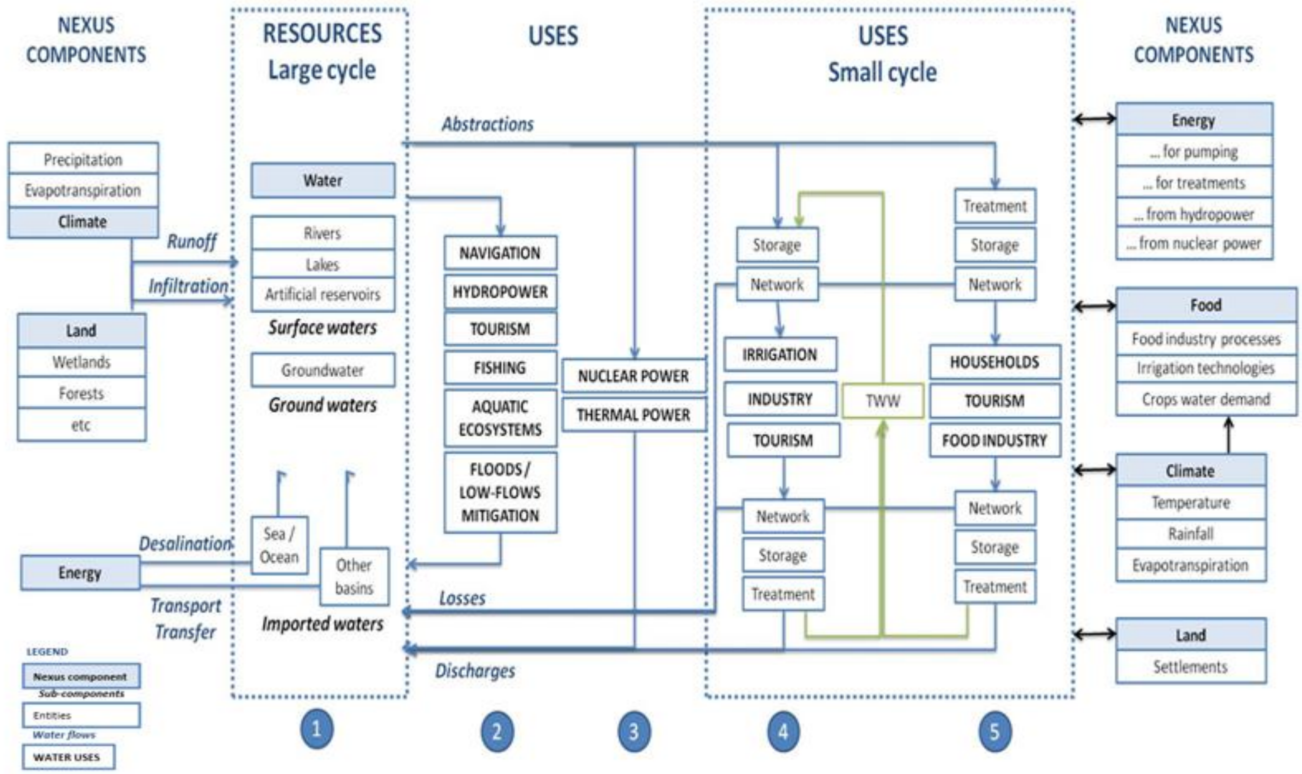

Figure 17. Water system mapping (elaborated by ACTeon).

4.2.4.2 Description of the Water system mapping

The water system mapping contains the large and small water cycle. It further incorporates five different sub-sections and loops, numbering corresponding to Figure 17:

1. Water resources
2. Run-of-river loop
3. Water-for-energy loop
4. Raw-water loop
5. Drinking-water loop

These five are described in detail below.

4.2.4.3 Description of water resources

In this mapping, we distinguish between three different types of water resources:

- Surface water: rivers, natural lakes or artificial reservoirs,
- Groundwater,
- Imported water from other basins / trans-basin water transfers (through ships or canals) or from the sea (through desalination processes)

Surface water resources are largely dependent on climate: quantity of precipitation (rainfall or snowfall) and intensity of evapotranspiration. The balance between precipitation and evapotranspiration is the amount of water that touches the ground. When water reaches the ground, it either sips into the soil (infiltration) or runs on the surface (runoff). These two mechanisms strongly depend on the nature of soils, and therefore on land-uses. A waterproof soil (urbanized land) will favour runoff, whereas a draining soil (forests, meadows, etc.) will favour infiltration. Infiltration water feeds groundwater aquifers. Depending on the permeability of soils, this mechanism can take from a few minutes (karst regions) to decades. The amount of water falling on a catchment basin is irregular through time (rainy vs dry seasons) and space (wet vs dry areas): artificial reservoirs have been built to retain water in rainy seasons and rainy regions, in order to use it in the dry season or channel it to drier places. Transporting water requires large amounts of energy; so does the industrial process to extract the salt from sea water in order to make it available for crops, livestock or drinking. However, in some water scarce areas, water transportation or desalination are the only sources of fresh water available.

The quality of the water resources is dependent on the surface and sub-surface activities (industries, agriculture, sanitation, etc) that are described in the loops below.

4.2.4.4 Description of the run-of-river loop

The first loop describes the water uses that run-of-river: there is no need for abstractions, networks or treatments before discharge. These are non-consumptive uses of water (no changes in the volume of water).

Navigation requires rivers or channels with sufficient width and depth. Low water levels can stop navigation or increase waiting time at sluices.

Hydropower also requires sufficient amounts of water to produce energy throughout the year. Hydropower is mostly associated to dams, blocking rivers to store water and channel it through the turbine to produce electricity.

Tourism, in this loop, relates to bathing and water sports. This use is dependent on water discharges (sufficient water depth for canoeing) but also on water quality (to limit risk of diseases for swimmers).

Fishing relates both to professional practice (including inland or coastal fish farms) and leisure. The quality of water (oxygen concentration, temperature, salinity, turbidity etc.) is the most important parameter. River morphology and continuity, as well as sufficient river discharges, are also important for this activity. Intensive fish farming can lead to high concentration of nutrients, causing disruption on downstream aquatic ecosystems.

Aquatic ecosystems evolve with the surface water bodies parameters: quantity, quality, morphology. The preservation of these ecosystems relies on the conservation or restoration of the rivers and lakes physical parameters. Healthy and functional aquatic ecosystems also provide many “ecosystem services” such as pollution reduction and aquatic food production.

Floods and low-flows mitigation is also an important use on surface waters. Reservoirs, channels, by-passes have been built to prevent damage from floods to human settlements or to artificially increase water levels on rivers in the dry season. These goals can often be competing with other uses that have developed on the reservoirs: tourism, fishing, irrigation.

In this first loop, the groundwater and the imported waters are not considered.

4.2.4.5 Description of the water-for-energy loop

This loop focuses only on water uses that abstract water, without treating or transporting it. Thermal power plants are located very close to a large river, lake, reservoir or coast, and use the water for heating and/or cooling. Limitations can appear if the water temperature exceeds thresholds or if water flows are not sufficient for abstraction. For instance, nuclear power plants abstract water for cooling: part of the water is evaporated or incorporated in waste (net abstraction); part of the water is discharged with a higher temperature. If water flows are too low and the water temperature in the river is too high, the nuclear power plant has to curtail or reduce its output (though it is not so easy to stop production).

In this second loop, the groundwater is not considered.

4.2.4.6 Description of the raw-water loop

In this loop are listed all the uses that abstract, store and transport water but do not need to treat the water before using it. However, these activities may have to treat the wastewater produced after using the treated water resource, in order to preserve or guarantee the quality of the water body in which the water is discharged (European Water Framework Directive, 2000).

Irrigation relates to water uses for crops (for food or for energy), as well as parks or gardens. Many irrigation techniques exist (sprinkler, drip, etc) with different water efficiencies. Depending on the region, water for irrigation is abstracted from groundwater, rivers or reservoirs. The pumping costs as well as the maintenance of the irrigation network weight heavily in the total expenses related to irrigation. Crops water demand varies according to crop species (maize or soya require large amounts of water), on the development stage of the crop (flowering often being a critical stage), but also on evapotranspiration rates. In addition to the irrigation requirements, livestock water demand is also an important factor that is considered in the overall agricultural water demand.

The industry sector also uses raw water in its processes. The water can take up pollutants during the industrial process, and needs be treated before reaching the natural environment again. The treatment is done in-situ for the largest factories; smaller factories are connected to the domestic sanitation network.

Tourism in this loop refers to the artificial production of snow in cold or mountainous areas to sustain ski resorts. The water is stored in the rainy season in reservoirs and used in winter time to produce snow and cover the ski slopes. The process required large amounts of energy.

Water systems' networks (to bring water to the users or to discharge water from the users) are never totally leak-proof. Part of the water abstracted or collected sips into the ground and is lost to the users.
All the above uses can be restricted or stopped when water levels (in rivers, lakes or groundwater) are too low and threaten the survival of aquatic ecosystems or the provision of drinking-water to populations.

The improvement of treatment technologies as well as the need to reduce abstractions of water led to a wider use of treated waste water (TWW). The legislation so far forbids the use of TWW for drinking water or in the food industry, but it is progressively allowed for irrigation, cleaning roads or process water in the industry.

4.2.4.7 Description of the drinking-water loop

The raw-water in this loop needs to be treated in order to meet standards for drinking-water. Drinking-water is used in households and touristic facilities for drinking, cooking and sanitation. Drinking-water standards are also required for food or beverage production. The treatment costs to produce drinking water are dependent on the concentration of pollutants in the abstracted water. Polluted raw-waters require costly treatments to produce drinking-water. If treatment costs are too high, abstraction points are abandoned and another water resource is mobilized. In times of water scarcity, provision of drinking-water to populations always ranks prior to other uses.
Households, touristic facilities and the food industry produce wastewater that is treated before being discharged to the natural environment or re-used for irrigation and industrial processes.

4.2.4.8 Interactions with other nexus systems

Following are a selection of interaction between Water and the other domains/systems, based on Laspidou et al (2017).

Climate
The hydrological cycle is highly dependent on the climatic conditions; on the other hand, water also governs the water vapour content in the atmosphere and is thus a contributor to the GHG's.

Land
Water provides a resources to, and constrains, the land use. Natural uses, such as forest, dessert and water bodies are all determined by the availability of water (and climatic conditions). For anthropogenic uses, such as agriculture and urban areas, the availability of water often determined the extent of these activities and may be a limiting factor for expansion.

Energy
Water is a necessary resource in the energy sector as it is required in cooling, heating, and extraction of fuels. Hydroelectric generation have little consumption of water, but may still disrupt flow regimes of rivers.

Food
Water is a necessity in food production as it provides water for crops (rain-fed or irrigated) as well as animals in livestock. The quality of water, e.g. salinity, is also important for the aforementioned activities; high salt content can cause salt stress on crops, and may not be serviceable for livestock. Quality is also

important for aquaculture and fisheries, water bodies with depleting oxygen level or increasing nutrient concentration threatens the fishing industries.

4.2.5 Food systems mapping

4.2.5.1 Introduction

A food system can be defined as "all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food and the outputs of these activities, including socio-economic and environmental outcomes". Moreover, a "food system interfaces further with a wide range of other systems (energy, transport, etc.), and faces various constraints" (HLPE, 2014). The food system is an interlinked system consisting of four interconnected components: farming, the economy, the social and political domain, and the environment, see Figure 18 (Nourish, n.d.). Many studies assess the impact of a given food system activity (e.g. producing or transporting food) on a given resource (e.g. land, water, minerals) or environmental outcome (e.g. GHG emissions) (UNEP, 2016).

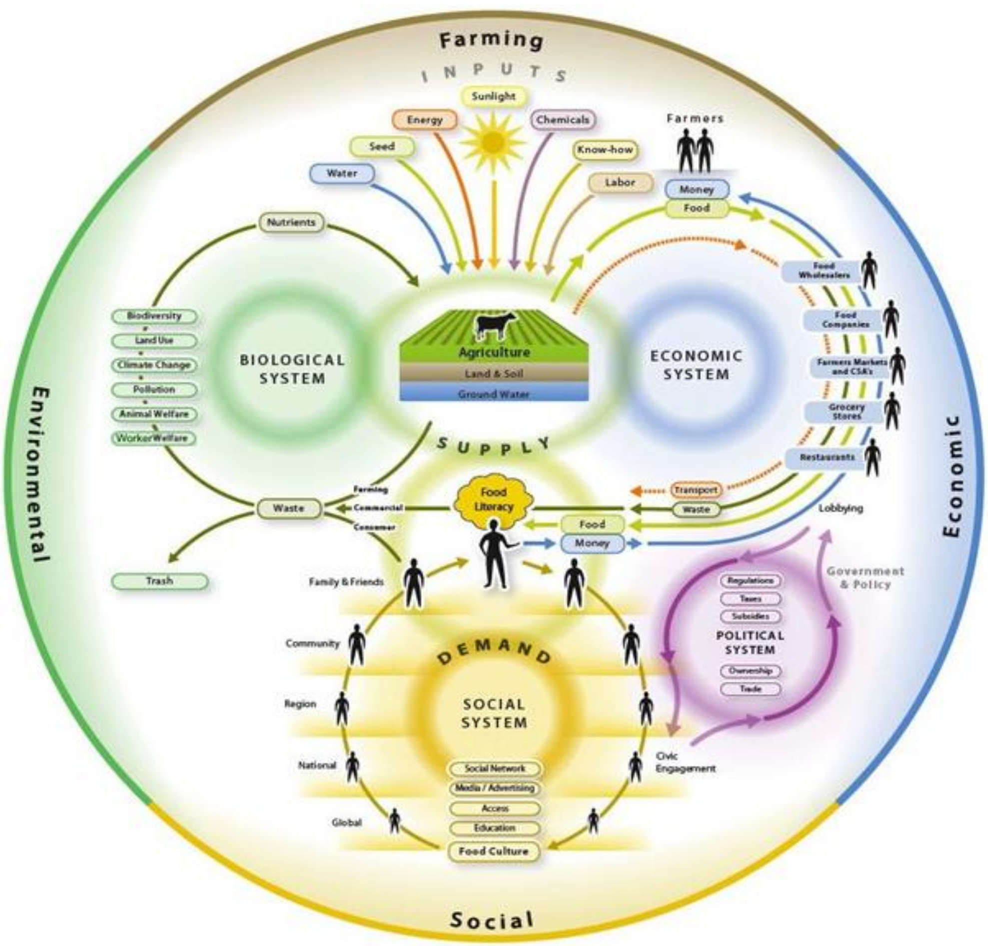

Figure 18. Food system map (Nourish, n.d.).

Food systems can be described as encompassing a number of activities that give rise to a number of food security outcomes. Food systems are themselves influenced by economic, social and environmental drivers (and their interactions). In turn, food systems feedback on environment, social and economic drivers (Ingram, 2011). These outcomes, interactions and feedback are all part of the framework of food system activities and natural resources (see Figure 19).

Many studies assess the impact of a given food system activity (e.g. producing or transporting food) on a given resource (e.g. land, water, minerals) or environmental outcome (e.g. GHG emissions). The food system concept provides a framework to integrate such studies to provide a more complete description of the 'food' two-way interaction with both natural resources and socio-economic conditions. Its main value is therefore in showing where the feedbacks to both socio-economic and environmental drivers lie, as these interactions are often the ultimate cause for further natural resource degradation. A thorough analysis of existing food systems can assist in identifying the most important issues regarding natural resources, as well as the opportunities for effective policy, fiscal, social and/or technical interventions (UNEP, 2016).

In essence, the food system comprises the chain of activities and actors that is in the centre of the figure. It is the exchange of information, contracts, standards and monetary flows between actors within the food system. This roughly corresponds with the farming and economic system depicted in Figure 18.

Generally, in developed countries, the chain of activities consists of the input industry, farmers and fishermen, traders and processors, the food industry, retailers and food service and, finally, consumers. In most developing countries however, subsistence agriculture rather is the norm. This can be defined as self-sufficiency farming, in which the farmers focus on growing enough food to feed themselves and their families. The output is mostly for local requirements with little or no surplus for trade, so traders, processors, food industry, retailers and the like play a very limited role.

The food system activities lead to a number of outcomes, for example outcomes regarding food affordability, food safety, food and health and rural and urban livelihoods. Moreover, the food system creates a certain amount of waste and sewage that should be dealt with. The food system, as described by (UNEP, 2016) not only includes agricultural production, but also processing, packaging, transport, retail, and consumption and disposing food and related items. An improved food system should therefore not only pay attention to agricultural production, but to the whole food chain from producer to consumer and even from consumer to the rubbish dump.

The food system actors are influenced by socioeconomic conditions. Socioeconomic drivers that have an effect on these conditions include changes in demographics, economics, socio-political context, labour availability, cultural context, science and technology, regulators, institutions, and NGOs. Simultaneously, socioeconomic drivers are affected by the food system outcomes, for example food affordability, or food safety.

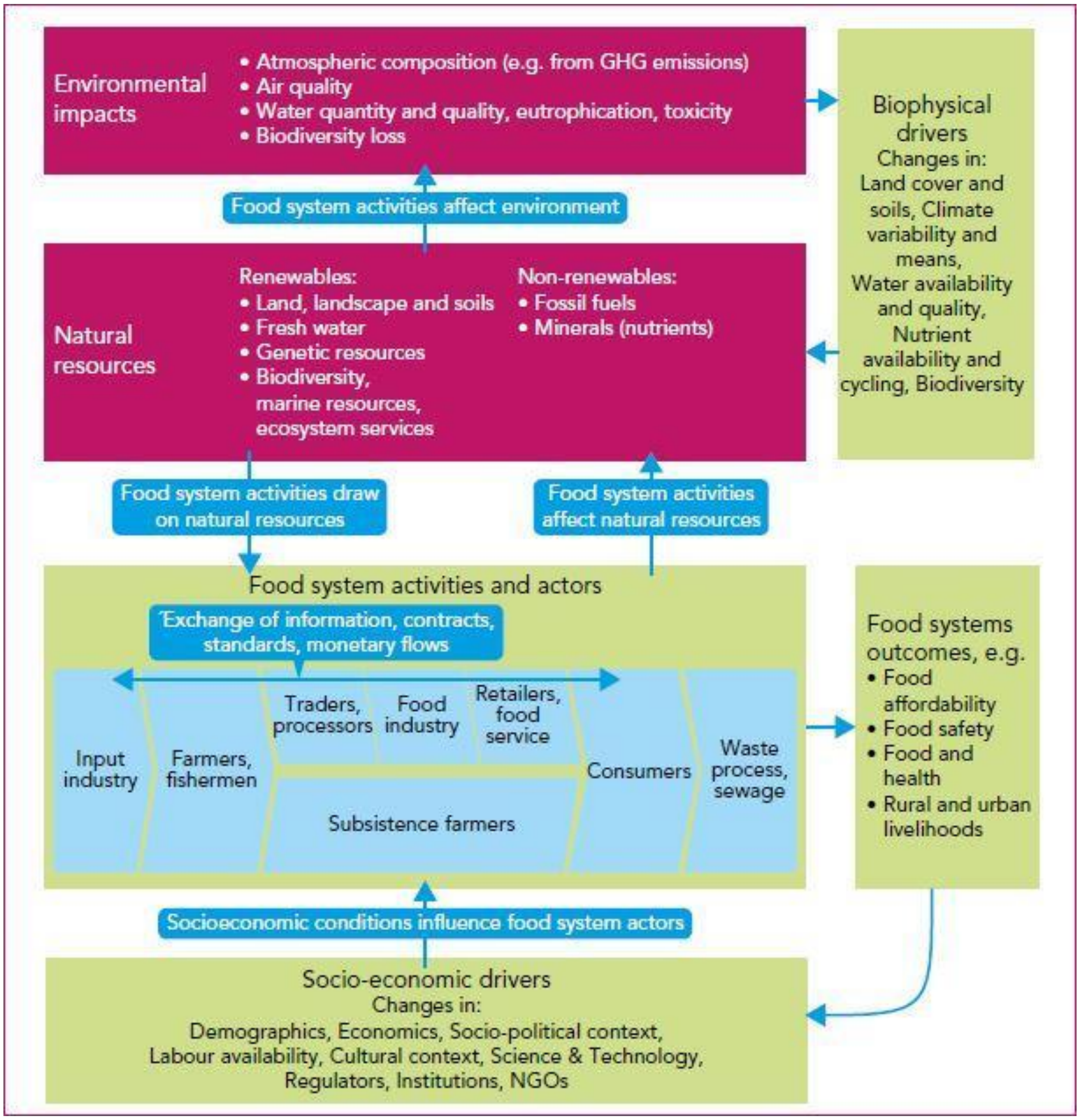

Figure 19. Conceptual framework of food system activities and natural resources (UNEP, 2016).

Food system actors, e.g. farmers, react on incentives, e.g. business opportunities, and on constraints, where an important constrain is limited excess to natural resources. The interaction between actor and both physical and social environment has an influence on both sides. According to (UNEP, 2016) with reference to (Ericksen, 2008) this has two implications. First, the development of a food system needs to be studied as the result of a mix of factors, such as relations influencing the actor, and access of the actor to markets, information, regulations etc. Secondly, it is argued that it is important to realise that even small changes may have unpredicted effects on different parts of the food system and that these effects can be positive or negative. The food system is complex, and it is essential to understand which factors are influencing the food system actor and how the actor reacts on it.

Food system activities are strongly related to natural resources. Natural resources include renewables, such as land, fresh water, genetic resources, biodiversity and ecosystem services; and non-renewables, such as fossil fuels and minerals (nutrients). Food system activities draw on these resources, but also affect them.

Furthermore, food system activities have environmental impacts, for example impact on atmospheric composition, air quality, water quality and quantity, or biodiversity loss. These impacts may consequently affect biophysical drivers such as climate variability or nutrient availability and cycling, which in turn influences the quality and quantity of natural resources. Human interventions, e.g. within the food chain, therefore have an impact on resources, as shown in Figure 20.

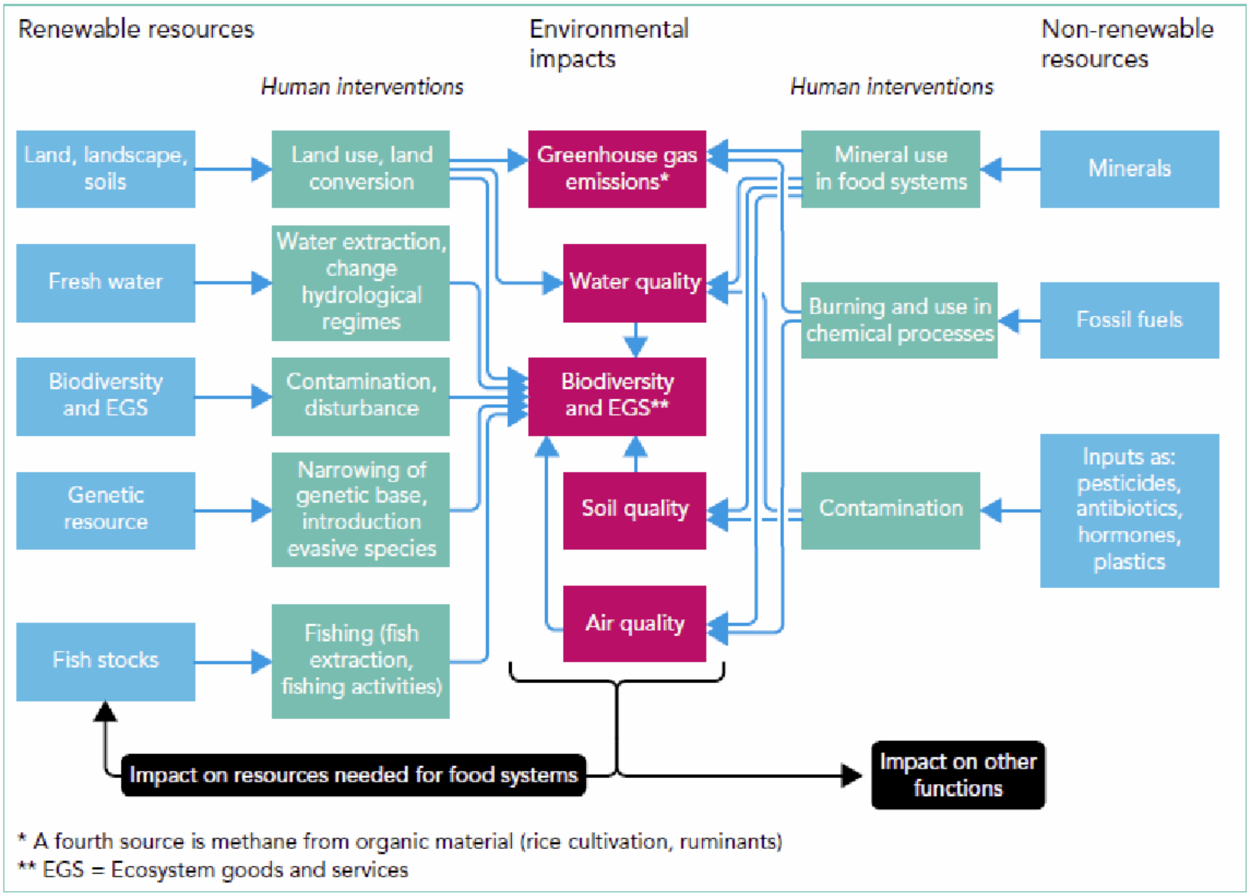

Figure 20. Relation between resource use (human interventions) and environmental impacts related to food system activities (UNEP, 2016).

As argued by (UNEP, 2016), the feedback of agricultural activities on the environment sometimes is very local and within a short timeframe (e.g. the effect of contamination on water quality), but the feedbacks may also be global and over a long period of time (e.g. the effect of greenhouse gas on climate). The effect of human interventions on the environment and within the food system is, however, not always directly linked to natural resources. In addition, synthetic products like plastics can lead to contamination and influence e.g. soil and water quality.

As shown above, the food system is very complex with many feedbacks. It is stated by (Achterbosch et al., 2014, p. 8) that “Sustained efforts are needed from policy-makers and the private sector to address agriculture’s role in today’s nexus around food security and scarcity.”

4.2.5.2 Farming

In the farming component, the farmer uses different kinds of inputs and resources to produce food, for instance, water (surface and groundwater), seed, energy, sunlight, labour, fertilizers and pesticides. Moreover, agriculture requires land and soil of right characteristics (e.g. enough soil moisture, right nutrients). Note that the current Figure 18 does not incorporate fisheries and aquaculture, if it would have, the figure would look slightly different.

4.2.5.3 Economic

Agriculture does not only provide food for the people, but also contributes to the economy in terms of export, sales and labour forces. Simultaneously, waste is created in the process of producing, processing and selling; making it possible for recycling for, for instance, power generation.

4.2.5.4 Political and social system

The political system debates and decides upon regulations, taxes, subsidies, ownership, and trade related to the food system. The demand from people are first of all basic need for survival; but also extends to social aspects, such as social networks, media and advertising, education, and food culture. Furthermore, socioeconomic drivers that have an effect on these conditions include, among others, changes in demographics, labour availability and science and technology. Simultaneously, socioeconomic drivers are affected by the food system outcomes, for example food affordability, or food safety.

4.2.5.5 Biological system

The food system creates a certain amount of waste that either will be deposited (for example on a landfill), burned or become part of the biological system for example through composting where bacterial activities transform the organic matter into nutrients. Both environmental and social elements are relevant to the biological system, such as biodiversity, land use, climate change, pollution, animal welfare, and worker welfare.

4.2.5.6 Interactions with other nexus systems

Following are a selection of interaction between Food and the other domains/systems, based on Laspidou et al (2017).

Climate
Food production, in terms of agriculture, livestock and fisheries, emits larges amount of GHG. In return, the food resources are highly dependent on the climatic conditions.

Land
Food production requires land and defines the ecological footprint; certain food requires larger area units than others to produce the same volume of food. Intensive agricultural practice can cause nutrient depletion in the soil and make the land insufficient for further practise. However, food as a biological substance is a part of the nutrient chain and is therefore important for the lands formation.

Energy

Globally, the food sector is highly dependent on fossil fuels, or burning of biomass, and the use of energy technologies for harvesting, processing and transport. In return, food provides waste that can be used for energy production.

Water

Food production is dependent of water as a resource, but in return food production may also affect the quality of water, e.g. through the disposal of waste an inaccurate means (e.g. dumping in uncontrolled landfills). However, if returned accurately, food return water to the nature as well as other nutrients.

4.3 Non-resource systems as driver of change

One can consider non-resource systems to be those that are not holding or constituting any resources, but comprise a system which is dependent on resources and also affect resources availability, quality and distribution. In other words, one can consider such a system to be a driver of change directed to the other systems. For instance, such a system can be defined to consist the socio-economic sector; socio-economic factors and activities are highly dependent on, and interplay with, the nexus sectors and their resources. Therefore, one can argue that these non-resource systems are the one driving the changes, or impacts, on or within the other systems. The socio-economic sector contains several factors and activities that can be considered drivers; however, limiting it to a few, one can focus on population, policy and economy. The population, no matter if focusing on global or local scale, are dependent on natural resources within their activities and for their pure existence. These activities and resources can be, to mention a few, drinking with usage of water; transport with usage of energy; agriculture with usage of land and diet with usage of food. An increasing population, or intensification of density, will drive the intensification of the usage of these resources; thus, cause a pressure of their availability and the response will be food resources-insecurity. A closely related activity to the population increase is the economic growth that, in similarity to population, may cause stress on resources availability. On the other hand, economic growth may also drive a possible diversification of activities, e.g. better use of agricultural practises or less use of cheap fuels in the energy sector. Thus, economic growth does not only imply depletion and stress on resources, but also possibility for a better management practise. Lastly, policies can have a large impact on how the practise and management of resources are being done. Furthermore, policies in one sector may have trade-offs or synergies with another sector; thus implying the need of holistic thinking and nexus approach even in policy-making. The latter is difficult, however can be argued to be vital in order to receive most feedback from the implementation of a policy.

From the perspective of the nexus domains in SIM4NEXUS, Table 3 presents selected socio-economic drivers of change in their practises and resources availability. Population, economic and policies are not specifically added, but thought to be a driver of change in all five systems.

Table 3. Selection of socio-economic drivers associated with each nexus system.

Nexus system	Socio-economic driver
Climate	Anthropogenic GHG emissions through, for instance, industry, agriculture and transport

Land	Intensification of land practices such as agriculture, urbanization, industry and forestry; or other general land requirements Trade Tourism & recreation Cropping patterns
Energy	Energy security and access Energy demand Carbon tax/Emission trading system Electricity trade RET development Fuel prices
Water	Water drinking demand and other requirements such as water for washing and public services Tourism Organic food production – less use of chemicals and thus less pollution Water system infrastructure Water pricing
Food	Food security Food demand Diet requirements Food prices

4.4 Interactions between systems

This section presents possible interactions between the systems and can be used to understand the interconnectedness in-between different system elements, sectors or activities. Throughout the chapter, under each section, examples of interactions have been discussed or touched upon; Table 4 presents a selection of interactions between the nexus domains. For a more descriptive and extensive summary of the interactions, please refer to Laspidou et al (2017). The table is here for the reader to summarize the possible interactions in order to understand synergies, impacts and trade-offs between the systems. Note that the table presents 2nd degree linkages only, i.e. only the interlinkage between two nexus system are considered. It reads as: the impact of system on the x-axis to the system on the y-axis.

Table 4. Selected interactions between nexus systems.

	Climate	Land	Energy	Water	Food
Climate	-	Forest fires	Solar irradiation	Precipitation patterns	Harvesting season (occurrence and duration)
Land	Carbon sink	-	Agricultural waste and other biomass	Runoff patterns and quality	Agricultural area

Energy	GHG-emission	Deforestation	-	Desalination and water treatment	Crops for biofuels rather than food consumption
Water	Water vapour	Floods and droughts	Water for cooling	-	Water requirements for crops
Food	CH_4 emission from enteric fermentation and manure management	Leaching of nutrients	CH_4 capture from landfills (anaerobic digestion of organic waste)	Water productivity	-

However, Table 4 is in many way a simplification of reality. Here only one way interlinkages of a second degree[2]

A more complex analysis than Table 4 would be to include all nexus components, i.e. 5th degree interlinkage. Depending on where the focal point is, one can expect different outcomes. For instance, Figure 21 shows the pathway of the interlinkage starting from increase of temperature (Climate). The increase of temperature would yield an increase in evaporation of water. This evaporation affects the soil moisture in the soil, in its turn affecting the crop yield assuming no additional irrigation is applied. The reducing crop yield will affect the food availability; also generating less food waste that could be used as an energy resource and hence other resources are needed.

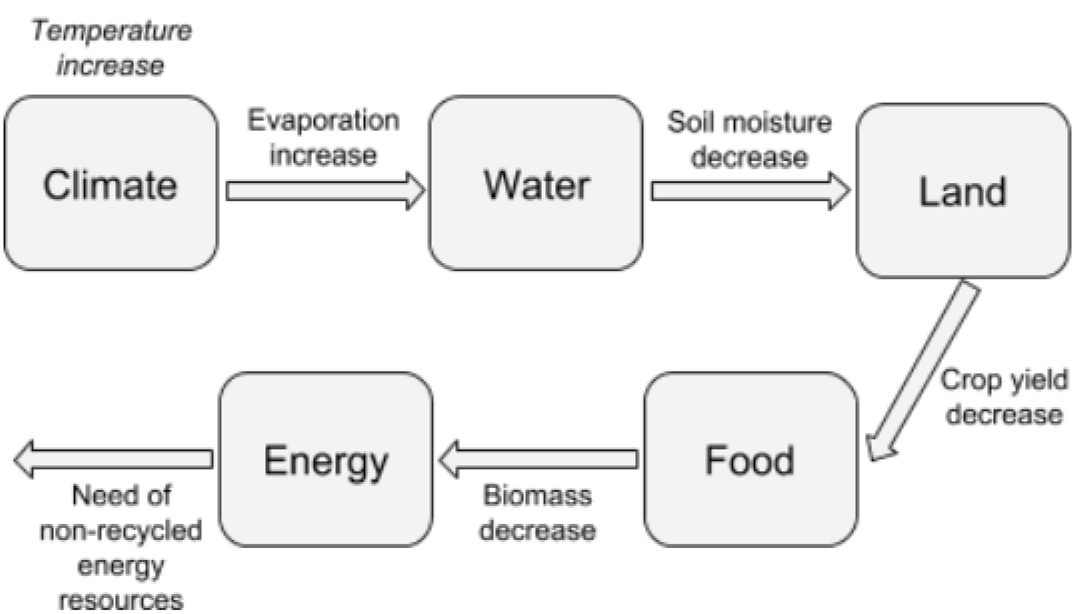

Figure 21. Example of a 5th degree linkage using all nexus components.

2 Defining the level of degree as the number of systems involved.

However, this assume a linear relationship, but instead one action will alternate several other ones within one system, e.g. through feedback loops. For instance, in Figure 22, we see that the increase in evaporation will also yield more water vapour linking back to the climate, which could further alternate other climatic responses. Furthermore, the soil moisture will affect the vegetation in general, not only the agricultural fields; and the reduction in crop yield will yield a food quantity reduction which may cause the need to change the pastoral system. Lastly, the evaporation from water bodies may be ones as reservoirs used for hydropower generation; if the retention time in the reservoir is long, one could expect the evaporation rate to cause negative effect on the water availability.

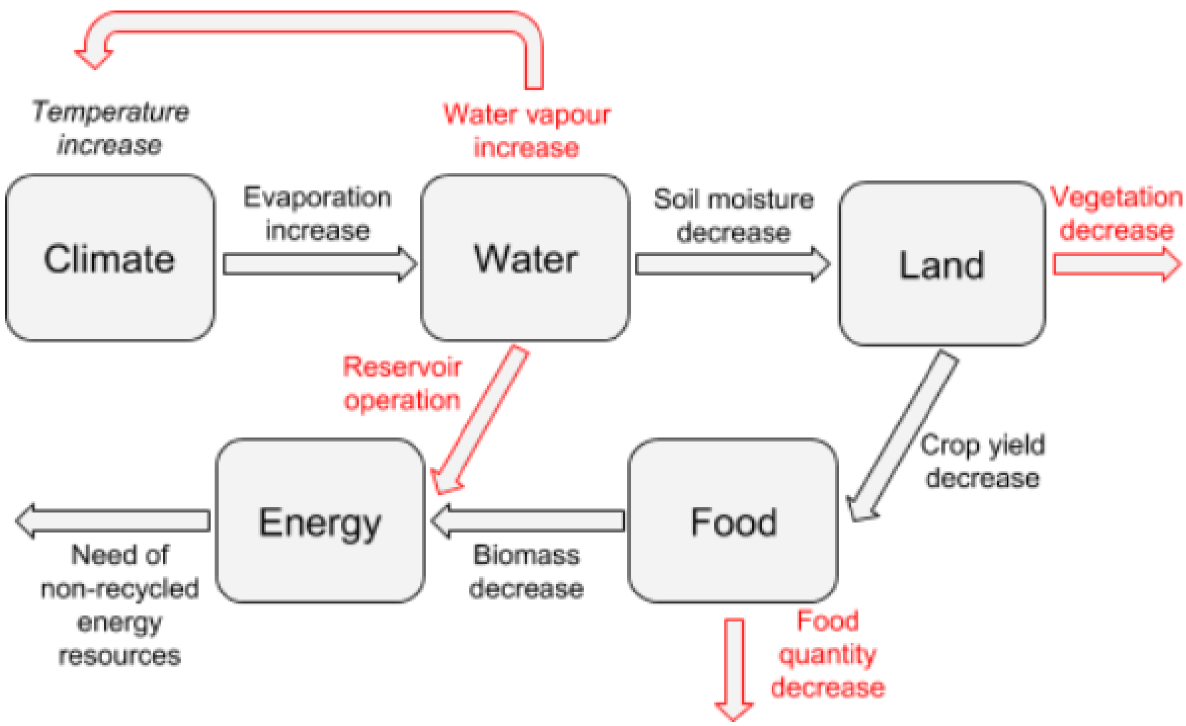

Figure 22. Example of a 5th degree linkage using all nexus components and accounting for more than one impact for different sectors.

Building on Figure 22, one could account for this two-way interlinkage; yielding even more complexity. Figure 23 shows one in which a 3rd degree interlinkage is display when allowing the return action to be accounted for. The same story as Figure 21 with Climate, Water and Land applies. One can follow the impacts with the parenthesis as "(order X of action: affected by action Y)". For instance evaporation increase is the order 2, and it is affected by temperature increase which is order 1; hence one obtains (2:1). The storyline of the figure is as following: the evaporation increase, the soil moisture will decrease as mentioned before, but this will also yield increase of water vapour in the air. Furthermore, the decrease of soil moisture may decrease the vegetation which in its turn causes the permeability of the ground to change. In case the vegetation decreases, there is less water staying on the surface of for instance leaves that may evapotranspirate, instead infiltration down the soil leading to less (instant) water vapour. Obvious is that the interlinkages are complex and also build up on uncertainties; one action may cause a change but which has negligible outcome but also vice versa may occur.

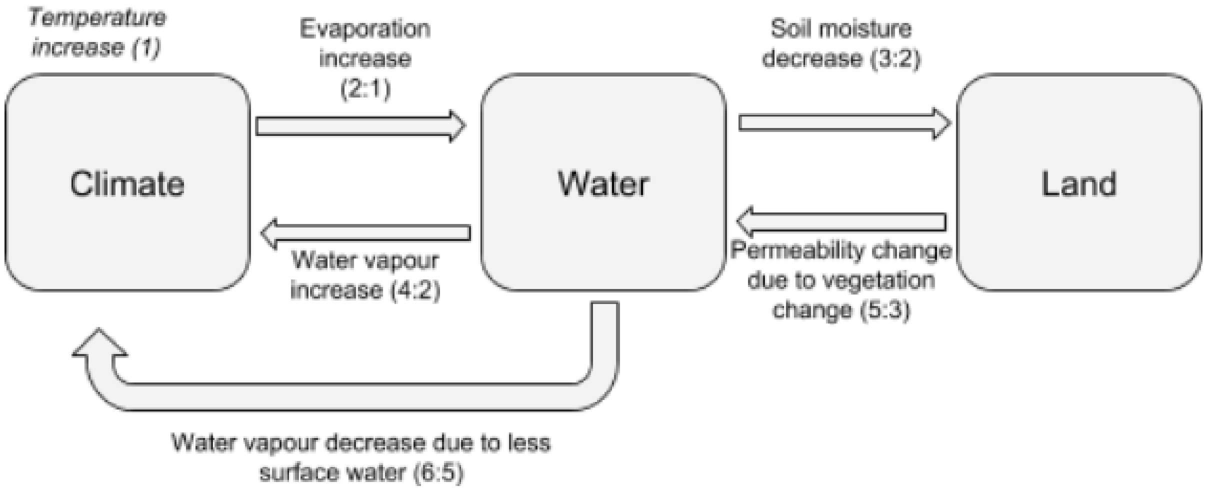

Figure 23. Example of a 3rd degree linkage using return actions.

4.5 Factors affecting the analysis

This section describes how the system mapping should be adjusted to capture the specific elements of a particular case. As the geographic scope of a study changes, different biophysical, economic, political and administrative factors come into play impacting heavily the analysis. Below are a selection of factors presented which will affect the use of the system mappings.

Scale

Scale analysis here refers to the different levels one performs their analysis on. This can be local, regional, national, transnational or global scale; or even something in between such as transboundary or city level. What differs in the use of different scales is the limitation to the details one obtains as we move up in scale as well as importance of certain components of the system. For instance, at a global scale, one could expect to have a more top-down approach where one represents each system in a more general manner. As an example, in the latter case one would maybe merge all agricultural sectors in different nations or regions to one. On the other hand, a local scale would be more of a bottom-up approach where the domains are more detailed and, in the example of agriculture, one would even divide this up into subsector or even crops.

Scalability example – energy systems

Over the past decades, various tools and methods have been deployed to analyse energy systems. Each analysis might differ to another in terms of geographic scale, time horizon and objectives. This is due to the fact that depending on the scale, the aspects to be considered by an analyst or a policy-maker may differ significantly. Below follows a list of some key differences to be taken into account that one may face when analysing an energy system:

- Often, GHG emissions matter less at a regional than a national level.
- Often, local pollutant emissions matter less at a national than a regional level.

- Energy security is not a concept taken into account at low geographic scale analysis.
- The lower the geographic scale the more disaggregated the demand analysis. For example, at a national level, demand may be split into major sectors (e.g. households, industry, transportation, commerce, agriculture). In the energy systems analysis of a village, every single household and business activity could be considered.
- Nuclear power, large scale hydropower and other large investment technologies are not considered in the energy planning of a small community/region.
- Small scale power plants are aggregated in a national energy systems analysis.
- The lower the scale of the system under analysis the lower the level of flexibility in policy suggestions (i.e. subsidies) and the greater the level of binding regulations.
- In a continental/global scale analysis gross assumptions need to be made on for instance, the techno-economic characteristics of power plants.

Data

The amount of data will also be a factor that affects the outcome of the results in one way or another. Either, the data will limit the possibility to make a full and adequate analysis, or it may not be possible to use in the analysis being done. This means that one may either have to interpolate data or make assumptions, possibly resulting in rough or very general outputs. Or on the other hand, one may have to change the data to fit the analysis (e.g. if using a model one could harmonize the data with the model inputs) that may yield overestimates or inaccurate assumptions. The data is connected to the scale of the analysis in the sense that one could argue that for a larger scale, one often uses less detailed data and hence the precision of this data is not as important. Whereas if one looks at a very small scale, such as a river basin or even a section of a river, the analysis tends to be more detailed and thus requires more detailed data.

Expertise

The knowledge about the area under analysis, in terms of expertise from stakeholders or other engaged partners, will also affect the analysis. Lacking the expertise in one area, may make the analyst to omit this area, or make assumptions or decisions which may not actually be feasible from an expert's point of view.
Geographic scale also affects the level and the type of expertise required. For instance, at a very small scale, direct engagement of the local population might be critical while at a national scale, the population is represented by certain institutions. On top of that, knowing the area of study may be catalytic when a small scale area is analysed while the broader the area the more general knowledge is required.
However, it is not only the knowledge about the area being studied, but also the in-depth knowledge of the analyst. There is a difference between modelling a small scale system which has less components but more details compared to a large scale system with more components but less details. Having more components in a system makes it possible to have several components that are interlinked; as described and elaborated on in the system mapping.

Precision of results

Depending on the precision of the results or the wish of the analyst, one could process the data enough to actually fit the required output. For example, at global scale the results would be used to glean information that could assist decision-makers come up with certain strategies. The latter tend to be highly debatable and not always adopted or implemented by all nations. At the same time, an analysis over a village is more likely to produce very precise results which will be adopted and turned into direct actions.

Models used

One of the aims with the SIM4NEXUS project is to understand what the thematic models may address in terms of nexus challenged and not. As it has been seen in SIM4NEXUS deliverable 1.3 (Fazekas et al., 2017), the various models have different capabilities in both the geographic scale they may cover, as well as the nexus sectors or even, the elements of those. Consequently, in order for an in-depth nexus analysis to be carried out, a suite of models has to be used. The scale of the analysis determines not only which models to be used but also how. For example, in the Global case study, OSeMOSYS uses a temporal resolution which does not consider a day/night split as it covers the entire world without splitting it further into smaller regions. Another example is the case study of Azerbaijan in which CAPRI has generated results for the so called Former Soviet Union (FSU) group of countries without national disaggregation. Therefore, in order for the data to be used, post-processing is required to downscale it. The complete picture of which models were used in case study, how were they used, what did they cover and what were the gaps identified will be presented in SIM4NEXUS deliverable 5.3 “Using the modelling approaches in 12 case studies” due in May 2019.

Stakeholder engagement

Engaging a number of stakeholders that represent each nexus each sector from the same geographical perspective is a challenging task. Assuming an example of a village or a small town where the agriculture sector is represented by a union that serves the interests of the local farmers. The energy sector in this case might not be possible to be represented by any local institutions as for instance the electricity might come from the national grid and be handled by a national company. In a transnational case (e.g. a transboundary river basin study), language barriers, cultural differences and administrative issues may affect significantly the decision-making process and the components of the nexus that can be actually taken into consideration. Nonetheless, the stakeholder engagement is a factor that may implicate how nexus interactions are represented, and prioritised, and is further discussed in Chapter 7.

Detail of interlinkages

The previous paragraph revealed certain limitations that might arise in nexus case studies due to their geographic scope. For example, the allocation of water for irrigation might be a request from local farming association. This however, might be in conflict with the energy sector which might be using the same source (i.e. a river) for generating electricity. Therefore, if the institutions in charge of the river management serve national interests rather than local, reducing the amount of water allocated for hydro-power might not be an option that can be taken into consideration. In a different example, assume that a nexus analysis is performed on a national basis. The influence of smaller communities in the analysis is limited (regardless of the sector).

5 Formulation of narratives

5.1 Introduction to the formulation of narratives

As complex it is to understand how systems interact in a particular context, more complex it is to communicate that understanding to others, such is the case of stakeholders from various types (e.g. government, private sector, civil society, NGOs). As was found throughout the development of this task, transdisciplinarity is essential to characterise objectively the state of the different systems, their pressures and to understand the implications of certain trends. Additionally, those analyses need to be combined and the systems understood in an integrative manner as a system-of-systems. This conceptualization can be achieved in different ways, for example using diagrams and conceptual maps (as explored in Chapter 4 – systems mapping and implemented by the case studies in WP3 MS18 conceptual maps). However, the interpretation of diagrams needs guidance, in particular to non-experts and audiences not familiar with the context. When developing an analyses, that involves/requires both qualitative and quantitative components, a link needs to be established between the two. The description of a case study, and of its starting point, is therefore essential to clarify what is at play and introduce information on main drivers, current development in different fronts, and inferences on how the systems tend to evolve in the future. This description of the starting point complemented with information on how the systems are interpreted/assumed/likely to evolve in the future correspond to a narrative or storyline of a baseline for the case study.

5.2 Investigating the application of the DPSIR framework in the assessment of the nexus

5.2.1 Overview of the DPSIR - a problem structuring method/decision support tool

The DPSIR (short for Drivers, Pressures, State, Impact and Responses) framework was developed as a recommendation to the European Environment Agency on how to proceed with the development of a strategy for Integrated Environmental Assessments (Kristensen, 2004). Similar to its predecessors[3], the DPSIR is a conceptual framework to analyze the cause–effect relationships existing between society and the environment and to support decisions in response to environmental issues (Spanò et al., 2017).

The DPSIR framework starts by identifying an issue or areas of interest, i.e. a focal point, acknowledged by decision-makers or stakeholders, from which an analysis to understand its effect is required. A focal point

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[3] Previous frameworks include the Pressure-State-Response (PSR) (OECD, 1993) and Driver-State-Response (DSR) (UN, 2001). Detailed description of these and other well-established and used alternative frameworks (e.g. the IWRM (Al Radif, 1999)) can be found in appendix.

of interest may be a river basin, urbanization within a specific region etc. The analysis is then split in the 5 elements: drivers, pressures, states, impacts and responses (DPSIR). Once the focal point is defined the main drivers are to be explored. By *drivers* one typically mean those societal forcing powers that have an influence on the system (economic growth, demand for recreational space etc.). As a consequence of those drivers, certain *pressures* are applied on the natural environment. Pressures can be excessive use of resources, emissions, pollution (to air or water), change in land use (e.g. from forest to cropland) etc. The pressures in turn affect the *state* of the environment (e.g. condition of the air/water/soil/biodiversity). Once the state of the environment (biological, physical or chemical) has changed, the generated *impacts* are identified and assessed. These could be environmental, economic and social. Finally, impacts – either fully understood in their causal chain or not – lead to *responses*, such as management or policy actions. When the causal chains are properly understood, response actions (e.g. policy, investment, technical interventions) can be targeted to the most interesting or cost-effective level (drivers, pressures, impact). If they are not well understood, response actions are typically only targeting impacts (remediation).

Figure 24 illustrates schematically the links between the DPSIR elements. A more detailed description of how to apply the DPSIR framework is provided in the following section.

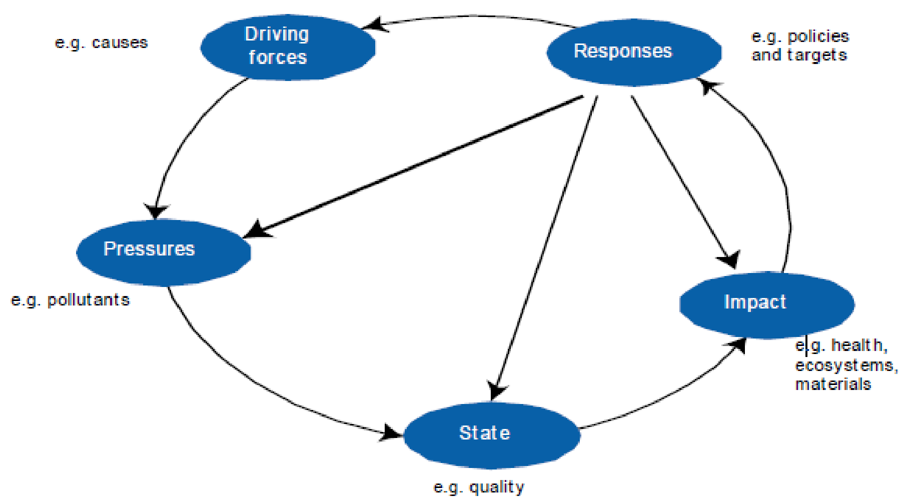

Figure 24. Schematic representation of the DPSIR framework for reporting on environmental issues, as suggested by the EEA (2003).

5.2.2 Use of indicators in the DPSIR

The quantification of the identified DPSIR elements is exerted through the use of indicators (usually more than one per element). This includes anthropogenic activities, impacts on the environment and subsequent responses by society.

- Indicators associated to *drivers* are typically based on economic, social and demographic contexts, such as consumption levels and means of production. Primary drivers usually pertain to population growth and the changes in activities (commercial, agricultural etc.) and demands of the population. This, in turn, applies pressure on the resources and the environment.

- *Pressure* related indicators are typically associated with emissions of pollutants (of various kinds), biological and physical agents as well as use of resources (including land) by humans for development activities. Pressure indicators could include: land area needed for an infrastructure project, other resources required for its construction, CO_2 emissions and freshwater withdrawals.
- *State* indicators aim at describing the conditions in a certain area through the quantification and qualification of various phenomena in the natural environment (physical, chemical or biological). Such indicators could include temperature or humidity levels, biodiversity levels (i.e. fish stocks), GHG (or other pollutant) concentration levels, noise level in a particular spot and forest cover.
- A change in state conditions can be described by *impact* indicators. In order for an indicator to describe an impact, it must directly relate to human functions associated with use of or dependence on the natural environment. For example human health impacts can be quantified here. Another example of an impact indicator is the “rate of loss of terrestrial biodiversity”[4].
- *Response* indicators describe actions taken or proposed by agents in society to address or mitigate these impacts. Measures may be applied that aims to alter a trend or pattern in consumption, increase production efficiency, or improve pollutant removal from a process. Response indicators may also include regulations, e.g. on the ratio of hybrid/electric vehicles in a market or the reduction in the use of plastics. Total amount of environmental expenditures is often used as a broad response indicator (Stanners et al., 2007).

Moving beyond phase/node specific conditions, the links between the DPSIR elements generate a number of intermediate indicators (Kristensen, 2004). These are illustrated in Figure 25.

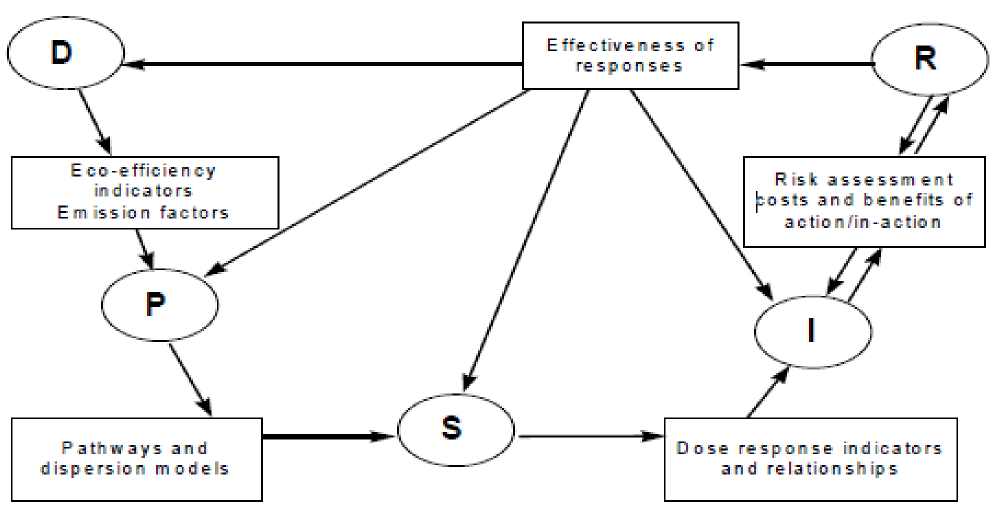

Figure 25. Indicators and information linking DPSIR elements (Kristensen, 2004).

[4] Despite the fact that a human activity related effect can cause a sequence of changes, only the last step is considered an impact indicator. For example, atmospheric pollution can result in a change in the radiation balance (state indicator). The latter could then stimulate an increase in the environmental temperature and subsequently a sea level rise. It is however, only the last link in this chain, terrestrial biodiversity loss that is considered an impact. This is due to the fact that human use of the environment can be directly affected by the availability of (land and) species.

5.2.3 Step by step application of the DPSIR methodology

The following actions constitute the main steps to follow to apply the DPSIR methodology.

Identify issue: The first step towards setting up the DPSIR framework is the issue identification. The issue is in DPSIR terms usually classified as either a State or an Impact. The issue may arise as a public concern, scientific observation or policy assessment and should be jointly understood (and agreed) among relevant stakeholders.

DPSIR narrative formulation: Once the issue has been identified, the DPSIR elements are identified according to the logic presented in 5.2.1. The definition of the narrative (as well as the subsequent steps) is to some extent based on the outcome of consultation workshops where panels of relevant stakeholders exchange ideas and share concerns.

Indicator list: Each of the DPSIR elements is further detailed by deploying a list of relevant indicators. In addition to the indicators used to describe the DPSIR elements, intermediate indicators are also employed to help define the correlation between the DPSIR elements and, subsequently, link the values of the element indicators. This step helps quantify and concretize the DPSIR causal chain.

Weighting of the indicators: When various indicators are used and trade-offs between those are recorded, assigning weighting factors helps illustrate the overall picture in a sensible manner. The weighting factors may be determined by analysts after taking into account the importance the different stakeholders give to the different indicators.

Exploration of alternatives/adjustments to the framework: After the framework has been set up and a complete narrative has been identified, alternative pathways may be explored. This entails changing some of the parameters (i.e. suggest a different response) but could also include adjusting the weighting factors (looking at things from a different perspective).

Decision making: The final step of the process is decision-making. Taking all the insights from the aforementioned steps into account, an optimal solution is selected and potentially adopted by the policy-makers involved. In case no optimal solution is found, negotiation between the decision makers is required in order to reach a compromise alternative.

5.2.4 DPSIR for the formulation of nexus narratives

It has been argued that the DPSIR is a limited approach for analysing the complex interactions between society and ecosystems, but therefore may be most useful if applied in a participatory and systemic 'multi-methodology' (Bell, 2012). As such, it has potential to add value to nexus assessments. In particular, the DPSIR framework can support the formulation of narratives at the early stage of a nexus analyse. Through its use of (weighted) indicators, it can further help clarify and quantify the dynamics within and between nexus domains and their systems.

Many case studies where the DPSIR framework has been used outside the nexus field are water focused studies (see appendix for table of reviewed case studies). The focal point of the analysis is then typically a river basin, a lake or a coast. Other resource systems might be explored – but without constituting the core of the study. Specifically, climate (especially micro-climate) study may be part of the environmental impacts which are usually subject to the PSI (Pressure, State or Impact) elements. Food and energy may be considered but mainly related to drivers (Oesterwind et al., 2016). For nexus assessment purposes, a challenge of the DPSIR framework is its design to focus a single identified issue of concern rather than trying to answer multi-sectorial problems. Serial or parallel DPSIR causal chains may therefore be necessary to cover the 5 nexus domains of SIM4NEXUS. As a starting point, rather than defining one point of interest pertaining to one sector and looking at it in isolation, key questions and needs could be defined for each of the nexus sectors. Then, various possible responses could be explored aiming at answering all the questions in the most optimal way. The complexity of such approach lies on the fact that one indicator could be classified under one DPSIR element when considering one sector but under another when a different sector is studied. For instance, increased food production might be a response to an issue covering food security but at the same time a driver to an issue pertaining to stresses on water resources. This challenge is already acknowledged for non-nexus specific application of the DPSIR, as the same variable may be placed under different elements in different case applications (Gari et al., 2015). With this inherent flexibility, and the multi-dimensional character of the nexus system interdependencies, subjectivity is likely to affect how the nexus narrative is developed. It is therefore crucial that the DPSIR framework in this context is applied through stakeholder participation, as a support tool for consultations and information gathering.

Further, in the modelling phase of the nexus assessment, some bottom-line goals for every system could be set as constraints when analysing the other systems. For example, setting a minimum limit on electricity production should be adhered to when reductions of water allocation for hydropower are suggested. If, however, a limit has been also set on the amount of water available for hydropower, then alternative energy sources (or conventional, depending on the objective of the analysis) must be explored. The employment of (single or suits of) models that consider every sector is crucial to solve such problems and the conceptual modelling framework (i.e. model soft-linking when more than one model is used) must be designed in a way to meet the needs of a specific case.

The role of the indicator definition remains crucial also in the DPSIR application for nexus assessments. Since different models can capture different elements, it is critical to use models capable of analysing the selected indicators. If two (or more) of the models involved can analyse the exact same indicator, it is important to understand the spatial and temporal resolution of each as well as the approach they follow (i.e. simulation or optimization) and then decide which model should be tailored to each indicator.

5.2.4.1 Testing the DPSIR method on selected case studies

To explore the potential practice for nexus assessments, implementation of the DPSIR was tested for two pilot cases: the completed CLEWs assessment of Mauritius and the conceptualization of the case study of Sardinia.

For Mauritius, the nexus analysis was originally conducted without DPSIR. In the following, it is however evident that defining the issue at hand through the DPSIR elements can help summarize the narrative, with challenges and solutions included. The analysis started by defining the issue of concern, followed by a description of the state of systems affected.

FOCAL ISSUE 1: Increasing ethanol blends in ***Mauritius****: a CLEWs challenge*

STATE (Describe the status of the starting system and directly affected system): The current use of biofuels (ethanol) and the land dedicated to cultivate crops that produce or could produce ethanol.

DRIVERS (Indicate what motivates the focal issue): The use of biofuels is motivated by energy security concerns, the potential to reduce fuel imports, sectoral demand from the transport sector, emissions reduction, etc. A driver could also be value chain of the crop (use of by-products in sugar production).

PRESSURES (Identify cross- and intra-system pressures that could result from the overcoming of the challenge): E.g. cross-sector: increase of water consumption for irrigation to increase productivity (if applicable) and/or expansion of cultivated area; competition within the land use system: use of sugar for ethanol production instead of sugar exports (and potential impact on economic activities).

IMPACTS (Describe interactions that can be interpreted as an impact): The increase of the ethanol blend may reduced emissions from the use of fossil fuels in the transport sector, reduction of fuel imports, but also: reduce water availability / water stress due to increased abstraction of water resources; require investments on water desalination for water supply; increase of electricity demand for pumping and/or desalination.

RESPONSES: Are there policies or technical solutions that can affect the state, release the pressures or decrease the impacts on the systems? Policy for the increase of the share of renewable energy sources in the transport sector.

The Sardinia analysis, which started with the definition of the 'state' of each nexus dimension, was conducted using as a starting point the poster of the case study (as presented at SIM4NEXUS workshop in Barcelona, November 2016). This is presented in Table 5. Example of characterisation of the nexus dimensions for the case study of Sardinia using the DPSIR framework (based on poster from November 2016). Note this is an exploratory exercise that was not iterated with the case study. Further information was interpreted and allocated to the other elements of the DPSIR. The next step included the confrontation of the nexus challenges identified at that stage of the case study development. This highlighted what aspects in the DPSIR diagram were directly linked to the challenge and what were either consequences or could have implications to those elements, not only the state itself.

FOCAL ISSUE 2: Water shortages in ***Sardinia*** *("The whole economy of the island gravitates around water availability." Quote from poster)*

STATE: Describe the status of the starting system and directly affected system: The seasonality of precipitation creates the need to store water in (interconnected) reservoirs. Water shortages are common and projected to increase with climate change.

DRIVERS: Indicate what is motivating the need to improve water resources: Sectoral demands compete for water, to supply services to the underlying societal demands of food and energy.

PRESSURES: Identify cross- and intra-system pressures that could result from the overcoming of the challenge: Water withdrawals for agriculture and energy (although hydropower is limited to 3.5% of total net energy production) as well as increased evaporation/evapotranspiration. This constraints the energy sector

IMPACTS: What interactions can be interpreted as an impact of the change in water availability? The pumping of water increases with drought and together with bringing water into pressure for irrigation, this accounts for a large share of the energy consumption in the island (about 5%) with an annual cost around 30M euros. Further, the goal of sustainable local food production is dependent on the provision of water for irrigation.

RESPONSES: Are there policies or technical solutions that can affect the state, release the pressures or decrease the impacts on the systems? Certain responses have been put in place to the general concern of water scarcity – namely storage reservoirs and interconnections between these. Suggested further responses include: increasing renewable, and water-independent energy sources (such as wind and solar).

Table 5. Example of characterisation of the nexus dimensions for the case study of Sardinia using the DPSIR framework (based on poster from November 2016).

DPSIR element→ ↓ Nexus Domain	DRIVER	PRESSURE	STATE	IMPACT	RESPONSE
CLIMATE	• Industrialization (not explicitly mentioned in the poster, inferred)	• Evaporation • Increased or similar rate of GHG emissions • Emissions of other atmospheric pollutants • Climate change	• RET solar and wind are for electricity generation	• Extended and more frequent droughts • Changes in precipitation patterns • Disruption of hydrological cycle • Change of local climate: temperature, precipitation, humidity.	• Reduce emissions – climate mitigation options (expanding the use of RES, energy efficiency)
LAND USE	• Tourism driver for potential land use change: • Ignored archaeological sites; • Generates demand for agriculture / food.	• Biodiversity sensitive to climate change	• Current land cover: 45% forests; 45% agriculture • Biodiversity sensitive to climate • Land used for wind farms (on- and/or off-shore?) • Natura network sites, and Sites of community Interest	• • Energy demand determines use of land (arable or not, it depends on the RES potential) for energy infrastructure.	• Adaptation to climate change (e.g. nature-based solutions, buffer zones, water-energy efficient irrigation systems, agroforestry)
FOOD	• Overall food demand (local and exported (?)) driver for irrigation requirements.	•	•	•	• Sustainable (local) food production – this is a goal
WATER	• Sectoral water demand (agriculture, tourism, domestic)	• Withdrawal of water • Evaporation • Pumping	• Economy of the island is dependent on water • Change on current water availability (water shortage and limitations on use of water are frequent) • Consumption of energy for water pumping • Water storage in reservoirs	•	• Operation of reservoirs (store water in months of higher precipitation, to be used later) • Network of reservoirs
ENERGY	• Electricity demand from water systems (all users of water) • Sectoral electricity demand • Other energy demand (cooling, heating, transport)	•	• Annual energy consumption • Electricity generation surplus exported to the main land • Use of fuels • Import of fuels	• Potential increase of fuel imports • Energy security: dependence of fuel imports	• Need to develop energy infrastructure (e.g. new power plants). • Sustainable tourism • Climate change adaptation • Development plans

6 Literature review on integrated assessments

6.1 Review of nexus Integrated Assessment Modelling (nIAMs)

This chapter expands on historical development of integrated assessments, when these emerged and under which context. The current status of implementation is presented as well as main applications and the use of integrated assessments applied to nexus analyses.

A review of integrated models and approaches undertaken to address the nexus between resource systems and policy

A society and its economy need food, water and energy services. Supplying those services, from resources, are 'delivery chains'. Historically those 'delivery chains' have often been modelled individually. Interactions between many chains were often largely inconsequential—supplies were abundant, and demand was small. Although practical, delineation generally discourages coordination. At best, it misses synergies; at worst it creates conflict. Sectoral interdependencies are increasing; for example, staggering amounts of water is required to produce food and energy. Water systems require (and can produce) large quantities of energy. At the same time, these sectors affect and are vulnerable to a changing climate (and resulting precipitation)**(Howells and Rogner, 2014)**. Given the advances in mapping, methods and tools, integration needs to be carefully, and consciously embraced.

Much effort, of late, has been dedicated to map **(Bazilian et al., 2011; IAEA, 2009)** the linkages between such models, and explicitly represent the 'nexus' between these systems – and the goals they help us realize. And methodologies have been established to include stakeholder processes **(de Strasser et al., 2016)**, notably where resources are shared between countries**(KTH & UNECE, 2014; UNECE, 2014)**. Models that have the underlying capability to explore the inter/intra sectoral (and system) interconnections are generally categorized as Integrated Assessment Models (IAMs).

At a global level, these models have often been used to understand development trajectories and the nexus between interlinked sectors. The so-called IAMs have become important tools in multi-national dialogue and scientific output, such as for the IPCC assessment reports **(Dessens et al., 2016)**. A model tree of the linked models is given below. Many of these have been—or are now being—adapted to national level analysis.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement NO 689150 SIM4NEXUS

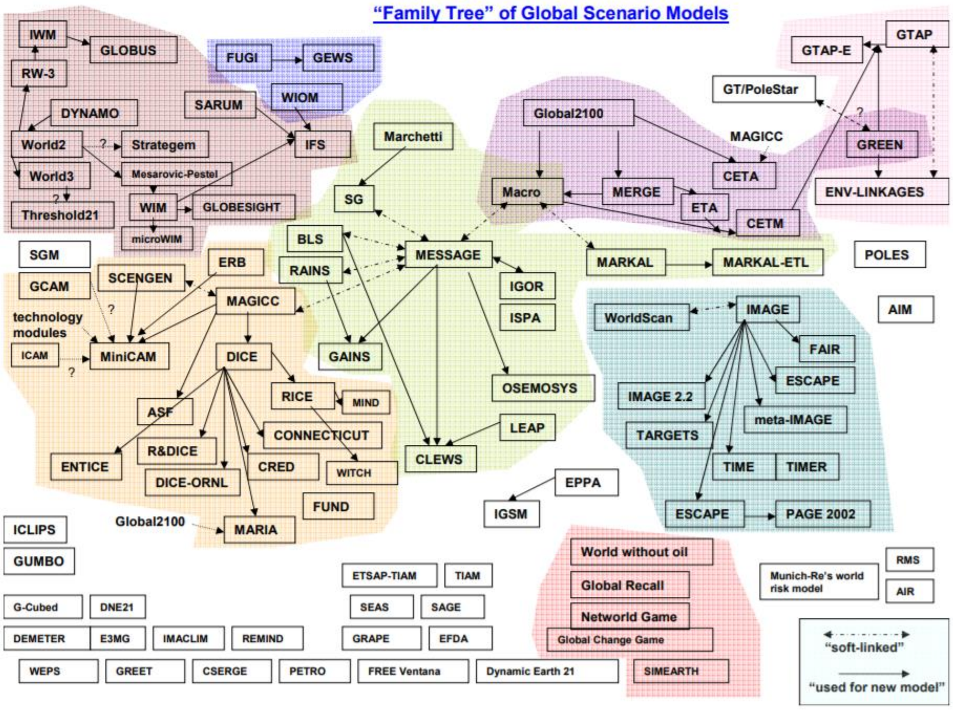

Figure 26: Family tree of scenario models, according to ("Sustainable Development Scenarios for Rio+20 - A Component of the SD21 project," 2013)

By way of background: computer-based models typically fall into two categories—Top-down Macro-Economic (TME) and Techno-BioPhysical (TBP). The former computes money flows and the latter physical flows. There is increasing integration between TME and TBP models. TME models often provide macro data that are important to TBP analysis. For example, to meet energy, water and other physical demands into the future, projections of their use are needed. Those are a function of technological, behavioural, demographic and economic development. Economic development can be a key output of a TME. Thus TME models can help project future requirements needed for a TBP model.

However, integration often ends there. Take the electricity sector for example. Depending on the future power supply mix projected by TBP model changes, the price of delivered power is likely to change. If demand is price sensitive, elasticities should be introduced. Or if it changes the relative competitiveness of energy-intensive producers, economic changes would be important to represent. But, neither elasticities nor economy-wide feedback is routinely examined. Some hybrid models allow this for example with price elasticities (Lavigne, 2017), input-output multipliers(Howells et al., 2010) and simple CGEs (Contaldi et al., 2007).

TME models are used (if appropriately disaggregated) to project demands for purchases of energy, water, food, income or economic activity. Each of those can be translated into demands on physical resources. Those, in turn, can be modelled with appropriate TBP models.

Increasing the integration between TME and TBP models holds strong potential advances. These include:

1. To aid TME models to incorporate more sectoral detail and the nexus between sectors
2. To help TBP models better communicate with fiscal policy analysis (where they do not link to physically connected systems)

3. To help with integrated assessment of policy coherence, technology appraisal and investigation of potential development trajectories.

All three of these are important goals. And they can assist with critical insights—A-E below. These include better alignment of physical realities with fiscal flows. **A. Cost-efficiency**: will improve the trade-off between where to spend scarce government income and transparency. Importantly options are then appraised not only within one but across several line ministries. **B. Policy assessments**: it is important for the policymaker to ensure that the policies adopted are as productive as possible. If multiple outcomes can be achieved by a single policy, the development cost-benefit ratio is improved[5]. Integration can facilitate **C. Policy Harmonisation**: there are many instances of contradictory policies throughout governments[6]. Often overlooked in siloed policy making, such inconsistencies can be more easily unearthed in an integrated assessment. **D. Technology assessments**: technology options can affect multiple resources at once. Appraising them across policy domains will be an important step[7]. **E. Scenario development**: in a sense distinct from the aims above, another goal is to further develop consistent scenarios, to understand future development opportunities. This is important to help understand, for example, whether current development is really sustainable? Are other development scenarios to consider?[8]

6.1.1 Linked models for nexus assessments

The literature points to the need for increased interlinkage within and between TME and TBP models**(Bazilian et al., 2011)**— or at least the development of 'frameworks'**(Howells et al., 2013b)** to help analysts integrate the insights that come from their relative strengths and weaknesses. To describe the linking between models, the terms 'unified-integrated', 'hard-linked', 'soft-linked', 'parameterized' and 'interpreted' are used. These are described below:

i. **'Unified-integrated'** linkages are where a single model covers many sectors and data streams. The data are not iterated between modules but are part of the same whole. When the model solves, all aspects of the model solve. Examples of such models include CLEWs.online**("CLEWS," n.d.)**, MARKAL Nexus**(Ahjum et al., 2018)** and SPATNEX-WE **(Khan et al., 2018)**.
ii. **Linked** between models can take place in at least four ways. These can either be:
    a. **'Hard-linked'** wherein data is automatically shipped between models, and the models are iterated, typically until they converge. Examples of such include the LEAP-WEAP nexus**(Dale et al., 2015)** tool and iSDG**(Collste et al., 2017)**.

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[5] See, for example, Howells & Laitner (2003), which shows (by looking across policy goals) that policies with multiple benefits can easily be identified.
[6] The government of India, for example, provides agricultural subsidies by providing farmers with free electricity; which is used to pump (irrigation) water to grow crops to feed the poor. But those subsidies cause water to be extracted faster than it is replenished, leading to dropping water tables, damaging land and straining the power grid. In time, the very resources needed for the poor will become damaged and unaffordable.
[7] An example is how nuclear power in the UAE could reduce GHG emissions, increase exports of domestic fuels (such as oil, as there is lower domestic demand in the power sector) and provide bulk electricity required for desalinating water. As with policies, an outcome of integrated policy making is to provide a more inclusive assessment of technological options.
[8] Some processes include, for example, the SDG focused voluntary national reviews("Voluntary National Reviews .:. Sustainable Development Knowledge Platform," n.d.) or climate focused Nationally Determined Contribution submissions("Nationally Determined Contributions (NDCs) | UNFCCC," n.d.). In the case of the former the SDG's are explicitly cross cutting. In the case of the latter climate change permeates many aspects of development(Nerini, 2018).

b. **'Soft-linked'** wherein data is moved between tools and iterated manually (often with some level of automation). Examples of this include(**Hermann et al., 2012; Howells et al., 2013b; Welsch et al., 2014**).
c. '**Parametrizing**': by using results from one or more models to inform the parameters of other models
d. '**Interpreting**': by using results from one or more models to inform the interpretation of the other models

For mathematical reasons 'integrated' and 'hard linked' models tend to allow for easier convergence to a common solution (as many iterations can be undertaken). While 'soft linked' models often rely on increased user competence.
A key limitation of multi-sector bottom-up integrated models is that they do not explicitly link with Top-Down Trends-and-Macro-Economic (TME) models. There are however TME models that do have some level of Techno-Bio-Physical (TBP) detail included and vice versa. However, these are typically simplistic, or as detail is added, computational time increases exponentially.

6.1.2 Traditional and new (nexus) Integrated Assessment Models (nIAMs)

This note deviates somewhat from the recent definition that(**"Some Contributions of Integrated Assessment Models of Global Climate Change | Review of Environmental Economics and Policy | Oxford Academic," n.d.)** describes as an integrated assessment model (IAM). Therein an IAM is described as a computer model that "describes the whole world at a minimum, includes some key elements of the climate change integration and climate impacts systems at some level of aggregation" of which approximately 20 exist (ibid. 23). We focus, instead on the growing number (mental and computer) of models used to undertake integrated assessments. This allows us to review not only traditional IAM methods but also new approaches appropriate for a nexus analysis. It also allows us to move beyond global climate focus (without omitting it). For this, the models will be referred to as nexus Integrated Assessment Models (nIAMS), and the focus of the following pages is to explore (review) of how they have been applied – with an emphasis on the integration between models and the resulting nexus of systems that they represent.

To undertake nexus-focused integrated assessments, five approaches have emerged with associated nIAMs:

- Route 1: *Qualitative expert elicitation and mapping* (for example UNECE Nexus **(de Strasser et al., 2016)** methodology and others). These are useful for co-creating knowledge and capacity building. They can focus on individual goals **(Nerini et al., 2017)** and map to others (via the nexus between sectors), or focus on all goals **(Nilsson et al., 2016; Zhou et al., 2017)** simultaneously. It involves mapping relations between policy goals and the systems that underpin them. Often this precedes modelling efforts. It has the strength of building buy-in and the co-creation of knowledge. This process has weakness if qualitative relations are not later quantified. (This typically needs to be done via models.)
- Route 2: *Top-down integrated models*. These focus on integration within a macro-economic model (such as SDGSIM **(Sokolov et al., 2005)**), or passing aggregate information flows between model modules (such as the econometric modules of iSDG **(Collste et al., 2017)**). They have the advantage of covering a large set of SDG indicators. They have the disadvantage of not capturing simultaneous structural interlinkages, in bio-physical systems.

- **Route 3**: *Integrated bottom up-systems models* (integrated, hard and soft linked) focusing on physical interlinkages. Several approaches WEAP-LEAP **(Weitz et al., 2014)**, E4MACS **(Amann et al., 2011)** and CLEWs **("CLEWS," n.d.)** undertake this approach. The strength is that physical systems are being explicitly and simultaneously modelled. There are typically limited interactions with top-down (TME) models.

  Route 4. Linked bottom up top (TBP) down (TME) *hybrid* modelling.
- **Route 5**: *Separate models* (that are either soft-linked, parameterized or interpretively integrated). (Top down and bottom up, with different levels of links. An example of which is the REEEM **("REEEM – Energy Systems Modelling Project," n.d.)**). A weakness of this approach is that significant human capacity is required to simultaneously run these models, ensure that the correct data is being passed between them or their operation and insights are appropriately interpreted. A strength is that an integrated rich multi-disciplinary team is a useful asset in policy analysis.

The choice of which modelling route to choose is inexorably linked to the purpose and some extent the modelling and human capacity resource available. With that in mind, the aims of nIAMs have varied, and include:

1. Simply understand the relationships between policy goals and sectors to manage processes and coordination bodies?
2. Attempt to pull together a set of policies across governments into a single quantitative narrative? (Which may be distanced from deep individual sector planning).
3. To develop national coherence in policy-making including integration of siloed ministerial planning?

The purpose will determine the criteria and relative importance of criteria when choosing a modelling route.

Allen et al. **(Allen et al., 2016)** provide one set of criteria[9] to judge top-down integrated models (route 2) used for integrated Sustainable Development (SD) analysis—the nexus of their systems and the SDGs in particular. As noted by Schmidt-Traub et al.**(Schmidt-Traub et al., 2017)**, the SDG indicators were politically selected, and they may not be the most appropriate for national policy. Even when the goal(s) may be similar[10], it has helped create important impetus for comprehensive development mapping, and modelling—with modelling evolving beyond the historically climate focused IAMs.

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[9] The criteria useful for defining models useful for SDG planning models included:

Criteria related to Scientific Strength

1. Integrated/Inter-linkages/Inter-disciplinary, 2. Dynamic & long-term perspective, 3. Systems-based yet realistic/meaningful, 4. Transformative, 5. Global-local perspective, 6. Participatory, transparent and legitimate

Criteria related to Model Application and Usage

1. Policy relevance, scenario analysis, & policymaking guidance, 2. Applications, visibility, flexibility – in both developed & developing countries, 3. Ease of use/user friendliness, 4. Cost, time and effort (for model development)

[10] Consider an industrializing country. Its energy intensity increase may well be outstripped by any energy efficiency improvements. Yet target 7.3 on energy efficiency is measured by indicator 7.3.1-namely energy intensity.

	1. Integrated	2. Dynamic & Long-term	3. Systems-based & meaningful	4. Transformative	5. Global-local perspective	6. Participatory, transparent, legitimate	7. Policy relevance/ scenarios	8. Application, visibility, flexibility	9. User friendly	10. Cost, time and effort
Threshold 21	2.920	2.546	3.807	3.840	1.914	4.456	2.565	4.671	3.060	0.799
LowGrow	0.550	0.252	0.562	0.594	0.256	0.202	0.387	0.151	1.052	0.799
MAGNET	0.293	1.130	0.278	0.210	0.357	0.256	0.387	0.848	0.205	0.389
Polestar	2.920	2.546	0.837	1.174	0.688	1.439	0.567	0.477	2.111	0.799
IMPACT	0.550	1.130	0.837	1.174	1.037	0.483	2.565	1.565	0.403	2.310
International Futures	2.920	2.546	2.918	3.840	2.697	2.030	1.233	1.565	3.060	3.286
InVEST	0.293	0.252	0.389	0.336	0.688	3.379	0.567	2.879	1.052	2.918
EC4MACS	1.550	0.748	2.115	1.174	4.318	0.909	2.565	0.497	0.554	0.227

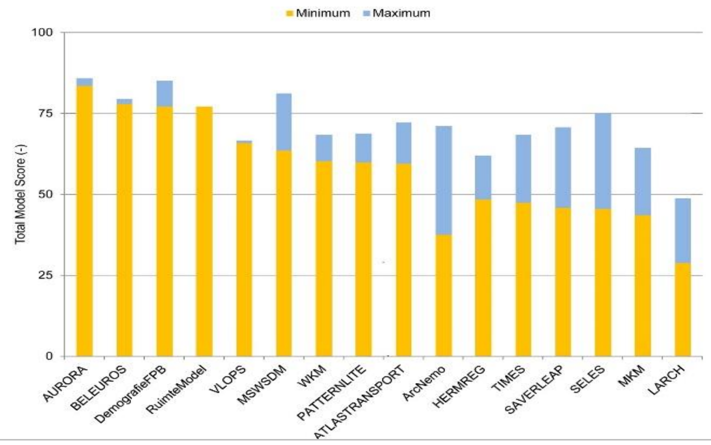

Figure 27: (Top) nIAM ranking based on Allen et. al31 including broad interlinkage between sectors (i.e. nexus) and SDG coverage—and (Bottom) model choice based on De Kok et. al33 including 'bottom-up' stakeholder demand

In contrast, an approach driven by the stakeholder demands and local policy imperative may lead to a different approach. For example see De Kok et. al(de Kok et al., 2017), where an example of Flanders is discussed; it is a local setting with high data and human capacity availability. Preferred to a single model, was running a set of models with complementary strengths. These involved common parametrization and interpretation (i.e. *Route 5*).

Approaches used in a snapshot of nIAMs are summarized in the next section.

6.1.2.1 nIAM Route 1 – Mapping interlinkages

The first route focuses on expert elicitation and mapping interlinkages between SDGs and development objectives. On the one hand, this might focus on explicit quantification of those linkages ("SDG Interlinkages Web Tool," n.d.) wherein specific targets or indicators are related. These might vary by setting.

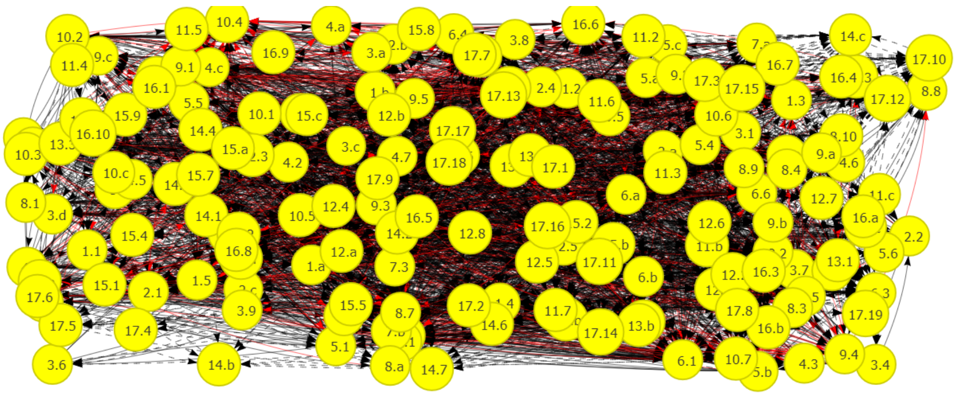

Figure 28: Taken from the "Sustainable Development Goals, Targets and Indicators" project ("SDG Interlinkages Web Tool," n.d.), which focuses on SDG indicators, data collection and the analysis of the interlinkages of SDG targets.

On the other hand, there are expert elicitation and mapping processes. In these, linkages between tools are mapped with experts and based on their importance; further analysis is both required and identified. An example is Fuso-Nerini et al **(Nerini et al., 2017)**. A hybrid approach proposed by Nilsson et al. allows for expert-based subjective scoring **(Nilsson et al., 2016)**. Both the methodologies mentioned above rely on high levels of expert input. However, these approaches cannot be used for more than indicatively exploring relations and uncovering issues that need to be included in quantitative analysis.

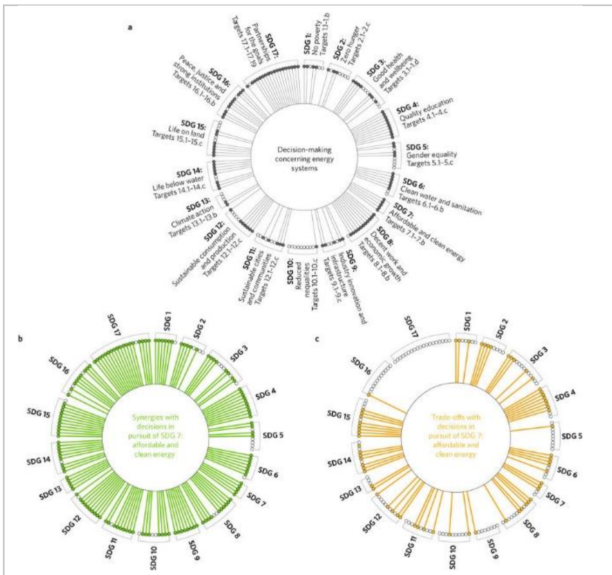

Figure 29: SDG mapping process from Nerini et. al **(Nerini et al., 2017)**.

GOALS SCORING
The influence of one Sustainable Development Goal or target on another can be summarized with this simple scale.

Interaction	Name	Explanation	Example
+3	Indivisible	Inextricably linked to the achievement of another goal.	Ending all forms of discrimination against women and girls is indivisible from ensuring women's full and effective participation and equal opportunities for leadership.
+2	Reinforcing	Aids the achievement of another goal.	Providing access to electricity reinforces water-pumping and irrigation systems. Strengthening the capacity to adapt to climate-related hazards reduces losses caused by disasters.
+1	Enabling	Creates conditions that further another goal.	Providing electricity access in rural homes enables education, because it makes it possible to do homework at night with electric lighting.
0	Consistent	No significant positive or negative interactions.	Ensuring education for all does not interact significantly with infrastructure development or conservation of ocean ecosystems.
–1	Constraining	Limits options on another goal.	Improved water efficiency can constrain agricultural irrigation. Reducing climate change can constrain the options for energy access.
–2	Counteracting	Clashes with another goal.	Boosting consumption for growth can counteract waste reduction and climate mitigation.
–3	Cancelling	Makes it impossible to reach another goal.	Fully ensuring public transparency and democratic accountability cannot be combined with national-security goals. Full protection of natural reserves excludes public access for recreation.

Figure 30: scoring system taken from Nilsson et. al **(Nilsson et al., 2016)**.

6.1.2.2 nAIM Route 2 Top-down Trend-Macro-Economic (TME) integrated models

These models employ top-down (CGE, Econometric or Input/Output) approaches and integrate them, either by including some level of 'bottom-up' representation, and by extending the coverage to more than one sector. In several instances, General Equilibrium models are expanded to include aspects of bottom-up models. An example is the Integrated Global System Model (IGSM) **(Sokolov et al., 2005)**. Similarly, econometric models may include simplified bio-physical modules. A notable example is E3GM**(Ekins et al., 2012)** of Cambridge Econometrics. In order to accurately include GHG production to account for mitigation, it includes a diffusion-based representation of the power and transport sectors using the Future Technology Transformations (FTT) diffusion model.

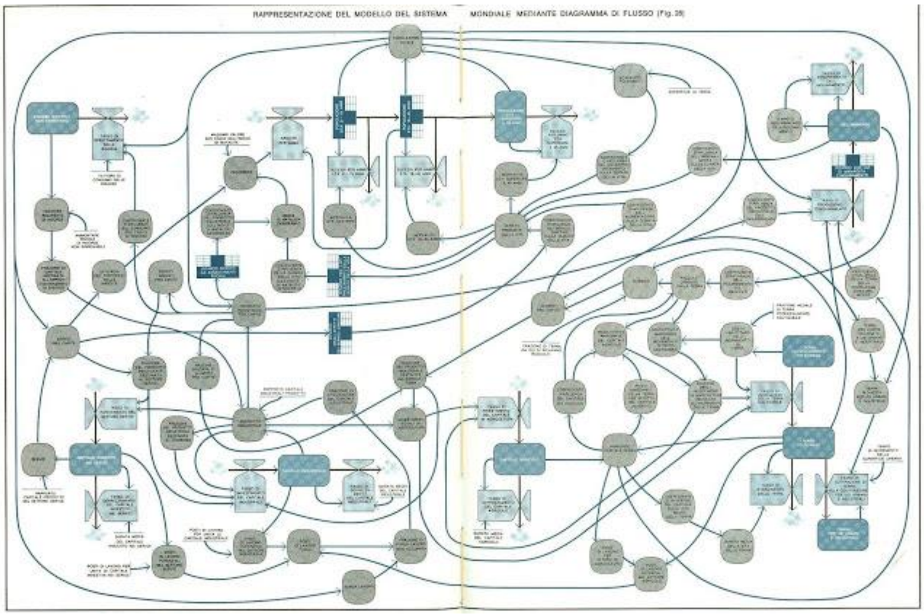

Figure 31: A scan from the Limits to Growth**(Meadows, 1972)** World3 model description.

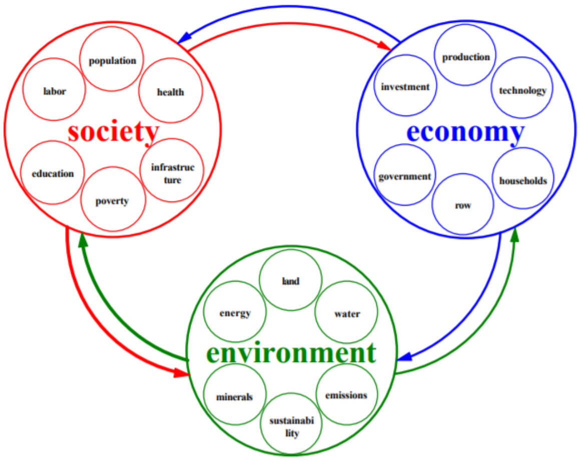

Figure 32: a simplified version of the Threshold 21/ iSDG (Collste et al., 2017) of the Millennium Institute.

Input-output models have been extensively applied in this space. Both as either economic or bio-physical models. Biophysical IO models have been extensively used in life cycle assessment studies. These are being systematically extended to include increasing impacts. A common criticism of these models is the fixed nature of the production functions used. Some approaches, such as the MuSAIM tool **(Gerber and Scheidel, 2018)**, combine both economic and biophysical IO models. This allows for various integrated policy analysis. Applications for such exist in Mauritius **("The Republic of Mauritius," n.d.)**. They are particularly useful if there is no expected change in the structure of production. However, this is changing, and cognizance thereof must be made.

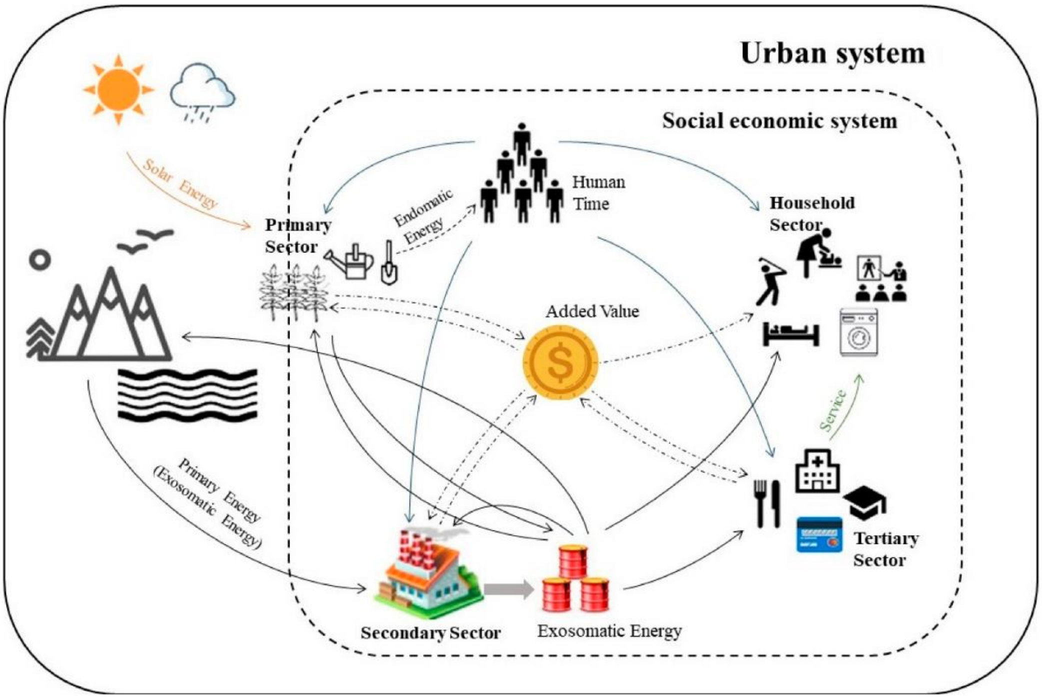

Figure 33: An illustration of relationships modelled with MuSAIM, for an application in a Chinese city(Wang et al., 2017).

6.1.2.3 nAIM Route 3 Integrated bottom up Techno-Bio-Physical (TBP) models

Integrated bottom-up systems models exist that are either hard-linked or soft-linked. Examples of hard-wired models include the Foreseer **(Allwood, 2015)** tool of Cambridge University, the WEF Nexus tool of Texas A&M **("Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making: Water International: Vol 40, No 5-6," n.d.)**, and CLEWs/OSiMOSYS.org, to name a few. All of the above have been applied to several country settings. Being 'hard-wired', they are consistent and are enabled to map deep bio-physical relationships. The first two are accounting models, and the latter—optimization.

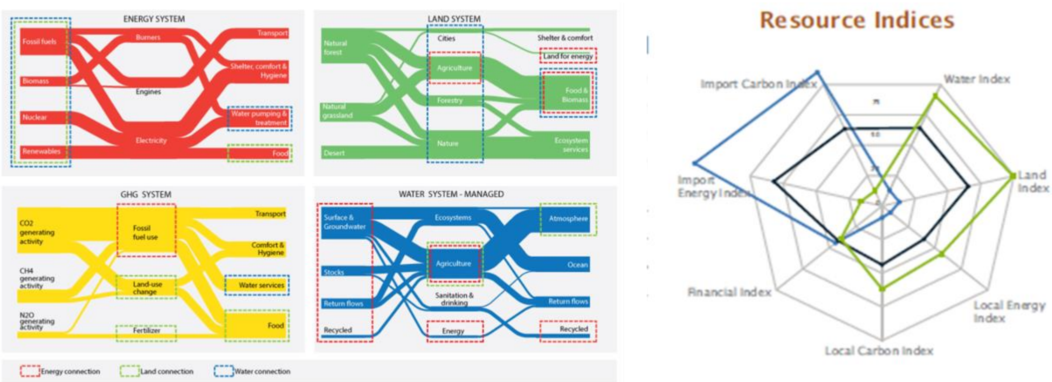

Figure 34: Engineering simulation of the (left) Foreseer**(Allwood, 2015)** tools from Cambridge University and (right) Texas A&M's WEF nexus tool**("Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making: Water International: Vol 40, No 5-6," n.d.)**

Hard-linked integrated models include WEAP-LEAP nexus tool of SEI. WEAP allows for a detailed water allocation analysis taking into account water networks. While LEAP is a detailed energy-environment accounting tool. As with Foreseer and OSiMOSYS-CLEWs, both allow for detailed specificity. However, unlike the latter, the WEAP-LEAP nexus tool consists of two separate models. They are run simultaneously until key variables (such as river water flows and hydro electricity production) converge.

Soft linked approaches have been employed with the use of the CLEWs-Framework (rather than OSiMOSYS-CLEWs). Applications exist for Burkina Faso **(Hermann et al., 2012)**, New York City **(Engström et al., 2017)**, Mauritius **(Welsch et al., 2014)** and others.

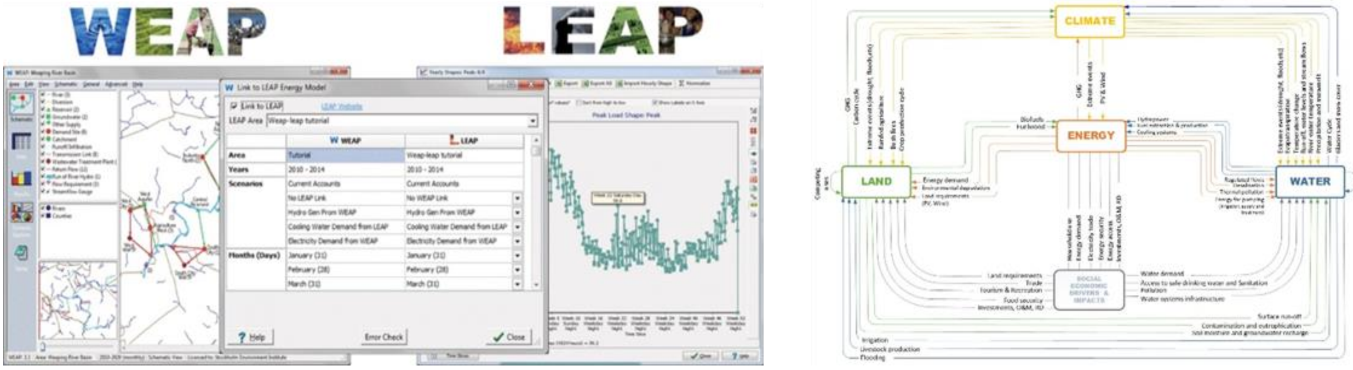

Figure 35: (left) WEAP-LEAP nexus tool(Dale et al., 2015) and (right) CLEWs framework of UNDESA, UNDP, KTH and others("CLEWS," n.d.)

The TIMES-Integrated Assessment Model (TIAM) and CLEWs-GLUCOSE tools have been developed with simple land, water and energy balance representations that are set up to meet demands for food, energy and water. Those demands can be either endogenous as well as exogenous. In the case of the former, detailed multi-region representation is made. In the case of the latter, material flows are included.

6.1.2.4 nAIM Route 4: Hybrid integrated (TME-TBP) top-down and bottom-up models

The IGSM framework consists of bottom-up 'bio-physical' sub-models that pass information to a detailed CGE. In the case of the latter, there is a focus on detailed electricity dispatching characteristics and has been applied at the national level in Mexico. Related examples include WITCH **("WITCH A World Induced Technical Change Hybrid Model on JSTOR," n.d.)** and Phoenix **("Phoenix | Joint Global Change Research Institute," n.d.)**. The latter generally applied at the global level, with regional disaggregation.

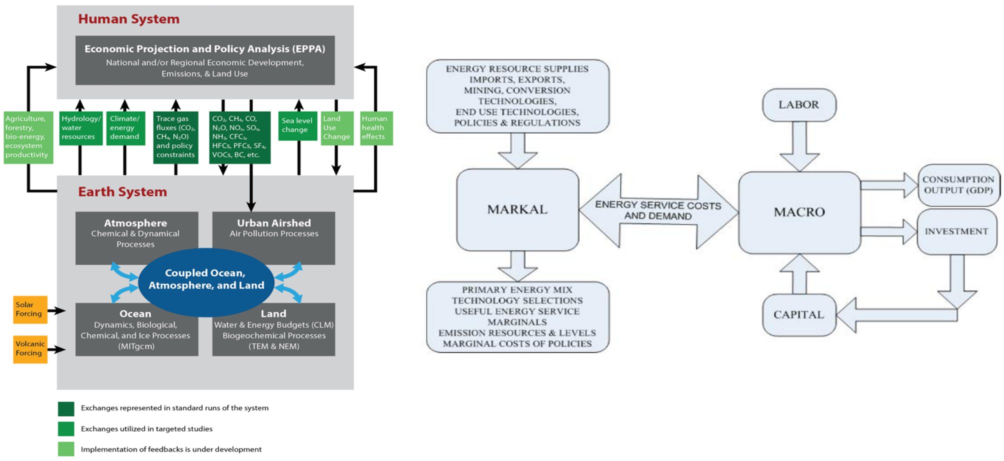

Figure 36: Representations of (left) the linked top town Integrated Global System Model (IGSM)(Sokolov et al., 2005) of which a national level model has been developed for Mexico(Veysey et al., 2016) of MIT and (right) MARKAL-MACRO taken from(Sarıca and Tyner, 2016).

Much like IGSM, the IMAGE framework of PBL moves beyond a limited integrated model to include coupling with the macro-agro-economic model—MAGNET. Carbon cycles are captured via a hard link to LPJmL. GLOBIO is used to assess ecosystem impacts. GLOFRIS incorporates flood risk. Hydrological balances are captured with PCR-GLOBWB. Nutrient flows are captured with GNM. And, the framework is applied to several settings.

6.1.2.5 nAIM Route 5: Multi-model (TME-TBP) systems with softlinks and without interlinkages

All integrated models have strengths and weaknesses. Running a single model simplifies the work of the analyst. Clearly, linking information flows requires careful consideration of the sub-model differences. Running multiple sets of models with key strengths, chosen to tackle the problem at hand can provide increased insight into complex problems/behaviour. However, these come with increased resource requirements, both regarding sectoral knowledge and modelling skill.

Examples of multi-model ensembles include the REEEM (“REEEM – Energy Systems Modelling Project,” n.d.) project, IAMC (“IAMC — Integrated Assessment Modeling Consortium,” n.d.), EMF (“Energy Modeling Forum,” n.d.), etc. These allow for a range of outputs to be compared and rationalized, but do not necessarily limit the richness to be gained by employing case appropriate modelling tools.

This is a key characteristic of the SIM4Nexus project.

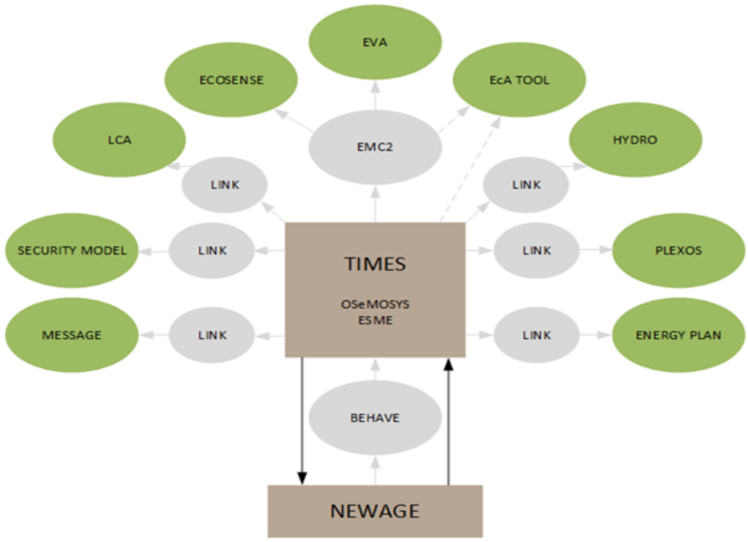

Figure 37: A schematic taken from the EU-DG Research funded REEEM("REEEM – Energy Systems Modelling Project," n.d.) project.

In the REEEM project, a complex set of models are linked. A CGE and energy systems model iterate selected data. Life cycle assessment, pollution dispersion, hydrological, ecosystem service, behavioural and other models are run in parallel, and some key data is shared to ensure aspects of a shared/consistent narrative.

6.1.3 Conclusions

This note reviews the integration of models for assessing several systems and the nexus between them. It includes integration between model types as well as the systems they represent. A growing set of integrated models (both qualitative and quantitative) is emerging. Their development is being driven by the advantages they bring to policy making.

A popular focus of the application of a class of IAM's has been to inform climate change related processes. While the promise of policy efficiency drives the much recent integrated assessments. To explicitly include the two, the term nexus Integrated Assessment Model or nIAM is used to guide the review.

A number of nIAM configurations are reviewed, and routes that their development has followed is described. They include that of qualitative mapping, top-down macro-economic (TME) models, bottom-up techno-bio-physical (TME) models, integrated TME-TBP models and the running of model ensembles. Further, the various methods of integration were identified. They include 'unified integrated', 'hard linked', 'soft linked', 'parameterized' and 'interpreted'.

7 Assessment of the nexus in the SIM4NEXUS case studies

This chapter summarises the current status, preliminary outcomes and future work of the case studies in SIM4NEXUS. This relates to how nexus interlinkages and challenges have been identified and represented in the thematic models, and how the quantitative analysis informs on the critical systems interactions subject to baseline, reference and scenario conditions. Noteworthy is that since the work is ongoing, the work presented here is preliminary and will be updated as part of the Deliverable 1.5 "Framework for the Assessment of the Nexus" due in month 48.

Furthermore, the work presented here is based on compilation of information from interviews (under WP5), the Deliverable 5.2 and WP3 Milestone number 18 "Conceptual Complexity Science Tools Finalised", as well on the early poster presentations during project meetings in Třeboň and Barcelona in May/June 2017 and November 2016 respectively. The overview presented results from a compilation of key messages and outcomes in the aforementioned deliverables and events, and it is not envisaged here to provide an extensive description of the status of each case study. Instead, the chapter aims to draw insights from each of the case studies' work in order to inform on the SIM4NEXUS Framework being developed.

The chapter is split into different sections summarizing the case studies as following: firstly, the interlinkages and nexus challenges and their identification are presented. This is followed by a status update on the conceptual mappings and how these cover the nexus domains. The use of the thematic models in addressing the nexus challenges is given section 7.1.3; followed by the role of policy analysis in the overall work in section 7.1.4. Lastly, a summary with conclusion and further work is presented in the last section of the Chapter, 7.1.5, which leads way to the forthcoming work in the case studies.

7.1.1 Identification of interlinkages and nexus challenges

This section summarises the process of defining nexus challenges in each case study. Case studies research questions and aims are different, for which challenges naturally differ. The definition of nexus challenges is a process that feeds from the understanding of each system in the case study context, with support from literature, and, very importantly, the participation of stakeholders from different sectors of the nexus domains. This sub-section outlines the relevant interlinkages in each case study, how stakeholders are involved in the assessment, the use of literature to support the identification of interactions and, lastly, how the nexus challenges were defined.

7.1.1.1 Compilation of most relevant interlinkages between nexus domains in each case study

Presented below, in Table 6, is a compilation of nexus interlinkages that builds from Deliverable 5.2 (Floor and Fournier, 2017). The interlinkages are better defined and explained in section 7.2 where the conceptual complexity science model is presented. Section 7.1.4 also presents a selection of case studies whom have detailed their nexus interlinkages in terms of which objectives will be addressed in relation to these in the thematic models. Note that, the Germany-France Transboundary case study is here merely summarised and presents selected interlinkages due to that the identified ones are too extensive to be covered here (please see D5.2 for a complete diagram). In addition to the nexus domain interlinkages presented in the table, other systems such as those in the socio-economic context or other systems such as ecosystem, have also been stressed to have importance by several case studies. The factors not considered here are important to keep in mind, as these are externalities can influence the system itself, and despite not integrated in the models, it shall be regarded as equally important, yet partially out of the scope of this study.

Table 6. Compilation of relevant nexus interlinkages between nexus domains in the SIM4NEXUS case studies.

	W → L	W → E	W → F	W → C	L → W	L → E	L → F
Andalusia	Irrigation need, soil erosion and salinization	Water for hydropower production	Water for irrigation	Evaporation	Competition of water resource between e.g. forest and agriculture	Land availability for energy production	Competition of land availability, e.g. agriculture and urban areas
Sardinia		Hydropower production	Storage of water may limit food production (crop yield)				
Southwest	Sludge disposal	Energy demand for water transport and treatment		Process and fugitive emissions	Raw water quality and surface drainage	Waste transport fuel demand	Land utilisation for agricultural production
Latvia			Water quality affecting food production		Nutrient leaching to water courses. Water conservation and protection	Land availability for bioenergy	
Greece	Water availability for irrigation, urban areas etc.	Hydropower production	Water for food production. Water quality impacts on food quality/quantity	Evapo-transpiration	Water quality and quantity	Land availability	Land availability
Azerbaijan		Water for cooling, hydropower, fuel extraction and production	Irrigation requirements				
Sweden	Intensification in extreme hydrological events	Intensification in extreme hydrological events			Reduction of quantity and quality of water in forestry practise		
Netherlands	Shortage of fresh water limits the productivity of land	Water is a production factor for energy production (biomass)			Agriculture impact on water quality	Availability of land for food crops and fibre	Availability of land for food crops

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement NO 689150 SIM4NEXUS

DE-FR	Flooding threatens settlements, water bodies work as purification and control of water; Vegetation cover and land fertility depends on the water availability (and quality) in the soil. Ecosystems – Water: Aquatic ecosystems depend on water quality and quantity; are influenced by infrastructure (e.g. hydropower plants, cooling systems, navigation). Aquatic ecosystems can have a buffering effect on pollution; mitigate water related challenges (e.g. flood mitigation, heat island effect).	Water requirements in power sector. Water is required for electricity generation (electricity is produced from hydropower, cooling systems in nuclear and/or thermal plants, but also cattle / industrial sludge, and biomass) Environmental flow regulations (flow regime, hydropower operation, cooling-related withdrawals).	Irrigation demand, aquaculture, quality of water factor for quality of food; Water for food processing and production: industry (processed food), cattle (meat) and irrigation (crops, vegetables, fruits); River parameters are important for fish population in rivers (either wild or in ponds); Healthy aquatic ecosystems benefit fish production.	Water bodies can reduce heat; Aquatic ecosystems play a role in the C cycle.	Irrigation need (forestry). The land use (e.g. urbanisation) influences the water balance (runoff / infiltration); Pollution of water bodies caused by land quality (soil components); State of the land (land quality as fertile, eroded, polluted) influence water balance (e.g. run-off) and water quality; Land use and management interferes with aquatic ecosystems.	Activities (agriculture, industries etc.) requiring energy, biomass potential (forests, crops, and crops' waste); Land requirements for the energy sector activities; Energy production competes with other uses for forest / crop / grass surfaces.	Availability of land for agriculture (food production); Fertile grassland and cropland are needed to grow food and raise livestock.
DE-CZ-SK	Flooding, droughts		Food production demanding water	Cooling effects from water bodies	Water storage capacity	Bioenergy	Land availability for agriculture
European							Land-use change from agricultural to, for instance, bioenergy land
Global		Power production sector	Irrigation		Water requirements for industrial, urban and other activities	Land availability for bioenergy or renewable energy expansions	
	L → C	E → W	E → L	E → F	E → C	F → W	F → L
Andalusia	Carbon sink	Desalination, pumping of groundwater,	Renewable energy instalments	Energy efficiencies in agricultural practises	GHG emissions	Groundwater overexploitation, fertilizer pollution	Soil pollution and productivity losses

		pressurise irrigation systems					
Sardinia		Water pumping			GHG	Irrigation systems, requirements and type of schemes	
Southwest	Greenhouse gas emissions and sequestration from land-use					Irrigation, livestock and food processing demand (also F -> E)	
Latvia		Water for hydropower production	Bioenergy requirements		More Renewable energy technologies will reduce GHG		Land requirements to meet food demand
Greece	GHG emissions or carbon sink	Water pumping, purification, heating etc.	Fossil fuel production and renewable energy technologies operation	Processing and transportation of food products	GHG	Water demand in food production (e.g. irrigation)	Land area requirements, competing other land-uses
Azerbaijan		Irrigation, water supply, water/waste water treatment			GHG	Fertilizers and intensive agriculture affect quality	
Sweden		Hydropower production demand	Bioenergy demand		GHG		
Netherlands		Water pumping, cooling water, energy for water management, fertilizers and pesticide in biomass production	Land use for energy production, ILUC	Competition between biomass and food production	GHG	Water footprints of food consumption in the NL	Changes in diets (protein) affect land use; Land footprint
DE-FR	Emission and sequestration of CO2, cooling effect through land cover, albedo effect	Energy is needed for water abstraction, purification and treatment. Aquatic ecosystems can be threatened by energy production (nuclear and hydro) and energy consumption through transportation.	Occupation of land for resources extraction and power technologies. Waste generation from energy sector activities (tailings, ash deposits). Soil contamination. Energy is required to restore degraded land.	Competition between food security and biofuels; Energy requirements in food processing, storage and transportation.	GHG (energy generation from coal, sludge, distribution and consumption).	Irrigation and precipitation needs; Livestock water demand; Agro-chemical contamination affecting water quality; Contamination from food production,	Cropland requirements as response to food demand. Food production generates pollutants and erosion (intensive farming only) to the land.

						processing and consumption; Intensive fish production threatens aquatic ecosystems (nutrients but also genetic competition).	
DE-CZ-SK				Competition between food and bioenergy crops		Reduced evapo-transpiration from ripe cereals, increasing sensible heat	
European	Afforestation	Decreasing water quality and quantity as results of bioenergy, hydropower production	Deforestation as result of bioenergy production	Increasing bioenergy demand conflicting food security			
Global	Afforestation		Land requirements	Bioenergy competing food security	Bioenergy as mitigation option to CO_2 removal		

	F → E	F → C	C → W	C → L	C → E	C → F	Other
Andalusia	Energy requirements (processing, transport, etc.)	Emissions and absorption of GHG	Water availability	Soil erosion	Solar and wind potential	Crop yield and harvesting date	
Sardinia			Run-off and evapotranspiration rates		Heating and cooling demand. Wind and solar potential		
Southwest	Irrigation, livestock and food processing demand (also F -> E)						Land to societal demand (within land use): land utilisation of the housing and housing demand
Latvia	Food waste for energy usage				Heating and cooling demand		
Greece	Production driven by fossil fuels. Food waste for energy production.	GHG	Precipitation, evapotranspiration and run-off. Flood risks	Floods, landslides, forest fires, hailstorms and heat waves.	Cooling and heating demand. Energy resources availability and potential	Crop production and yield	

Azerbaijan			Water availability			Crop production and yield		
Sweden				Increasing temperature will increase forestry production				
Netherlands	Energy used for food production; food crops for renewable energy.		Availability of fresh water					
DE-FR	Food waste as an energy source (methane, biodiesel from oil and grease-rich food); crop and cattle raising waste can be used for energy generation; biofuels from crops.	Soil management, fertilizers production, albedo effect and loss of other climatic regulation services (e.g. wetlands); CO2/CH4/N2O « GHG » emissions from food production (food crops' cultivation and livestock);	Precipitation patterns, flood and droughts. The climate influences the water balance (run-off, evapotranspiration, infiltration), as well as the water temperature; Aquatic ecosystems are dependent on temperature, rain water and GHG Concentrations.	Floods, droughts, landslides, heatwaves, hailstorms. Soil fertility is influenced by climate conditions (temperature, humidity, precipitation).	Wind and solar potential, heating and cooling demand,	Crop yield and productivity (due to higher temperature and carbon concentration in atmosphere), water availability for food and livestock, water temperature affecting aquaculture	Socio-Economy -> W: water demands (withdrawals, discharge, net consumption); demand is influenced by climate condition; Socio-economy -> E: energy demand (regional, national, and international (neighbouring countries); Socio-economy -> L: Human settlements and activities influence land use and management. Socio-economy -> F: food demand and consumer choices influence the food sector (both locally and internationally via food trade). Socio-economy -> C: climate parameters influence the economic development (production, consumption, etc), which in turn affect GHG emissions.
DE-CZ-SK					Wind and energy potential		

European		GHG					
Global			Increasing water temperatures	Increasing temperatures affecting ecosystems (both land and in water)		Climate change mitigation may cause food prices to increase, e.g. afforestation causes land and water to becomes scarce	

7.1.1.2 Use of literature, SIM4NEXUS milestones and deliverables

As part of WP1 activities, Deliverable 1.1 “Scientific Inventory of the Nexus” compiles an extensive list of interactions between nexus domains. At the point of interviews held in November 2017, the case studies of Greece and Transboundary German-France indicated having used Deliverable 1.1 to identify nexus interlinkages in their case studies, step which then assisted the definition of nexus challenges. Other case studies indicated the use of other literature in combination with the expertise of the group leading the case study as well as in result of interactions with stakeholders.

7.1.1.3 Stakeholder engagement and participation

As part of each case study, workshops with stakeholders are to be held in order to engage experts in the topics of each case study and to, among others, received insights on the nexus interlinkages identified and verify modelling results. Case studies have until the date of this report held their 1st workshop, except Azerbaijan, all at different dates and also all under different settings. With settings it is meant with difference in length of workshop, what is covered and also how stakeholder were engaged before, during and after three workshop. For instance, the Andalusian case study prepared a questionnaire in order to inform on the nexus interlinkages identified and to receive feedback from the stakeholders prior to the workshop.

Notable is the complexity the inclusion of stakeholder brings. In other words, the larger the geographical area, the more stakeholders there are; similarly, the larger the research objective is in terms of challenges found, the more expertise is required and available. For instance, the European and Global case study have both a significantly different scale of their analysis, compared to other case studies. This implies a larger difficulty in involving stakeholders from all sectors and all countries. Furthermore, stakeholder tends to identify and discuss around challenges, which either are in their field, or closely related to it; which implies the necessity of having a wide spectrum of stakeholders that cover all systems and sectors in order to not miss any important aspects. On the other hand, the expertise of the stakeholder have been proven to be important in order to validate, and elaborate further on, the first conceptual models drawn for the resources systems of the case study.

In terms of number of workshops, this also varies between the different case studies. This can be explained by several factors, one of them being when the project started in more practical terms, e.g. some case studies are advanced because they started earlier, whereas others are more behind due to difficulties in setting of the project. For instance, Azerbaijan has not had its first workshop yet, whereas Netherlands have already planned for having four during the project and have outlined its objectives. Setting up the projects and engaging stakeholder can be argued to be complex as it is determined by the region, knowledge in who to invite as well as other external factors.

Table 7 summarises the current status of the 1st workshop that has been held, as well as preliminary plans for the 2nd workshop, mostly planned for 2019.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement NO 689150 SIM4NEXUS

Table 7. Overview of stakeholder participation in each case study.

	Date of 1st workshop	Stakeholder representation	Challenges identified	Activities performed prior to the workshop	What was covered in workshop	Planned date of 2nd workshop and objectives
Andalusia	26th of October 2017 in Seville	Agencies, ministries, research associations, universities from water, energy, agriculture, environment areas	Stakeholders may not agree, or think alike, on nexus challenges	Semi-interview: Seven questions guiding questions to get stakeholders understanding of nexus challenges	Identification of nexus relationship and challenges	Date not available. Validating model results and using the Serious game
Sardinia	Was planned for January 2018. Focus group on: 26th of May 2017	Eight stakeholder representing generally water, agriculture and food authorities, unions, consortiums	Silo thinking of stakeholders	Contact with three key stakeholders for Water and Energy.	Focus group: Definition of conceptual mapping for Sardinian case study. Identification of policies to drive analysis (post-interviews for policy coherency was performed in December 2017)	N/A
Southwest	Previously scheduled for 25th of January 2018	16 participants from ministries, universities, business sector, NGO's and others	N/A	N/A	Discussion on pathways, nexus interlinkages, identification of most critical issues, data availability and accessibility	TBA. Discuss and validate first model outputs and SDM
Latvia	15th of November 2017		N/A			
Greece	23rd of June 2017	15-20 participant s from: ministries and public organizations, representatives of the business sector and academic institutions	N/A	Interviews to gain knowledge from stakeholders on nexus-related policies	Nexus interlinkages, conceptual mapping, policy goals and instruments. Post-questionnaire was send out with complementary questions	TBA. Validate policy coherence study.
Azerbaijan	Planned for September 2018		-	-	-	1st workshop: validate/confirm nexus interlinkages, polices and scenarios Provide data and suggest KPI's.

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Sweden	18th of April 2018	From NGO's, consultancies, municipalities, researchers, governmental agencies	Receiving response from stakeholders. Not all sectors were fully covered	Questionnaire about the interlinkages for validation and elaboration send to stakeholder not able to participate	Nexus interlinkages and challenges, policy identification and validation	Preliminary fall 2018. Validate first model outputs
Netherlands	26th of October 2017	14 stakeholders ranging from governmental, NGO's, agencies consultancy to researchers,	Coverage of stakeholders (waste, agriculture and nature sector was missing in 1st workshop)	15 interviews with stakeholders in the perspective of the importance of biomass in Netherlands	Opportunities and challenges with biomass	Previously set for April/May 2018 Preliminary results and policy coherency
DE-FR	Previously though for 1st semester of 2017	Interviews: range of stakeholder covering all sector and from research, business, government, NGO's etc.	Workshop not held due to, among others, difficulties in identifying stakeholders, and understanding of the project. Further, language, as two languages are necessary	Interviews with stakeholders during 1st semester of 2017 – helped to frame the case study and understanding nexus challenges and sectoral policies	N/A	N/A
DE-CZ-SK	March 2018	7 stakeholders from Germany and Slovakia, more than 7 more Czech Republic	Organizing a case study involving stakeholders that need to travel far	N/A	N/A	N/A (will take place in Slovakia)
European	2nd & 3rd of October 2017 (Internal)	Internal partners of SIM4NEXUS	N/A	N/A	N/A	External workshop planned for 2018 in Brussels.
Global	2nd & 3rd of October 2017 (Internal)	N/A	N/A	N/A	Nexus interlinkages, nexus processes possible in thematic models,	N/A

7.1.1.4 Definition of nexus challenges to be adopted in the thematic models

Some case studies, have in addition to the compilation of nexus interlinkages and challenges in section 6.1.1 also summarised their main Nexus Challenges in terms of overall issues in their case studies. Section 6.1.1 presented the interlinkages and challenges, whereas the ones presented here are defined as themes of more prominent and important ones that are to be modelled in the thematic models.

For example, Andalusia defined, with the help of their stakeholders, the following challenges which are defined (Brouwer and Fournier, 2017):

1. Sustainable management of water resources. Inclusion of water quantity and quality issues o Consideration of the water/energy ratio in all decision-making processes
2. Mitigation and adaptation to climate change. Integration of climate change goals in policies related to water, energy, land, and agriculture o Adaptation to climate change should be considered transversal policy
3. Energy efficiency and promotion of renewable energies. Consideration of the energy (water) footprint of water (energy) o Downsizing the machinery park and outsourcing to service companies o Reduction of VAT (21%) for companies that follow Certificates of Compliance with Regulatory Requirements (CCRR)
4. Fight against soil erosion and desertification. Integral soil management o Sustainable urbanization o Consideration of climate change impacts (e.g., soil biota, absorption capacity) o Competition for land use
5. Resource efficient food production. No subvention for natural resource use in food production (e.g., water) o Green taxation
6. Sustainable socioeconomic development. Holistic management that should be sustainable, intelligent and inclusive

Furthermore, the case study of Netherlands have also defined their main nexus challenges explicitly, to be addressed in more detail in their analysis in the project (Brouwer and Fournier, 2017):

1. Biomass should be produced and collected in a sustainable way. The domestic supply of sustainable biomass is limited and will be insufficient for the various demands in The Netherlands, so imports are needed. Sustainably produced biomass is a scarce resource;
2. Application of biomass for energy production at a large scale will affect the availability and quality of land, water, food and energy and will affect climate;
3. It is debated whether the use of biomass for energy generation contributes to a net reduction of GHG emissions or not. The sustainability criteria for biomass are also debated.
4. In addition, biomass has a negative image because it is often associated with the use of coal for energy production (co-firing) and with large scale deforestation. It is also associated with land grabbing and competition with local food production;
5. In addition, there are knowledge gaps by politician and the public about the diversity of biomass and the best application of these different types.

7.1.2 Conceptual mapping and relation with systems mapping

Conceptual mapping is done as part of the Conceptual Complexity Science and are referred to as Conceptual Complexity Science models, which will serve the development of the System Dynamics Model (SDM) (WP3). Each of the case studies have based on their identified nexus interlinkages, prepared a conceptual model combining all nexus domains (Water, Energy, Land, Food and Climate) considered in the SIM4NEXUS project and possible to be broken down in detail for each of these nexus domains. As part of WP3, a compilation of all Conceptual Complexity Science models was performed as part of Milestone 18 led by the Consortium partner UNEXE. As these mappings are to serve the development of the SDM, it is of importance to understand the interlinkages between systems. Chapter 4 in this report serves to inform the reader on how the nexus domains are organised, in a simplified manner. The development of the conceptual model would benefit from the inputs from Deliverable 1.1., system mapping (Chapter 5), to further understand how these activities share or transfer resources. This understanding is vital in the development of the SDM and to ensure the dynamics interactions between systems are accounted for, leading to the abstract representation of the Climate, Land, Food, Energy and Water nexus.

The different case studies have, in graphical means, presented their systems differently. For instance, in the case study of Sardinia, special focus is given to the water sector, as it is the core of its research objectives. On the other hand, case studies such as Andalusia and Greece present one general map with the linkages between the five nexus domains, and further disaggregate each domain separately and in more detail. The latter is the case for most case studies; however, the graphical presentation may vary. Nonetheless, the importance of breaking it down into each of the nexus domains allows for better representation of activities and linkages within the domain, but also increase the resolution and specificity of the cross-system interactions. Furthermore, though each case study has a different set of main nexus interlinkages and challenges defined based on their research objective(s), similarities can be established with Chapter 4 mapping exercises. Despite the aforementioned chapter being general and overarching of activities within each nexus domain, this generalization allows for analysts to develop a broader understanding of the different systems, which is particularly valuable if knowledge of certain systems´ falls outside their area of expertise. Thus, the justification for that chapter lies within the reasoning and understanding behind the conceptual model and its nexus domains.

7.1.3 Quantification and assessment of interactions between nexus domains

This section presents the use of the thematic models for assessing the nexus and how this, together with the conceptual complexity science models, will feed the development of the System Dynamics model (SDM).

7.1.3.1 Use of thematic models

The seven thematic models used in SIM4NEXUS are applied differently throughout the case studies, all informing on different interlinkages and pathways for each study. Table 8presents the use of the thematic models in the different case studies. Case studies were themselves allowed to choose between the models based on their research objectives as well as preliminary idea of the nexus challenges that needed to be addressed. For further detail, Deliverable 1.3 (Fazekas et al., 2017) presents each of the thematic models and how they can be used in the case studies, as well as what nexus interlinkages the models are able to present.

Table 8. Use of thematic models by each case study (Fazekas et al, 2017).

	E3ME	MAGNET	CAPRI	IMAGE-GLOBIO	OSeMOSYS	SWIM	MAgPIE
Andalusia	X		X				
Sardinia	X	X	X				
Southwest UK	X		X				
Latvia	X	X	X				
Greece	X	X	X	X	X		
Azerbaijan	X	X	X		X		
Sweden	X	X		X			
Netherlands	X	X	X				
Germany-France	X		X			X	
Germany-Czech-Slovakia			X			X	
European	X	X	X	X			X
Global	X	X	X	X	X		X

Notable from Table 8 is that there is a large concentration of usage of E3ME, MAGNET and CAPRI, the latter being used in all of the models. However, regardless of the geographical extent of the case study, all of them make use of more than one modelling tool. Important to note is also the flexibility of some of the models, e.g. some models may only be applicable at a larger scale and may thus not be able to downscale into the areas of Andalusia and Sardinia. If values are given on a national scale, also transboundary case studies may face issues of how results can be integrated and understood from the perspective of a single basin in each respective country. On the other hand, when modelling nexus interlinkages, these may not be limited to a small region or area, instead, national level modelling may be necessary but the extraction of results are done for the regions itself. Therefore, it is important to choose the models not only based on the systems covered, but also the capacity of these to represent the relevant nexus dynamics. For instance, in the Andalusian case study selected the thematic models to inform on food-water linkages (irrigation and livestock) and food-energy linkages (biofuel markets), achieved with the use of CAPRI; E3ME is used to investigate energy-food linkages (energy use in agriculture and biomass production) and the energy-water linkages (hydropower). This thus implies that future scenarios applied for each of the two models will therefore drive the evolution of the interlinkages and thus the implications to the nexus challenges. If the biofuel market expands in response to policy decisions in the energy sector, this could affect the food production sector and also policies that are adopted in the food sector.

In the case of Andalusia, the thematic models have explicitly been stated on how they can address the nexus challenges identified. Recalling these from section 7.1.1.4, CAPRI is said to be able to capture all the challenges, whereas E3ME is said to be able to capture challenges number 2, 3 and 6 (p.99). What this implies is an initial thought from the case study on how their identified interlinkages, and so forth challenges, can be captured by the models and how these models may therefore drive the analysis. Furthermore, the Latvian case study identifies the nexus challenges which are not possible to address in the thematic models used in the case study, and thus stressed the gaps models may pose on an analysis. However, because the coverage does not exist in one model, does not mean it does not exist in another; which is what the Latvian case study shows. For instance, use of fertilizers is not possible to model in E3ME or MAGNET, but CAPRI is instead able to do so. This implies the necessity of using several models to receive full coverage of one's nexus challenges. Nonetheless, the Latvian case study have identified land erosion/leakages as a challenge, which is not possible to model in either of the chosen models. The German-France Transboundary case study also identifies the gap of modelling ecosystems' response or evolution under a set of drivers, indicating that these are not made clear in the models used. The importance of identifying these gaps results in the need of complementing these challenges with, for instance, qualitative studies.

In terms of soft linking the models, Azerbaijan case study have been the only case study that have explicitly stated that this will be done and is mostly done in terms of harmonisation of model inputs and output values. Beginning with, the model MAGNET and e3ME have a number of common input parameters and hence, in order to create a base for comparison, the data in the final version of the baseline scenario is expected to be (to a large extent) harmonised. In addition to this, the electricity demand is an output of E3ME (calculated mainly based on economic parameters) but an input to OSeMOSYS. Thus, once the baseline scenario in E3ME is completed, the electricity demand will be fed back to OSeMOSYS. Other links may be identified in the future depending on modelling set-up and priorities. Lastly, techno-economic data for power generation technologies across E3ME and OSeMOSYS will be harmonised. There are further ideas of potentially using food price change from MAGNET in E3ME, however this has not been decided upon yet.

7.1.3.2 Use of the System Dynamics Model and complexity science theory

Currently, the System Dynamics Model (SDM) has been developed for the case studies of Sardinia and Greece, and under development for the case of Andalusia. The remainder case studies have been focusing on the development of the Conceptual Complexity Model that informs the SDM.

7.1.4 Role of policy analysis

Policy analysis for each case study are necessary in order to make first an initial screening of what is there and what the evolution of such policies may do on the nexus domains. Further, a policy in one sector may have trade-offs in another sector; similarly, there can also be synergies. Policy analysis has been done in the project, e.g. D2.1 (Munaretto and Witmer, 2017), and will also serve the scenario formulation, which are of policy scenario character. This section presents first the identification and definition of the nexus policy challenges in the case studies and further how these are serving the scenario definition and adopted therein.

7.1.4.1 Identification and definition of the nexus policy challenges

To be updated later, either this Milestone or the Deliverable in month 48.

7.1.4.2 Definition of scenarios

Scenarios are here defined as Policy scenarios; however, at this stage of the projects, the case studies have not defined these in detail. Nonetheless, the baseline scenario exists and correspond to SSP2 that take into account large socio-economic and population trends for pre-Paris era for 2010-2050. In addition to the baseline scenario, some case studies have added a climate mitigation policy that introduces the Paris Agreement and the 2 degrees Celsius target. For instance, the MAGNET model is available with the reference scenario and an addition with a generic mitigation policy that consists of reductions targets for each economic sector across the countries and economic sectors. The policy scenarios will inform the modelling teams in WP3 on the changes to be made in comparison to the baseline scenario and are all case study specific based on relevant, existing and proposed policies that may come into force. As the scenarios are policy-based, the lack of physical scenarios are obvious. E.g. increasing precipitation is the latter, whereas the actions needed to limit global temperature to 2 degree Celsius is the former.

The policy scenarios are planned for the coming months, each case study have already proposed so-called pathway or preliminary scenarios for their case studies, which will work as the foundation for the definition of the policy scenario. An issue which have already been stressed by the project team is that the policy scenarios may not be able to cover all Nexus sectors. A compilation of these pathways/policy scenarios are presented in Table 9 (Brouwer and Fournier, 2017).

Table 9- Compilation of pathways/policy scenarios for each case study (Brouwer and Fournier, 2017).

Case study	Pathways per case study
Andalusia	1. Reduction of diffuse emissions of 18% in 2030 (by E3ME) 2. Reduction of demand for irrigation water (by CAPRI) 3. Improvement of governance, transparency, and information
Sardinia	1. Methane development (to reduce energy costs) 2. Energy independency of the Regional Water Management Authority (ENAS) (reduce water pumping costs) 3. Increase of renewable energy and decrease of CO_2 emissions 4. Sustainable tourism development
Southwest	1. Increased or decreased regulatory burden 2. Water trading – whole sale market separation 3. Cost of energy (influenced by government mechanisms) 4. Utility tariff model (for both energy and water utilities) 5. Capacity market – Energy Market Reform 6. Efficiency (water and energy utilities)

	7. Low carbon energy (decarbonisation) 8. Carbon trading 9. Disposal/Reuse of Bio solids 10. System Resilience 11. Paid ecosystem services 12. Embodied elements of service delivery
Latvia	1. Increase the use of renewable energy sources to produce electricity and heat in centralized power plants 2. Dissipate power generation at localities (more small scale production) 3. Increasing use of biofuels (first and second generation)
Greece	1. GHG reduction (to be detailed) 2. Increased renewable energy penetration (to be detailed) 3. Climate agreements (e.g. Paris agreement) (to be detailed) 4. Water pricing, flood prevention, and water management protection (to be detailed) 5. Sustainable agricultural practise (to be detailed) 6. Regulations of land use (to be detailed) 7. Sustainable tourism (to be detailed)
Azerbaijan	1. Transition from high-carbon intensive economy to low carbon future (to be detailed)
Sweden	1. RCP4.5 and RCP8.5 greenhouse gas concentrations trajectories 2. Increasing share of renewable energy (100% penetration in 2040) 3. Water and forestry pathways to be detailed later
Netherlands	1. Low-carbon economy in 2050 (to be detailed later)
DE-FR	1. Transition to low carbon economy (to be detailed) 2. How could cooperation between Germany and France be strengthen and performed in a more cost-effective manner (to be detailed) 3. Which changes in policies could enhance the coherence between both policy domains (to be detailed) 4. What are (visible or foreseen) impacts, positive and negative, of these policies on the management of natural resources, in particular water, ecosystems and biodiversity? (to be detailed)
DE-CZ-SK	1. SSP3 “Regional rivalry – A rocky road”
European	1. RCP - 6.0 and 2.6 2. Energy policy pathway (renewable energy, efficiencies, energy sectary and internal market and competiveness)

	3. Food policy pathway (following objectives of Common Agricultural Policy) 4. Land use policy pathway (biofuels, uptake of GHG emissions from land) 5. Water policy pathway (improving ecological status of water while reducing pollution, abstraction and storing hydro-morphology and environmental flow)
Global	1. Climate change mitigation 2. Other scenario to be defined

7.1.5 Summary and conclusions and next steps

This chapter has provided a short summary of how the 12 case studies of the SIM4NEXUS project are evolving regarding in terms if definition of nexus interlinkages and challenges definition, engagement of stakeholders and use of thematic models and scenario definitions. All case studies have indicated, some more than others, potential nexus interlinkages and challenges and further adopted these in their conceptual models serving the conceptual complexity science models. Stakeholder engagement remains a difficult task in many case studies, yet almost all have been able to hold their first workshop with good results in feedback of nexus interlinkages and policy identification. As only the baseline scenario is available, the policy scenarios are yet to be formulated; however, all case studies have indicated pathways that are possible to implement. Since the project is ongoing and the coming months will provide more modelling outputs and formulation of policy scenarios, the presentation done in this chapter is merely preliminary and indicative. However, the material presented here is an important part of the development of the Nexus framework and to understand the evolution of the project and to be able to guide and structure the months ahead. Nonetheless, not only this chapter, but also this report a whole, wish to serve as a summary of current position in the nexus work and development and what can be build further upon. Therefore, the case studies and other partners are highly encouraged to adopt the insights of this chapter to their work, for instance through the realisation of differences between case studies and thus taking inspiration from others. The nexus framework continues, and is ought to be a continuous process throughout the project and build upon, among others, the lessons drawn from the case studies and thus it will continue to follow their work.

Below are a few summarising steps that will follow:

- Update the nexus interlinkages and definitions of nexus challenges
- Follow up on Stakeholder workshops in each case study and understand its importance in relation to the Nexus framework development
- Analyse and elaborate on the driving force of the thematic models on nexus interlinkages (once results are available and further when scenarios are deployed)
- Follow up the SDM development and better clarify its role in the nexus framework development
- Once policy scenarios are formulated, understand its impacts on the nexus domains and its trade-off synergies therein.

8 Conclusions and next steps

The SIM4NEXUS Nexus assessment framework is a key output of the SIM4NEXUS project. If on the one hand it compiles experiences and knowledge from the perspective of case study leaders and experts, on the other consolidates a process which enables the integrated assessment of resources towards resource efficiency and a low carbon future. This is achieved by the strong focus given to policy analysis and coherence of the nexus, and its sound incorporation in the quantification analysis.

As for next steps, the current version of the framework will be further improved and iterated with partners. Work packages and task leaders more directly involved with the different steps will be engaged in the development of the framework. We aim at sharing for discussion updated versions of the framework prior to the forthcoming project meetings.

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10 Appendices

Appendix A: SIM4NEXUS Glossary of Terms

Table 10. Glossary of terms used in SIM4NEXUS.

Glossary term	*Definition*	*Example*
A		
adaptation	The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as the adjustment in natural or human systems in the response to expected or actual climatic changes in order to take the appropriate actions to prevent, or minimize, damage or taking advantage of the opportunities emerging. In contrast to "mitigation", adaptation refers to adapting to the climate change effects that are already unavoidable.	Develop drought-tolerant crops Set aside land corridors in order to help species migrate
C		
circular economy	"Reduce, re-use, recycle". A system in which resources that are being used are minimized and when a product reaches the end of its life, it will be recycled to create further value. Thus, waste becomes a resource in the beginning of the loop. Opposite to *linear economy* that adopts a "take, make, dispose" chain	Recycling of plastic bags (minimizing waste, and re-using material)
climate change	Change in the statistical distribution of weather patterns, given that the change has lasted over an extended period of time. The change can either occur in the average climate conditions, or the time variation of that climatic region.	Change in intensity or duration of precipitation Alteration in extreme climatic events such as storms
Complexity science conceptual model	Conceptual (sometimes also known as a 'mind map') representation of the key interactions between and within nexus systems in the form of a qualitative diagram. The conceptual design of how nexus domains interact in a case study will serve as the basis for the development of the quantitative System Dynamics Model (SDM). The conceptual model is an abstraction of reality, usually with both a physical and social	Flow chart of energy system to reflect the actual flow of energy in a region

	meaning, and aims at providing a representation of the main complex relations between the sub-systems under investigation.	
D		
determining agent	An element or factor that determines the nature or outcome of something.	A greenhouse gases (GHG) emission reduction target determines how the energy system is transformed.
E		
energy efficiency	Reducing the amount of energy that is required in services or products, which is done by using more efficient technologies or processes to, among others, reduce energy losses.	Insulation of buildings. Electric vehicles.
G		
goal	Understood as a preferred future (Bishop et al, 2007). That results from analysing a combination of outcomes and performance metrics to see whether one have reached their objective (could be indicators).	Sustainable Development Goals (SDGs)
I		
indicator	Metric used to express, in quantitative terms, the status of important elements within each nexus domain. They serve to evaluate the performance of an action, measure or change of status (climate), infer on its potential impact and/or implication, either directly or indirectly (proxy indicator). Further, indicators are often directly related to goals.	Energy: Carbon intensity of electricity generation - CO_2/kWh; Water: annual water consumption per capita (m^3 PC)
indicator, success	A success indicator provides a quantitative reference /benchmark of the desired performance of a sector or system. It is derived based on the policy targets defined for that sector or system.	European Union Intended Nationally Determined Contribution (INDC) target - minimum of 40% domestic reduction in GHG emissions by 2030, in comparison to 1990 levels

impact	The change in status a policy mechanism and/or a technology innovation (or shift) may exert. Impacts can also be cross-sectoral if an action in a sector has an effect on another.	Change in river morphology from damming a river (water system domain). Using the example above, a cross-sectoral impact could be alteration of riverine habitats.
implication	The effect, consequence or repercussion that an action will have on something in the future. While impacts are direct effects, implications are possible consequences that are not always obvious and clear.	Increased demand due to electrification of residential heating or transport.
influencing determinant	An element or factor that influences the nature or outcome of something.	Oil price influences oil exports.
innovation	(The use of) a new idea or method (Cambridge Dictionary); the creation of a new way of doing something, whether the enterprise is concrete (e.g. the development of a product) or abstract (development of a new philosophy or theoretical approach to a problem). Alternatives to the conventional – which does not mean that the innovation is necessarily something completely new and can also be something that exists applied in a different way. Can be divided into technical, institutional and social innovation. Technical innovations refers to the introduction of new technologies, methodologies and/or approaches to tackle challenges solve problems or simply change something established following a less conventional approach, method, idea, etc. Institutional innovations refers to introduction of policies and governance structure to improve, for instance, the performance of a sector. Social innovations refers to strategies, ideas or concepts that meets social needs, for instance working conditions or health service, with the aim to strengthen civil society Innovations can be divided into technological, institutional (policy-related) and social. Technological innovations refer to the introduction of new technologies, methodologies and/or approaches	Technical: Moisture sensing technology included in irrigation systems. Institutional: Subvention of solar PV installment in rural areas. Social: Fair trade in coffee sector to improve and sustain the life and livelihood of coffee farmers

	to tackle challenges solve problems or simply change something established following a less conventional approach, method, idea, etc. Institutional and policy innovations refer to introduction of policies and governance structure to improve, for instance, the performance of a sector. Social innovations refer to strategies, ideas or concepts that meets social needs, for instance working conditions or health service, with the aim to strengthen civil society.	
interaction	A mutual or reciprocal action, effect, or influence between two or more entities (agents, sectors, systems, elements in a system, etc.). Does not exclusively represent a co-dependence between the actors.	Water consumption in agriculture for irrigation - interaction between the water system (water availability, irrigation technology and infrastructure) and agriculture (food production). Energy policy may be determined by an interaction between Ministry of Finance and Ministry of Energy Resources
K		
key performance indicators (KPIs)	enable to assess the extent objectives and expected impacts of a projected are reached	Number of deliverables published according to work plan of SIM4NEXUS
Knowledge Elicitation Engine	A Knowledge Elicitation Engine is the inference engine of an expert system (the Serious Game in SIM4NEXUS). Knowledge elicitation comprises a set of techniques and methods that attempt to elicit an expert's knowledge through some form of direct interaction with that expert.	Serious Game
M		

mitigation	IPCC defines mitigation as the anthropogenic intervention done in order to reduce other human induced actions on the climate system, for instance through greenhouse gases emissions. In contrast to "adaptation", mitigation means reducing or stabilizing the greenhouse gases in the atmosphere that may yield effect on climate	Switching to low-carbon energy sources Preserving, or expanding, the forest to serve as a carbon sink
N		
narrative	(Concise/short) Qualitative description of the relationships among different trends and socio-economic developments assumed in a scenario. Narratives can be used with quantitative information to infer more detailed representation of local and regional conditions while maintaining consistency with trends at the scale of the globe or large regions (IPCC website). Storylines that convey the overall logic underlying the related quantitative descriptions of future economic, demographic, technology, and emissions trends. Narratives facilitate extrapolation of scenarios for other research (Van Vuuren, 2012).	Shared Socioeconomic Pathways (SSPs) narratives
nexus	Interaction and interdependency between selected resource sectors/system domains in terms adopted to understand trade-offs and synergies	Water-Energy-Food nexus: understanding trade-offs or synergies when expanding irrigation schemes (water) for agricultural production (food) while in parallel expanding the hydropower system (energy)
nexus approach (D2.1)	A systematic process of inquiry that explicitly accounts for water, land use, energy, food and climate interactions in both quantitative and qualitative terms with the aim of better understanding their relationships and providing more integrated knowledge for planning and decision making in these domains.	Water-Energy-Food nexus (developed by United Nations Food and Agriculture Organization (FAO))

Nexus-induced challenge	Complex task or combination of factors that requires a solution which is not always straightforward and thus requires a "nexus approach". In a nexus context, the problem could be derived from one nexus domain and be reflected in several others and/or could be linked to feedback mechanisms.	Cross-sectoral water allocation: safeguard water availability for agriculture, food production, domestic consumption, industry, energy.
nexus compliant practices	Such practices cope with (e.g. mitigate) trade-offs between the Nexus sectors and build synergies.	A water-efficient bio-based economy.
nexus interlinkage	A factor, connection, relation or association that connects or ties one thing to another (the condition of being linked) - in a nexus perspective it corresponds to interconnected elements within the same or between different nexus domains. A "linkage" is frequently used to convey a physical link or assemblies between parts of a mechanical device. A nexus challenge is derived from a nexus interlinkages but the latter does not necessarily imply the former.	Water is required for food crop development (water-food linkage) Land is used for cattle raising (land use - food production linkage). Electricity is used to power water systems and water is needed for cooling systems in thermal generation (water-energy interlinkage).
nexus performance indicator (NPI)	Indicators linking at least two Nexus dimensions and quantifying their co-dependence, thus identifying possible vulnerabilities of one nexus dimension compared to another one. More advanced Nexus indicators will link three or four Nexus dimensions, e.g. the amount of *water* and *energy* required for the production of a unit of *food* and the amount of CO_2 produced (*climate*).	*Energy* required for the production of *water* through desalination. A high value for this indicator will mean that the production of desalinated water is highly dependent on the availability of energy.
nexus dimension / domain	Refers to a specific sphere of activity or action related to or characterized by specific features or elements. SIM4NEXUS focuses on the nexus domains of water, food, land, energy and climate.	Water nexus domain includes resources and their natural availability and dynamics (surface water river networks, aquifers, etc.); and activities for the production and/or use of water (water supply

		infrastructure, wastewater disposal and treatment, irrigation system, desalination, etc.).
nexus sector	A distinct part or division of a regional, national, continental or global economy. Does not represent the natural availability of nexus resources (e.g. the water cycle is not an element in of the water sector; climate is not a sector). Nexus sectors commonly exist within nexus domains, with the exception of the climate domain.	Energy sector (all activities and actors from fuels availability, transport, conversion, distribution to the final users)
nexus system	An assemblage or combination of parts or elements forming a complex or unitary whole. The parts can result from a set of interdependent elements that have a specific role, purpose or function within the complex whole; for instance, nexus sector within the nexus system. I.e. the sector is an entity within the system and thus a system can include more than one sector.	Energy system (which may involve interactions between several sectors such as water, land, energy and food).
P		
parameter	A factor that represents input data that feed into models.	Current installed generation capacity of photovoltaics (PV).
pathway	Represents a particular course of action or route to reach or achieve specific result(s)/outcome(s). It is defined by a collective action process, which is retrieved from the analysis of the outcomes of scenarios that can secure the transformation or transition envisioned.	"A *climate-resilient pathway for development* is a continuing process for managing changes in the climate and other driving forces affecting development, combining flexibility, innovativeness, and participative problem solving with effectiveness in mitigating and adapting to climate change." (IPCC, WGII AR5, Chapter 20)
policy	Guidelines of paths of actions to achieve goals and objectives. Policies are more specific than strategies.	Agriculture Sector Policy

	They narrow down the set of principles and rules that define how the goals and objectives will be achieved.	
policy coherence	Reinforcement of policies across government departments in order to create synergies between agree objectives and to avoid, or minimize, negative effects into other policy areas.	Policies across agriculture, fisheries, energy and trade in order to strengthen policy coherence for *food security*
policy goal (D2.1)	Policy goals are the basic aims and expectations that governments have when deciding to pursue some course of actions. They can range from abstract general goals (e.g. attaining sustainable development) to a set of less abstract objectives (e.g. increase energy efficiency) which may then be concretized in a set of specific targets and measures (e.g. achieve 10% renewable energy share).	Increase energy efficiency; SDGs.
policy means (D2.1)	Policy means are the techniques/mechanisms/tools that governments use to attain policy goals. Similarly to goals, means range from highly abstract preferences for specific forms of policy implementation (e.g. preference for the use of market instruments to attain policy goals); to more concrete governing tools (e.g. regulation, information campaigns, subsidies); to specific decisions/measures about how those tools should be calibrated in practice to achieve policy targets (e.g. a specific level of subsidy in the renewable energy sector).	Government sponsored grants for the installation of rooftop photovoltaics at households.
policy target	Policy goal expressed in a quantifiable manner. See policy goal. It informs on the success of achieving a policy.	Achieve 10% renewable energy share in a given year.
R		
resilience	The ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions (IPCC).	Infrastructure works to protect a urban area from a flash floods event

resource use efficiency	Efficiency is the maximisation of outputs for a fixed input amount, or unit of resource used. Since our natural resources are limited, efficiency refers to the best use we can make from them.	Producing more food using more efficient irrigation methods, and thus using less water.
S		
scenario	It represents/illustrates a potential way, outcome, vision in which a situation may or may not develop - a possible future. It results from a planned definition of possibilities for one or more selected determinants that are relevant for the hypothetical future. Scenarios provide a context for the analysis and result from the description of drivers, implications and outcomes.	Climate change mitigation scenario.
scenario - baseline	Scenario that aims at representing the current trends of the systems being modelled. It does not include future policies, but only the ones under implementation up to the base year of the analysis.	Energy demand assumed to follow the same annual growth rate of the average annual growth rate of the last 5 years.
scenario - reference	The reference scenario develops from the baseline, but incorporates the near-term policies or policies that are certain to be implemented in the sectors under analysis.	Transposition to national policies of EU policies up to 2020 or 2030.
Scenario - policy	A policy scenario is defined as a package of policy interventions placed in a timeline, to reach policy objectives, and policy goals. Policy interventions may be policy instruments, e.g. a law, subsidy, tax, communication campaign, or measures, e.g. repair leaking water infrastructure, and insulate a house, reforestation.	
strategy	Policy strategies define major courses of action or patterns of successful action, usually in the format of a plan, to achieve organizational goals and objectives.	Development strategy for the energy sector
sustainable development	Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland report)	

synergy	The interaction of two or more elements or agents that when combined produce a total effect that is greater than the sum of the individual effects or contributions. It can also result from the cooperative interaction between groups and sectors, which result in an enhanced combined impact of coordinated actions or efforts.	Multi-purpose reservoir (hydropower, irrigation, tourism). Resource efficient farming practices could offer high crop output per unit of water used.
system dynamics model (SDM)	Quantitative representation of the interactions and feedback loops within and between processes in a complex system (in the case of SIM4NEXUS, the main system structure is identified in the conceptual models). Relationships can often be non-linear and may include delay mechanisms. In SIM4NEXUS, the structure of the complex system developed for the SDM will be case study-specific (i.e. is developed in the form of the conceptual model with close cooperation with case study lead partners and stakeholders) and integrates elements from the five nexus domains in which the project focuses on. SDM is a modelling approach/philosophy, for which there are many software tools and graphic environments to develop quantitative models. SIM4NEXUS uses STELLA as the modelling software to develop the SDMs for each case study.	The interactions between water, land, energy food and climate
T		
target	A measure of the degree of one's success. Can be an indicator that is established to determine how successfully you have achieved a goal.	Decrease in CO_2 emissions of 10% in a specific year, in comparison to the CO_2 emissions in a reference year.
thematic model	A mathematical model which covers one, or several, specific topics that relate to the nexus dimensions under investigation in the SIM4NEXUS project. Quantitative analysis of the nexus in the case studies results from the combination and/or use of more than one thematic model. These are chosen based on the nexus challenges that are identified in each case study. Thematic models can differ on the system(s) they cover, type of modelling tool, and level of detail of	Models used in SIM4NEXUS: CAPRI, e3ME, IMAGE-GLOBIO, MAGNET, MagPIE, OSeMOSYS and SWIM

	representation, which then translates into a different set of input and output data.	
trade-off	An exchange of one thing in return for another, often linked to the relinquishment of one benefit or advantage for another regarded as more desirable. It can also be interpreted as the loss in quality or quantity of a resource when the quality of quantity of another resource increases.	Decrease in forest area due to increase of biomass extraction for energy production.
V		
variable	Outputs / results obtained and/or derived from models.	Wind power generation capacity in 2050.
variant	Elements in the modelling exercises (e.g. parameters, variables) that can be manipulated to structure/define a specific scenario or a scenario family.	Electricity demand, water use factors, emission limits, etc.
vulnerability (to climate change)	IPCC defines it to the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change	Agricultural land flooding

Appendix B: Predecessors and variations of the DPSIR framework

Predecessors and variations to the DPSIR framework

The matrix below lists selected publications related to the development and implementation of the framework and classifies them based on the type of analysis that was conducted. The latter is classified as: generic (theoretical analysis covering a field/type of societal process rather than a particular study case), comparative (where various examples are used in order to develop a reasoning) or case-study specific.

Table 11. Overview of the DPSIR and other related frameworks

Paper	Author	Publication year	Methodology	Type of analysis
OECD Environmental Indicators 2001 Towards Sustainable Development	OECD	2001	PSR	Generic
Environmental decision making in multi-stakeholder contexts: applicability of life cycle thinking in development planning and implementation	Lanka Thabrew, Arnim Wiek, Robert Ries	2008	Comparative study of Environmental impact assessment (EIA), Social impact assessment (SIA) and Risk assessment (RA). Development of Stakeholder-based life cycle assessment (SBLCA)	Generic /Comparative
Does research applying the DPSIR framework support decision making?	Karen Tscherninga, Katharina Helming, Bernd Krippner, Stefan Sieber, Sergio Gomez y Paloma	2011	DPSIR	Comparative analysis based on 21 case studies
DPSIR = A Problem Structuring Method? An exploration from the ‘‘Imagine’’ approach	Simon Bell	2012	DPSIR within the Imagine approach	2 coastal applications: Malta and Slovenia
Socio-ecological accounting: DPSWR, a modified DPSIR framework, and its application to marine ecosystems	Philip Cooper	2013	DPSWR clarification of the acronym required	Generic
A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems	Sirak Robele Gari, Alice Newton, John D. Icely	2014	DPSIR discrete tool and different variations	Based on many applications

Drivers and pressures - Untangling the terms commonly used in marine science and policy	Daniel Oesterwind, Andrea Rau, Anastasija Zaiko	2016	DPSIR	Generic (with hypothetical examples)
Sustainability Assessment of indicators for integrated water resources management	A. Pires, J.Morato, H. Peixoto, V. Botero, L. Zuluaga, A. Figueroa	2016	IWRM - clarification of the acronym required	Generic
Sustainability assessment of regional water resources under the DPSIR framework	Shikun Sun, Yubao Wang, Jing Liu, Huanjie Cai, Pute Wu, Qingling Geng, Lijun Xu	2017	DPSIR	A case study of Bayannaoer - Inner Mongolia
Root-cause analysis (e.g. biodiversity loss)	To be added			

A review of the publications presented in **Error! Reference source not found.** helps comprehend the main characteristics, strengths and weaknesses of each methodology. A short description of each Methodology is presented below.

Pressure - State – Response (PSR): Conceptualized by the OECD, a predecessor of the DPSIR framework is the PSR. Based on literature, the pressure, state and response indicators are determined in the same way regardless of the methodology. Therefore, the fundamental difference between the two frameworks is that PSR does not analyse the driving forces but rather focus is given to the pressures exerted as the initial point of the analysis. Pressures are best used to describe environmental issues while drivers may include institutional, social or economic activities. Moreover, impact indicators are a "missing link" between the state of the environment and societal responses. DPSIR was developed at a later stage and considers a more in-depth analysis of the impacts.

Stakeholder-based Life Cycle Assessment (SBLCA): The Life Cycle Assessment (LCA) methodology can estimate the overall impacts/resource requirements of a product or service "from cradle to grave". Depending on the scope and the objectives of a study, water/carbon footprint, energy use and environmental impact may be considered. Every stage such as production, disposal or transportation for every component of/material used for a particular product is considered. The SBLCA framework is based on LCA but aims at analysing a case from a broader perspective by engaging stakeholders and considering different points of view. The main domain of application is development projects where the net benefits at all stages of the project's lifetime are estimated. Then, multiple scenarios are formulated and compared in order to determine the most beneficial pathway from relevant stakeholders' points of view. A fundamental difference between the DPSIR and the SBLCA framework is that the former's initial point is usually an already existing problem which needs to be tackled in the optimal way, while SBLCA starts from a future goal (i.e. construction of dwellings in a post-disaster era) and examines "how best" to achieve it.

Drivers – Pressures – State – Welfare – Response (DPSWR): The DPSIR framework covers environmental, social and economic aspects. Particular focus can be given to each of the three depending on the scope of the case analysed. One modification of this framework is the DPSWR where W represents Welfare. The philosophy of the concept is that States and Impacts are strictly interrelated and do not necessarily require two separate categories to analyse them. Thus, all the environmental effects are accounted for under the broader "State" category while "Welfare" cover the social impacts. A schematic representation of the DPSWR framework is shown in **Error! Reference source not found.**. It has to be noted though that the classification of impacts as ecological or social is not always straightforward and can be subject to the analyst's or the stakeholder's judgment. Natural scientists may find it perplexing to use the word "impact" for describing both social and environmental effects and thus, differentiating between the two terms (by using the word "welfare") can facilitate communication with them. One key element of the DPSWR framework is its anthropocentric nature which renders it a useful tool for examining the impacts on human well-being (including economic aspects). For example, a polluted ecosystem can result in reduced recreational and tourist activities.

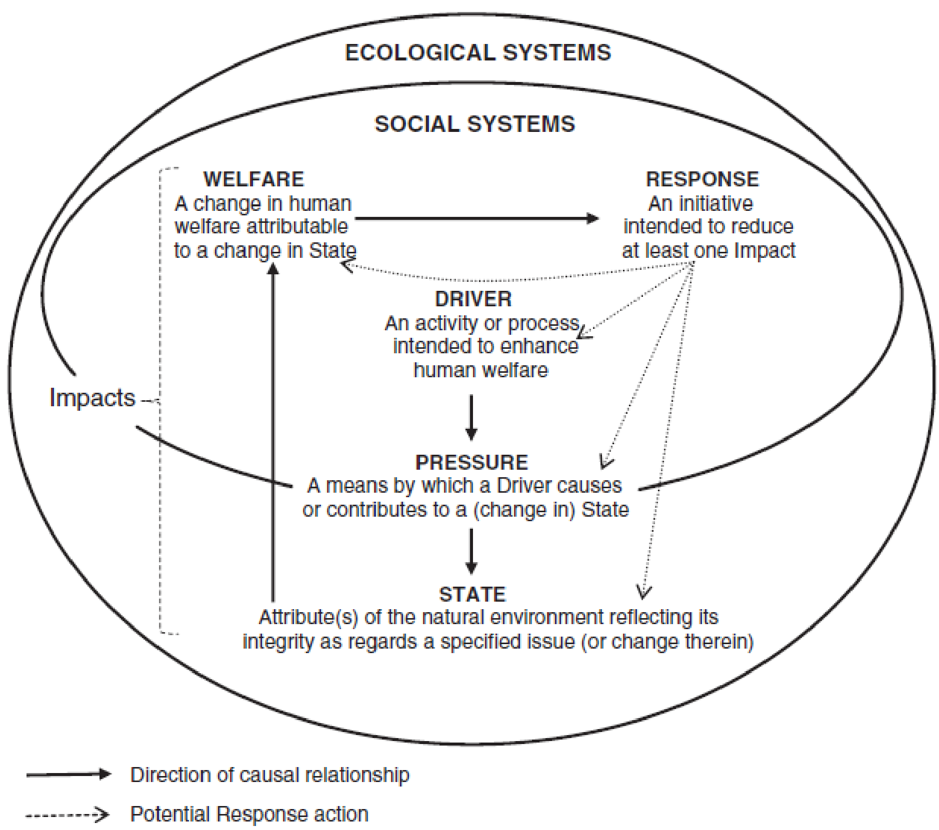

Figure 38. Schematic representation of the DPSWR framework (Cooper, Socio-ecological accounting: DPSWR, a modified DPSIR framework, and its application to marine ecosystems, Ecological Economics 94 (2013) 106–115).

Integrated Water Resources Management (IWRM): Standing for Integrated Water Resources Management, the IWRM methodology is a concept originated in the 1980's. It was designed to facilitate water governance, e.g. social, economic, political and administrative aspects of water management through the involvement of stakeholders. The methodology aims to maximize the social and economic benefits derived for the exploitation of water resources but in a sustainable manner which will allow future generations to meet their own needs. Diversity is a key component of IWRM, since cross sectoral approaches and various aspects needs to be considered to meet this aim. For instance, land use practices and developments in the watershed may have to be analysed in conjunction with the water system, both political and technical parties may need to be involved, trade-offs between quantity and quality are looked at while both environmental, social and economic aspects are investigated. Special focus is given to the communication part. Since the groups of stakeholders involved in the process can (and should) be diverse, communicating the information in a simplified/accessible manner is critical. The analysis is based on indicators similarly to the case of DPSIR. The indicators are categorized as sustainability indicators, one-dimensional indicators, bi-dimensional indicators and indicators that are not linked to sustainability criteria. As a matter of fact, the two frameworks do not seem to contradict each other but rather the IWRM is a first attempt towards water management facilitation, and probably most used and disseminated amongst practitioners, which can be classified under DPSIR.

Appendix C: Selected DPSIR case studies

This section describes how the DPSIR framework was applied on two cases, a subnational (Bayannur - Inner Mongolia, China) and a national (South Africa).

- Case study of Bayannur - Inner Mongolia, China

The sustainability of the water resource system in the city of Bayannur was assessed using the DPSIR framework by **(Sun m.fl. 2016)**. The city suffers from water shortage driven primarily by population and economic growth. The indicators identified are listed in Table 12. Once indicators were identified, different weighting factors were assigned to each based on their importance. The predominant indicators are highlighted in bold.

Table 12: Indicators identified to characterise the DPSIR elements in the case study of Bayannur (Sun et al, 2017).

DRIVERS	PRESSURES	STATE	IMPACTS	RESPONSES
GDP	**overall water usage**	regional water resource quantity	**the available resources of blue water**	**water conservation project investments**
GDP growth rate	**the water usage ratio among different sectors**	the water system capability of meeting the demand, the water resource quantity available	the blue water footprint	**measures that increase the efficiency of the irrigation system and the ratio of wastewater**
increasing consumption demands	the potential annual average evapotranspiration	**the water resource exploitation ratio**	**the level of the water resource scarcity**	**measures that decrease the water consumption rate per economic output and the comprehensive crop water footprint range**
Population	**the usage of chemical fertilizer usage per area**	the per capita average water use	the discharge of Chemical Oxygen Demand (COD)	measures that increase the utilization of ecological water rate of forest coverage
the Engel Coefficient (a measurement of a country or region's living standard)		the overall irrigation per area	the grey water footprint	
cultivated area		**the water footprint of different agriculture products**	**the level of the water resource pollution**	
		the consumption of water needed for one unit of economic output	the groundwater salinity	
		the wastewater discharge total quantity		

The scaling of the indicators lead to an overall score per DPSIR category and a comparison between the year of 2000 and 2010 was carried out. It turned out that despite the fact that the measures taken as a response to the problem resulted in increased efficiency of the water system, the pressures coming from the increasing water demand were not offset and thus, the state of the water resources deteriorated. More specifically, the overall Response score rose from 0.21 in 2000 to 0.70 in 2010 (implying that the society responded actively) while the respective figure for the State dropped from 0.71 to 0.36, suggesting that the sustainability of the water resources is deteriorating.

- Case study of South Africa

In Kristensen (2004), the DPSIR framework is applied on the case of South Africa to identify core indicators for inland water resources. Two major drivers (anthropogenic and natural) affect six inland water systems. Certain pressures on the water systems are generated by the drivers (i.e. variable rainfall) and in turn, the state of freshwater resources is affected either in terms of quantity or quality of surface or ground water. More specifically, six issues were identified and the DPSIR framework was applied to each of these accordingly. The issues are listed below:

- Limited resources of freshwater (both surface and groundwater)
- Changing quality of freshwater (both surface and groundwater)
- Degradation of freshwater ecosystem and loss of integrity
- Inland water resources management – focus on drought and flood

Political & Socio-Economic Issues related to Inland Waters:

- Services distributed inequitably and inadequately
- Conflicting water sharing interests, both national and international.

The diagram that summarises the application of the DPSIR framework for the issue of "limited freshwater resources" is presented in Figure 39.

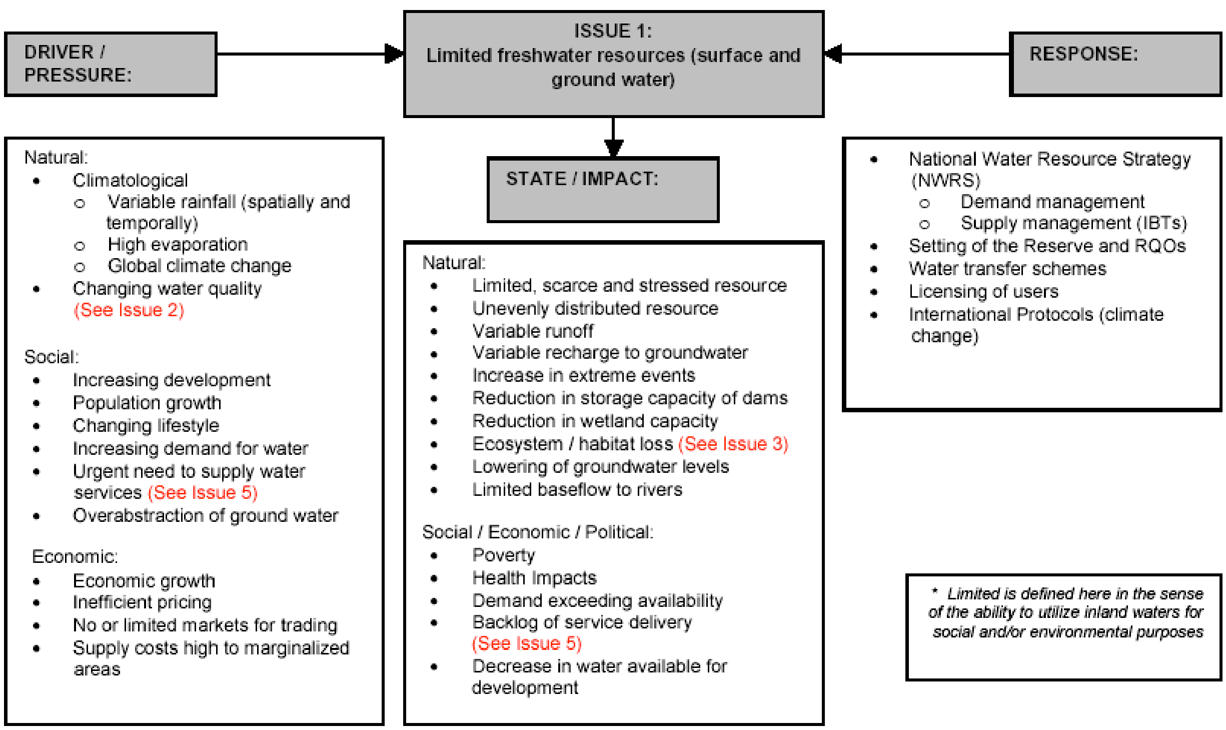

Figure 39. DPSIR conceptual framework applied to assess the issue of limited resources of freshwater in South Africa (Kristensen, 2004. The DPSIR Framework, Paper presented at the 27-29 September 2004 workshop on a comprehensive assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nairobi, Kenya).

Horizon 2020 Societal challenge 5
Climate action, environment, resource
Efficiency and raw materials

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