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

D1.8: PROGRESS OF INNOVATIONS TO IMPROVE THE NEXUS FOR THE CASE STUDIES

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The deliverable is accepted after these minor editorial adjustments are done:	
- p. 15, p. 25, Error! Reference not found	Error messages not found.
- Appendices seem to be incomplete. Normal?	To be added. **Appendix E: SSP2 parameter assumptions per case study and model developed** The table was updated so that it represented the information available. Fields with no information were deleted. The table will be revised for Deliverable 1.5. **Appendix F: Trade-offs identified in the baseline (SSP2) scenario** Appendix updated with and information reviewed by the case studies. **Appendix G: Summary of scenario elements per case study** Appendix updated and reviewed by case studies. Narratives in section 4.3 were reviewed again by the cases.

Table of Contents

Executive summary

In SIM4NEXUS, the Shared Socioeconomic Pathway (SSP) 2 baseline data is applied to case studies that vary in geographic scale, from global, continental, regional (transboundary cross-country) to national and sub-national levels. In those, several systems and sectors that belong to the domains of water, land, energy, food and climate, are investigated. Society and economy are also taken into account as they play a key role as drivers to most of the dynamics of those domains.

This deliverable extends the "basic" SSP2 global narrative used to develop a local narrative. (Global SSP2 data are retrieved from the International Institute for Applied Systems Analysis (IIASA) SSP database – and 'downscaled' where possible.) The local narrative is then simulated and a local scenario is developed. The narrative is simulated by running models applied to each case study. To do so, interactions at the nexus between each domain are found for each case study. The (nexus) interactions are then represented in the initial conditions of the thematic models for each case study. The thematic models are run with varying levels of integration. The output determines the baseline scenario. Inter-domain (nexus) dynamics, impacts and system responses inherent in the baseline are subsequently identified. The baseline scenario provides a picture of the outcomes expected from an SSP development future across the nexus domains, society and the economy. Against the Baseline Scenario, others can be compared. Different drivers, constraints and other assumptions will define those scenarios.

SSPs describe global plausible futures. Each SSP is characterized by different socio-economic development trajectories. They result in different combinations of adaptation and mitigation challenges. The trajectories are qualitatively and quantitatively described. Specific elements of that description include: demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and resources. These are framed at a global level, and are ideally suited to inform integrated assessment models (IAMs) of emissions and land use, climate impacts, adaptation and vulnerability.

Of interest in all scenarios are inter-domain (nexus) dynamics, impacts and responses to the drivers, pressures and states modelled. The nature of the responses can vary and it is in this task that we summarise what these are. In particular, we wish to identify responses that we term 'innovative interventions'. Here we consider an innovation new - or a new application of existing - technologies, policies, practice or combination thereof. A nexus Innovation is an innovation that takes advantage of linkages between domains. (As noted innovations need not represent something absolutely new. They can also be a novel way of applying existing technology or knowledge. For instance, a desalination plant might be used to produce fresh water, and use much electricity to do so. Yet an increased deployment of intermittent renewable energy might result in a surplus of power that is later curtailed/wasted. In response, the desalination plant might then be run during times of excess power – storing excess energy – and lowering curtailment and waste. There is little new about the technology. Yet the operational policy is an innovative response to the pressure from the integration of the water-energy domains in the scenario described.)

This deliverable includes a summary of nexus innovations that span three main categories: technology, policy and society. It is foreseen that these innovations derived in one case study might be adopted or considered in another.

Changes with respect to the DoA

The local SSP narratives are taken from SSP2. It is a "middle of the road" future. The other four narratives are omitted as per a decision taken in a partners meeting on March 2017. As for the Shared Socioeconomic Pathways – Representative Concentration Pathways (SSP-RCP) framework, since the Representative Concentration Pathway 6.0 (RCP6.0) was selected for the downscaling of climate data to the case studies, also other RCPs will not be explored in detail in this deliverable and task in the section dedicated to the SSP-RCP framework. The development of scenarios is conducted as part of Work Package (WP2), for the policy scenarios, and as an outcome of the WP3 and WP5 activities. As described in the task description, scenarios are not developed in T1.6 although information in this deliverable can assist with scenario development (see sections 3.5 and 4.5).

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. It can further assist the production of narratives for the policy scenarios using inputs collected from workshops and/or contact with stakeholders.

Short Summary of results (<250 words)

Not applicable.

Evidence of accomplishment

The deliverable is presented in the format of a report.

Glossary

Innovation: The use of, or simply, a new idea or method; 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 be something that exists, applied in a different way. In SIM4NEXUS, we classify innovations in three categories:

- **Technological innovation:** 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 and policy 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

Narrative: Qualitative description of the relationships among different trends and socio-economic developments assumed in a scenario. Narratives, or storylines, 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).

Pathway: See “Scenario”.

Scenario or pathway: 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. In SIM4NEXUS we specify the scope of different types of scenarios:

- **Baseline scenario:** 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. Baseline is interpreted as similar to “Reference Scenario”.
- **Policy scenario:** 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.

Storyline: see “Narrative”.

Acronyms

Term	EXPLANATION / MEANING
AgMIP	Agriculture Model Inter-comparison Project
CIB	Cross-Impact Balance
CMIP5	Climate Model Intercomparison Project (CMIP5)
CSO	Civil Society Organisation
DPSIR	Drivers-Pressure-Status-Impact-Response
FEEM	Fondazione Eni Enrico Mattei
GDP	Gross Domestic Product
GEO	Global Environment Outlook
GVA	Gross Value Added
IA	Integrated Assessment
IAM	Integrated Assessment Model
IIASA	International Institute for Applied Systems Analysis
INGO	International Non-Governmental Organisation
MA	Morphological Analysis
MDG	Millennium Development Goals
MEA	Millennium Ecosystem Assessment
MGA	Modelling to Generate Alternatives
MORDM	Many Objectives Robust Decision Making
MPA	Multi-Pattern Approach
NGO	Non-Governmental Organisation
NIES	National Institute for Environmental Studies (Japan)
OECD	Organisation for Economic Cooperation and Development
PBL	Netherlands Environmental Assessment Agency
PIK	Potsdam Institute for Climate Impact Research
PNNL	Pacific Northwest National Laboratory
RAP	Representative Agricultural Pathways
RCP	Representative Concentration Pathway
RED	Renewable Energy Directive
RDM	Robust Decision Making
SAS	Story-And-Simulation
SPA	Shared Climate Policy Assumptions
SRES	Special Report Emission Scenarios
SSP	Shared Socio-economic Pathways
WP	Work Package

1 Introduction

Structure of the document

This report is structured in six Chapters and eight Appendixes as follows. Chapter 2 provides an overview of the most important interactions between Task 1.6 “Innovations to Improve the Nexus for the Case Studies” and other relevant tasks in Work Package 1 and with other tasks from different work packages. Chapter 3 presents a summary of the Shared Socio Economic pathways narratives, their development, status and application. An overview of the SSP-RCP framework is also included in Chapter 3, followed by a discussion of the applicability and transferability of the narratives to nexus assessments. Included in the previous is a sub-section dedicated to methodologies of scenario narratives. In Chapter 4, the implementation of the SSP2, “middle of the road” pathway, summarises for the different case studies. Narratives for each case study are produced based on the quantitative incorporation of the SSP2 assumptions in the modelling exercises performed in each case study. An inventory of innovations and low-carbon options considered in the scenarios developed up to October 2018 in the case studies is the focus of Chapter 5. The concluding chapter summarises the findings from the analysis performed and provides recommendations on the next steps of the SSP2 extension of the narratives as well and on the use of the innovations inventory for the nexus dialogues. Also discussed in this Deliverable is the contribution of Task 1.6 work to the Nexus Framework developed in Task 1.5.

2 Interactions with other Work Packages

In the Work Package 1 list of objectives, Task 1.6 is attributed the aim “To provide narratives for scenarios and specify innovations through a Nexus Dialogue with the stakeholders to be run by the Serious Game (Task 1.6)”. This chapter presents a summary of the main interconnections between Task 1.6 and tasks in other work packages is presented. These interactions are an iterative process.

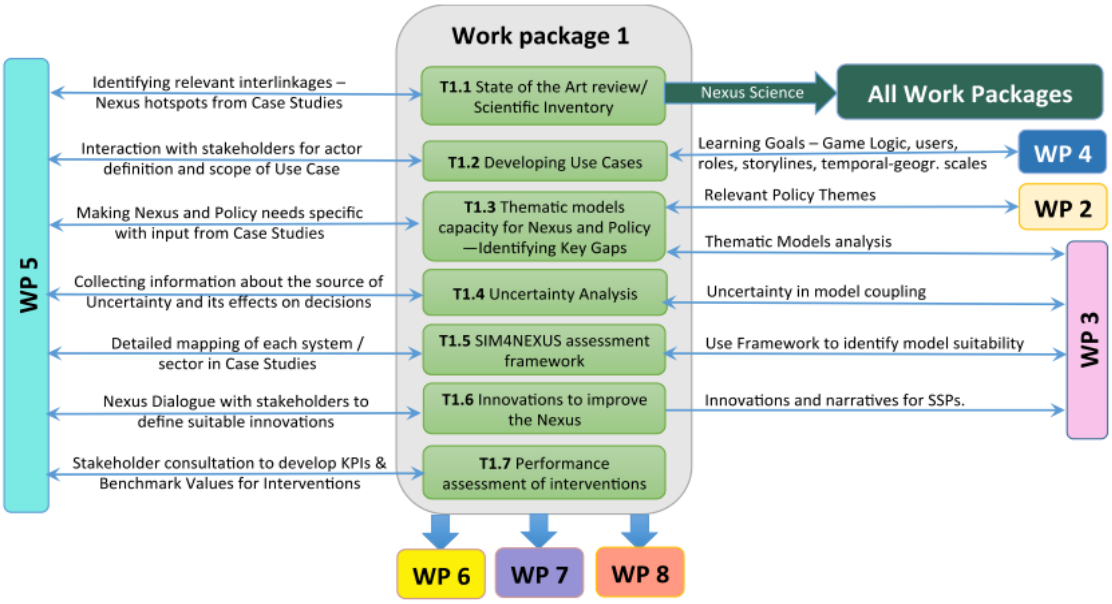


Figure 1. Task by Task diagram of Work Package 1 and interactions with other Work Packages in the project as established in the SIM4NEXUS Grant Agreement.

2.1. Interactions within WP1

Within WP1, Task 1.6 receives inputs from Task 1.1 “Scientific Inventory” and Task 1.5 “Nexus Framework”. It can also be of use for the development of use cases, Task 1.2, providing technological and low-carbon options that could potentially be included in the development of the Serious Game.

2.2. Interactions with WP2

Although no explicit connections are pointed out in the Grant Agreement on interactions between WP2 activities and task 1.6, it was found that interactions do exist. This is of particular relevance for the formulation of policy scenarios in for the identification of innovative policy options to address nexus challenges. Additionally, policy instruments and mechanisms often required technological change and innovative approaches. In the context of the nexus, policy interventions that can be deemed as conventional from a sectoral perspective may turn to be innovative when their application is performed in an integrated cross-sectoral manner.

2.3. Interactions with WP3

According to the task-by-task Work Packages diagrams in the Grant Agreement, Task 1.6 is fed by Task 3.2 “Downscaling of climate / climate change and socio-economic scenarios”. Task 3.2 provides insights about innovations and narratives for SSPs. Therefore, Deliverable 3.3 “Final Report on downscaling”, submitted in May 2018, is taken into consideration in the development of this task for the downscaling of Representative Concentration Pathways in line with SSP2. Other WP3 outputs relevant to task 1.6 are considered in the preparation of this report, namely D3.1 “Report on the “first run” simulation results of the thematic models: identifying gaps”, submitted in May 2017, and M17 “Thematic models applied to all case studies”, due in July 2018.

2.3. Interactions with WP5

Task 1.6 is relevant to the work in the case studies providing storylines for the baseline case, recommendations on innovations to improve the nexus. All of which pertinent for the forthcoming planned dialogues with stakeholders. The outputs of the task will also assist the case study leaders and teams in the production of scenario narratives and assessments of potential innovations to investigate in their case studies. Scenario narratives can be used to guide scenario model development and facilitate comparison of modelling results.

Sub-task 5.2.4 “Putting policy recommendations and innovations into practice” will be informed by Task 1.6 work, in terms of innovations and low-carbon options recommendations. WP2 will deliver recommendations based on policy papers analyses, bottom up interviews regarding implementation in practice and knowledge about success stories as a result of work developed in tasks 2.1 to 2.4. An executive summary on “Relevant policies and recommendations for policy improvements” is due in May 2019. Consequently, the policy innovations recommendations included in this report will not be extensive as this analysis falls beyond Task 1.6 scope.

3 The SSP scenario narratives

This chapter presents a summary of the SSP narratives. That includes why and how these were developed, and how they have been and are being used for selected applications of importance to the nexus. The chapter also includes a section dedicated to the SSP-RCP framework where its potential contribution in nexus assessments is explored. Particular focus is given to the SSP2 narrative as this was selected in the project as the benchmark for model development in the different case studies, constituting the baseline scenario for all case studies. Limitations on the use of the narratives are also discussed.

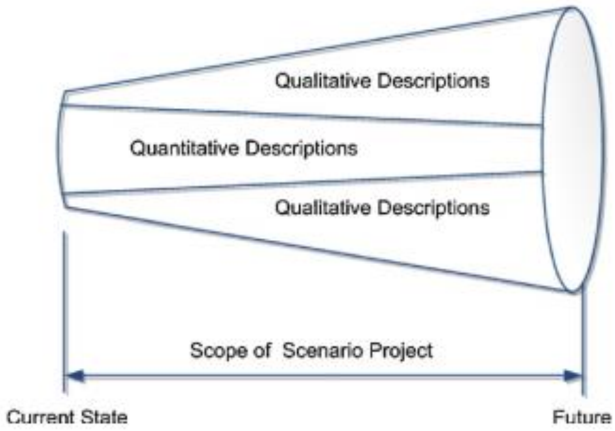


Figure 2. Illustration of qualitative and quantitative space of scenario narratives (Amer et al., 2013).

Scenario are an important tool used to describe potential futures that are lined to a set of assumptions, in a coherent and consistent manner (van Vliet et al., 2010), with the capacity of exploring temporal, spatial and functional scales (Kok et al., 2006). Narratives, or storylines, are a qualitative description of scenarios that aim at setting the boundaries for the specific future, while being broad enough to capture the inherent uncertainties related to the relationships and drivers in question. The quantitative representation of scenarios usually derives from the interpretation of a narrative by analysts. The latter explore how modelling or quantification frameworks are able to represent the future being described and what space of the narrative it is able to cover. **Error! Reference source not found.** provides a visual clarification of the scope covered by a narrative versus its interpretation with a quantitative scenario analysis. It is therefore essential to understand the differences between the qualitative (narratives) and quantitative (modelling) characteristics of scenarios, summarised in Table 1. As highlighted by (Johansen, 2018), scenario formulation should respect three main principles: plausibility (scenarios should be logical and build from cause-and-effect associations); consistent (assumptions should not be conflicting); and relevant (purpose is clear and useful).

Scenarios analysed in the SIM4NEXUS case studies will result from a plausible and consistent combination of development trends and interventions across systems and sectors. Once the scenario narratives are produced, then the translation into modelling tools is initiated

Table 1. Difference in characteristics of narratives (storylines) and models (van Vliet et al., 2010).

Narratives / Storylines	Models
Qualitative	Quantitative
Capture future worlds in stories, ideas and visions	Capture future system in numbers and rules on systems' behaviour

All aspects important to stakeholders can be included	Inclusion of aspects depend on data availability
No rules for validation on current system	Validated on current system
Above leads to large flexibility	Above leads to limited flexibility
Social effects included	Hard to include social effects
No fixed set of assumptions	Fixed set of assumptions
Not always internally coherent	Internally coherent
No clear system understanding	System understanding
No data needed	Need for data

3.1. Overview, development and status

The SSP narratives describe five plausible global development futures based on interactions between large regions of the world without taking into account the impacts of climate change nor incorporating climate policies (O'Neill et al., 2014). Their conceptual framework has its foundation in scenario development for using Integrated Assessment Models, primarily used in climate change research. The latter includes the analysis of emissions, land use change, mitigation, adaptation, impact and vulnerability analysis. The narratives, produced following a backcasting scenario formulation approach, consider a combination of changes to aspects that influence how societies may develop in the future. These aspects include demographic, economic, technological, social, governance and environmental factors (O'Neill et al., 2017), which are grouped in six categories for the development of the narratives which are referred to as "elements". The same elements are used in this deliverable to structure, draft and produce the SSP2-baseline storylines in each case study (which are presented in Chapter 4) and correspond to demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources (O'Neill et al., 2017). The challenge in this task is to contextualize and characterize socio-economic trends across the aforementioned elements into a multidimensional space of the nexus of domains in SIM4NEXUS. Some of them are clear drivers to resources demands; such is the case of demographics, human development, economy and lifestyle, and policies and institutions. The remainder, technology, and environment and natural resources, relate to the availability of resources and goods.

The narratives evolved from a maturing process of global scenarios development in different fields, from climate, social development and environmental research. Previous global scenarios efforts included: the Special Report Emissions Scenarios (SRES)(Nakicenovic et al., 2000), used in the IPCC 3rd and 4th Assessment Reports; the Global Environmental Outlook Scenario Framework (Raskin et al., 2004); the scenarios in the Millennium Ecosystem Assessment Report (MEA, 2005); and the RCPs scenarios used in the IPCC 5th Assessment Report (Moss et al., 2010). In a scenario comparison exercise between SSPs, RCPs and SRES, (van Vuuren and Carter, 2014) suggest that SRES scenarios B1[1] or A1B[2] could

[1] SRES B1 scenario family considers a world with global population peaking in mid-century, followed by a decline, and economies transitioning to services and information. Investments increase in clean and resource-efficient technologies. No climate initiatives are considered (IPCC, 2000 – summary to policymakers) (Nakicenovic et al., 2000).

[2] In the SRES A1B scenario, the world experiences fast economic growth, population peaking around mid-century followed by a decline) and the deployment of new and more efficient technologies, with a balanced distribution of resources used (i.e. not only non-fossil energy sources) (Nakicenovic et al., 2000).

correspond to a combination of SSP2 (middle-of-the-road) and RCP6.0[3]. In this analysis, the authors compared both the storylines and climate projections (e.g. atmospheric composition, radiative forcing). The selection of potential climate futures resulted from combining climate outcomes with different socio-economic pathways. This was performed at first as a qualitative exercise with the later objective of enabling its transference to quantitative interpretations (O'Neill et al., 2014) and then used in modelling exercises.

The development of the SSP narratives aimed at addressing limitations from previous global scenario narratives, to ensure that climate futures were consistent with socio-economic assumptions. The harmonization of assumptions and their reporting makes the SSPs an important tool in research (O'Neill et al., 2017), with the ability of providing a clear starting point to analysis. In addition, depending on the case-specific investigation, they can serve as benchmarks to modelling assumptions. In SIM4NEXUS, SSP2 data is used with the same principle of providing a starting point to the case studies models that characterise the baseline. As explained by (O'Neill et al., 2014), the formulation of SSPs resulted from the combination of two different approaches in scenario formulation: 1) selection of key socio-economic drivers and development pathways from their consistent combination of assumptions; and, 2) starting from the outcome and derive the socioeconomic assumptions that would lead to it, also known as "backcasting".

Five narratives characterize alternative and plausible global pathways of future societal development. SSPs 1 to 5 result from a different combination of challenges to mitigation and adaptation, as illustrated in Figure 3. The summary of the narratives is presented in Table 2 and the complete description from (O'Neill et al., 2017) is available in Appendix A. The baseline scenarios in the SIM4NEXUS case studies use data assumptions from SSP2. Challenges to mitigation are linked to fossil fuel use and limited international cooperation in addressing global environmental issues, such as climate change and GHG emissions. Intensity of challenges is influenced by the socio-economic trends like demographics and/or economic development that may lead, for example, to increased demands for energy, materials and food. Conversely, low mitigation challenges are presented by societies and economies that are energy efficient and with a low energy intensity. As for adaptation, high challenges are assumed to be connected to low socio-economic development, increased inequality between, barriers to trade and economic isolation; whereas low adaptation challenges are considered in pathways with increasing investments in human capital, reduced inequality and economic development that supports infrastructural development.

[3] RCP6.0, characterised as medium-baseline or high mitigation case, considers stabilization of radiative forcing, without overshooting, to 6.0 W/m2 after 2100 (van Vuuren et al., 2011).

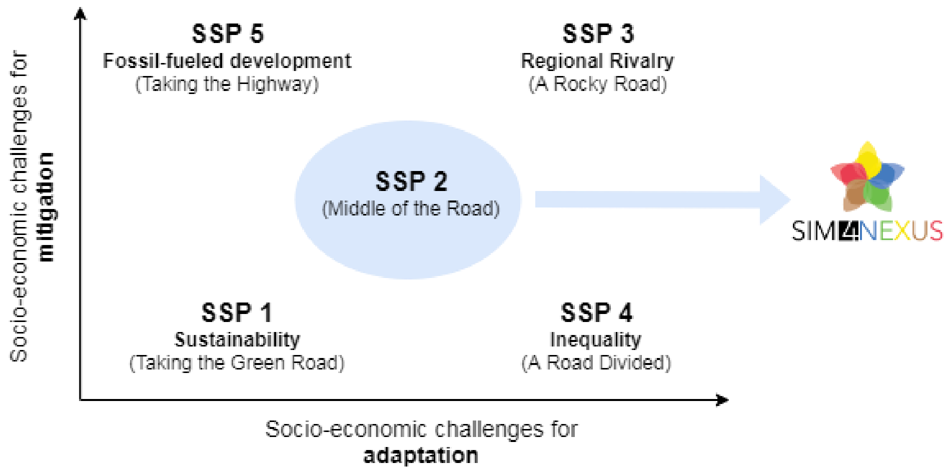


Figure 3. Illustrative diagram of SSPs in terms of combination of challenges to adaptation and mitigation (adapted from O'Neill et al. 2017).

The global SSP narratives are to be interpreted as "basic". They contain enough information to characterize development pathways that are reasonable and comparable in terms of mitigation and adaptation challenges (O'Neill et al., 2017). If a narrative were to be applied to smaller spatial scale or sector, it would require its "extension" to that particular case. The "extended" SSP narrative would have to respect the "basic" SSP pathway from which derives from. In quantitative terms, it could affect modelling assumptions. As suggested by O'Neill et al. (2017), "extended SSPs" should refer to assumptions that are consistent with the "basic" SSPs, but consider variables that allow for the characterization of the narrower scale and/or sectoral assessment. These narratives should be concordant with the global ("basic") narrative and, at the same time, case- and/or sector-specific, in a way that they can be translated into quantitative inputs to be used in modelling exercises. The "extension" of SSP narratives, in particular SSP2, is one of the aims of this task, to provide the translated application of SSP2 narrative to different scale case studies.

Table 2. Summary of SSP narratives (adapted from O'Neill et al., 2017, 2014). See Appendix A for the complete version of the narratives.

Pathway	Description
SSP1 (Sustainability)	Pathway that considers low challenges to mitigation (due to technological change, use of renewables, low energy demands and international cooperation) and to adaptation (driven by improvements in human well-being). The world follows a sustainable path, where sustainable goals are achieved, the environment is respected, and economies transition to resource-efficiency, decrease in inequality, land productivity increases and economic growth shifts to human well-being.
SSP2 (Middle of the road)	Intermediate case between SSP1 and SSP3 characterised by moderate mitigation and adaptation challenges. Social, economic and technological trends follow historical patterns with slow progress in the achieving sustainable development goals, no major technological advances; income inequality persists, as does social stratification.
SSP3 (Regional Rivalry)	High challenges for both mitigation and adaptation. Technological development is low, there is poor international cooperation, inequalities persist and regions and countries focus on national security goals, and environmental systems are strongly affected.
SSP4 (Inequality)	Large mitigative capacity due to technological development, however adaptation challenges are high due to demarcated and widened social stratification both within and across countries. Polarized capacity to overcome adaptation challenges: industrialized

	and high-income countries have economic means to tackle these issues; while low-income countries have limited capacity to cope with such problems.
SSP5 (fossil-fueled development)	Emerging economies and developing countries experience economic and social development, and there are investments in technological innovation, Education and health, which leads to an improvement of human and social capital. There is financial and technological capacity to address mitigation challenges (e.g. geoengineering) at local level, while global environmental awareness is low. Development is supported by intensive use of fossil fuels and societies tend to adopt lifestyles that are resource- and energy-intensive.

Due to the global perspective of the narratives, several open questions are left to address by the research community (O'Neill et al., 2017). These include: the transferability of the mitigation and adaptation challenges to smaller scales, e.g. local contexts (at macro-region level, local challenges may be balanced out in result of the aggregation); the diversity of the narratives and their usefulness (there should be intermediate pathways or a mixed combination of development pathways in different regions); the possibilities of multi-pathway development (narratives that explore different combination of mitigation and adaptation challenges, and also the timings of shift in trends); and the extension of the narratives (development of more detailed narratives to support detailed analyses, either per sector, domain or scale).

Many of these questions will be explored in Task 1.6, derived from the implementation of SSP2 in the development of the baseline scenario in the case studies. Extensions of the SSP2 narrative are presented in Chapter 4. In this chapter not only the transference of the narrative is explored, but also other elements of the narrative, not derived from the SSP database, are investigated. Since the analyses cover different nexus domains and their sectors, the interpretation of the "middle of the road" cross-sectoral assumptions are analysed. It is important to note that the framing of the SIM4NEXUS narratives differs from the SSPs. Less emphasis is given to adaptation and mitigation challenges, and we aim for the development of a "nexus" challenge space, that is related to the integrated operation and functioning of the different nexus systems under different development and policy assumptions.

3.2. The SSP-RCP framework

The Representative Concentration Pathways set emissions and concentration trajectories of atmospheric constituents for the 21st century (van Ruijven et al., 2014; van Vuuren and Carter, 2014). Datasets are available online at the RCP Database (version 2.0.5)[4], a repository hosted by IIASA. The trajectories did not result from a specific analysis process that lead to their estimation. Alternatively, they resulted from the selection of emissions pathways based on results from existing independent climate change modelling assessments, with climate forcing ranging from 2.6 to 8.5 W/m2, that meet the criteria defined for the selection of the representative trajectories (van Vuuren et al., 2011). The RCPs were created to be used as inputs in climate models that then assess the potential impact of the concentrations of gases to the climate system, as was done in the Coupled Model Intercomparison Project Phase 5 (CMIP5). A summary of the RCPs is presented in Table 3, and radiative forcing and CO2,eq concentration projections for the World in Figure 4. In SIM4NEXUS, RCP6.0 was selected has the

[4] RCP Database online - https://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=about

"reference" climate future and climate data was downscaled to the case studies (Deliverable 3.2). The trajectories for concentration and radiative forcing, in RCP6.0 do not differ greatly from RCP4.5, especially until 2050. The projected concentration and forcing in RCP6.0 is quite similar to RCP2.6 up to 2040, and lower than in RCP4.5 until 2060.

Table 3. Overview of RCPs ("RCP Database," n.d.; van Vuuren et al., 2011). Radiative forcing levels include the net effect of all anthropogenic GHGs and other forcing agents.

		RCP 2.6 (lowest mitigation scenario)	RCP 4.5 (intermediate mitigation scenario)	RCP 6.0 (medium baseline or high mitigation scenario)	RCP 8.5 (high emission scenario)
Description		Peak in radiative forcing at ~3 w/m2 (~490 ppm $CO_{2,eq}$) before 2100 and then decline (the selected pathway declines to 2.6 w/m^2 by 2100).	Stabilization without overshoot pathway to 4.5 w/m^2 (~650 ppm $CO_{2,eq}$) at stabilization after 2100.	Stabilization without overshoot pathway to 6.0 w/m^2 (~850 ppm $CO_{2,eq}$) at stabilization after 2100.	Rising radiative forcing pathway leading to 8.5 w/m^2 (~1370 ppm) by 2100.
IAM, Publication		IMAGE (Van Vuuren et al., 2007)	GCAM (Clarke et al., 2007; Wigley, 2006; Wise et al., 2009)	AIM (Fujino et al., 2006)	MESSAGE (Riahi et al., 2007)
Scenario component	GHG	Very low	Medium-low mitigation; Very low baseline	Medium baseline; high mitigation	High baseline
	Agricultural Area	Medium for cropland and pasture	Very low for cropland and pasture	Medium for cropland but very low for pasture (total low)	Very low for cropland and
	Air pollution	Medium-low	Medium	Medium	Medium-high

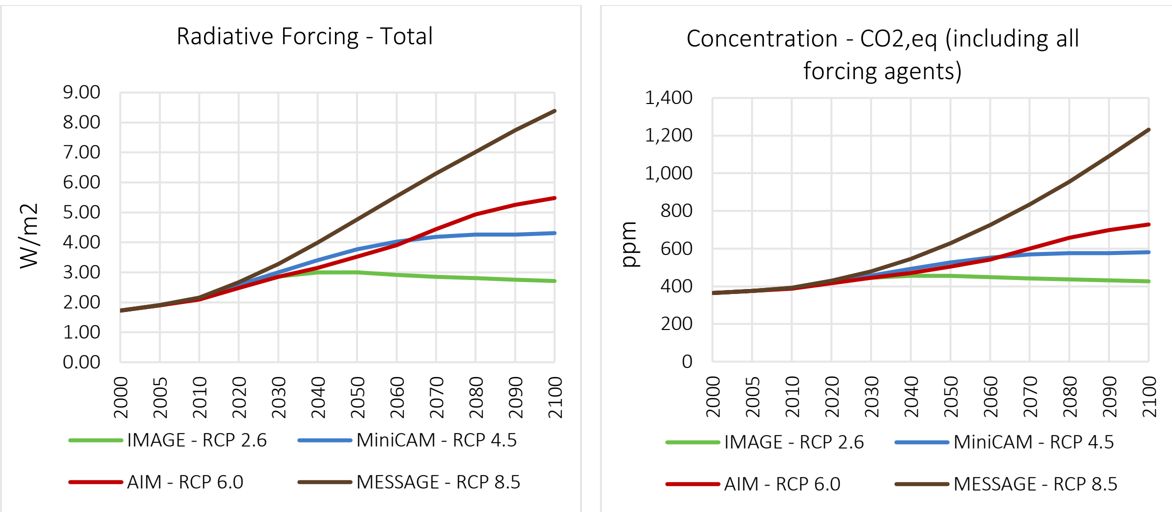


Figure 4. Total radiative forcing (left) and $CO_{2,eq}$ concentration (including all forcing agents), at global level, for RCPs 2.6 – 8.5 (RCP Database).

Even though the RCPs are linked to underlying socio-economic assumptions considered in each IAM analysis, these assumptions are specific to the modelling framework used to produce the emissions outputs. This means they may differ among IAMs in terms of inputs and methods.

The development of the SSPs narratives facilitated the definition of a challenge space for mitigation and adaptation for different futures of socio-economic development (e.g. population growth, economic development, technological change), in disregard of any particular climate outcome and incorporation of any climate policy (van Vuuren and Carter, 2014). This means that the quantification of the SSP narratives leads to specific emissions that are a function of how the elements of the narrative were defined and set. See below results for the baseline SSP scenario markers for different variables related to population, GDP, climate, energy and land use for the region of the countries part of the Organisation for Economic Cooperation and Development (OECD), for the baselines of each SSP marker (Figure 5).

From the results presented, it is possible to link the qualitative descriptions in the “basic” narratives to their quantitative interpretation and subsequent analysis using the IAMs. Taking as an example SSP2, the “middle of the road pathway” considers moderate changes to population and GDP in the OECD region, which do not differ much from SSP1 (sustainability) and SSP4 (inequality) scenario markers values.

Dynamics of other narrative elements across SSPs, e.g. technology, environment, human development, and their translation into the different models, is reflected in outputs that are linked to such type of assumptions. Note that we present here selected results for the OECD group of countries, which means that the trends indicated are not necessarily the same as experienced in other regions of the world. Take the example of emissions and primary energy (Figure 5c and d). Although primary energy consumption does not vary substantially between SSP2, 3 and 4; emissions in SSP3 (fossil-fuelled development) are higher than for the other two scenarios’ baseline, which is linked to the consumption of fossil fuels and little transition to the use of low carbon sources. For other regions in the world, assumptions related to inequality and international cooperation affect greatly the consumption of primary energy and therefore the emissions, and for a clear understanding of the narrative, dynamics in the different regions need to be analysed. At global level, and since most of the European countries under analysis in the SIM4NEXUS case studies belong to the OECD, different socio-economic futures might not lead to major differences in the certain nexus domains, energy and land, due to the actual level of development. However, national and sub-national contexts are different, and it will be important to capture such differences in the case studies, which in this task assumes the form of narratives.

SSPs can be coupled with RCPs adding a dimension of mitigation analysis to the modelling exercises, since SSPs do not consider any climate policy in their design (Bauer et al., 2017). Such assumptions imply that most of these basic SSPs are expected to result in emission levels consistent with the higher-end of the RCP range (with exception of SSP1). It is only by introducing mitigation policies (a component of Shared Policy Assumptions, SPAs) that emission levels can be oriented towards the lower-end of the RCP range (and here (van Vuuren and Carter, 2014) cite (Kriegler et al., 2014)). The RCPs can then be used to investigate mitigation solutions/policies to achieve different concentration pathways under each set of global socio-economic assumptions.

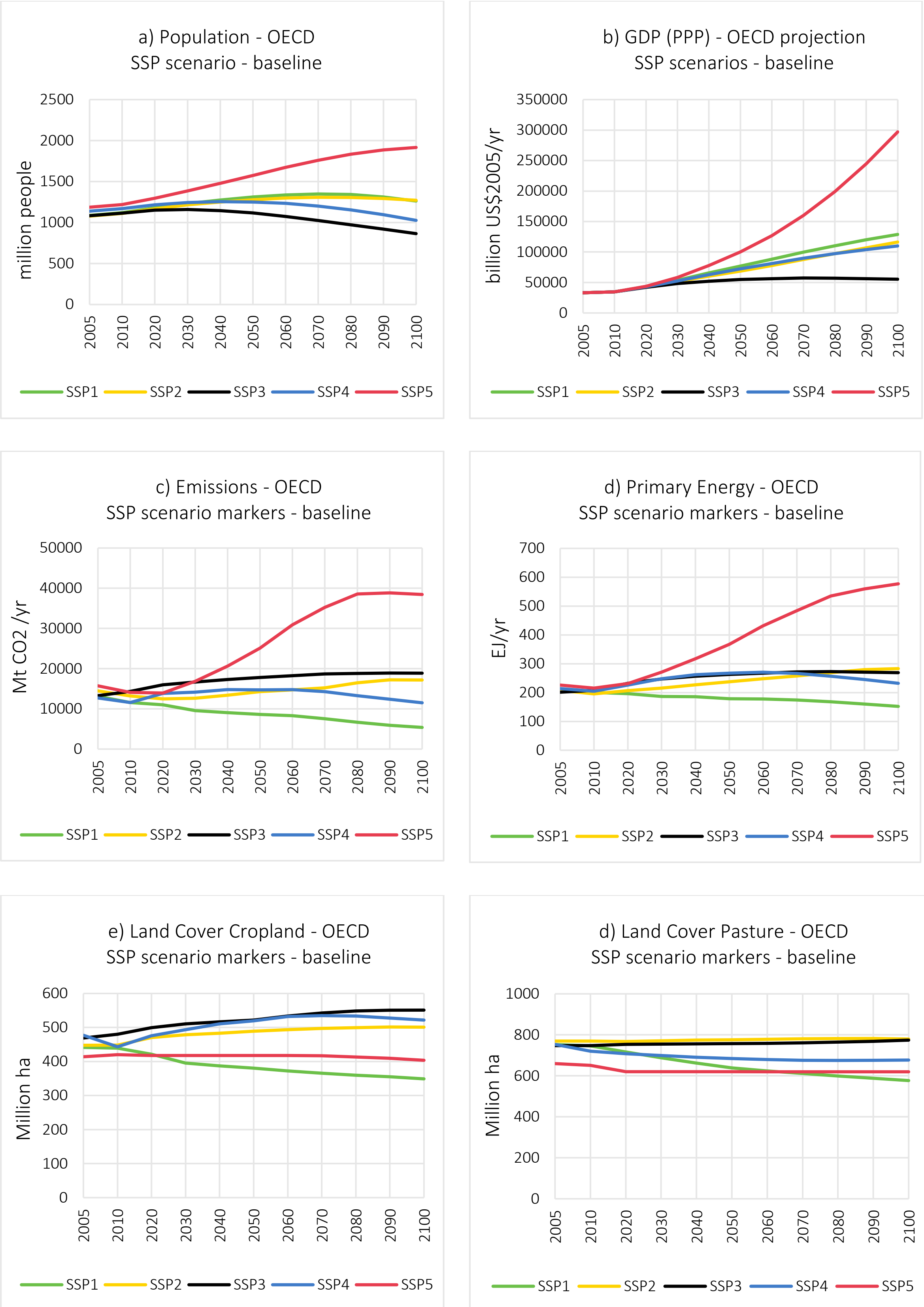


Figure 5. Selected results for SSP 1 - 5 scenario markers for the OECD region: a) population; b) GDP; c) total CO2 emissions; d) primary energy; e) land cover – cropland; f) land cover - pasture (data retrieved from the SSP database).

Figure 6 compiles selected results for SSP2 baseline and RCPs 2.6, 4.5 and 6.0, obtained in the SSP2 scenario marker (MESSAGE-GLOBIOM) for the world. The analysis of the emissions results indicates the baseline as the scenario with highest CO2 emissions, followed consecutively by the highest to lowest forcing SSP2- RCP combination scenarios. The achievement of a radiative forcing in line with RCP6.0 would require the mitigation of 6.6 Gt CO_2 from 2010 to 2050; and, 97 Gt CO_2 from 2010 to 2100. Reaching these mitigation targets implies the implementation of climate policies that span across different sectors represented in the modelling framework used in the investigation. For example, forest cover would be required to increase and final energy consumption to decrease.

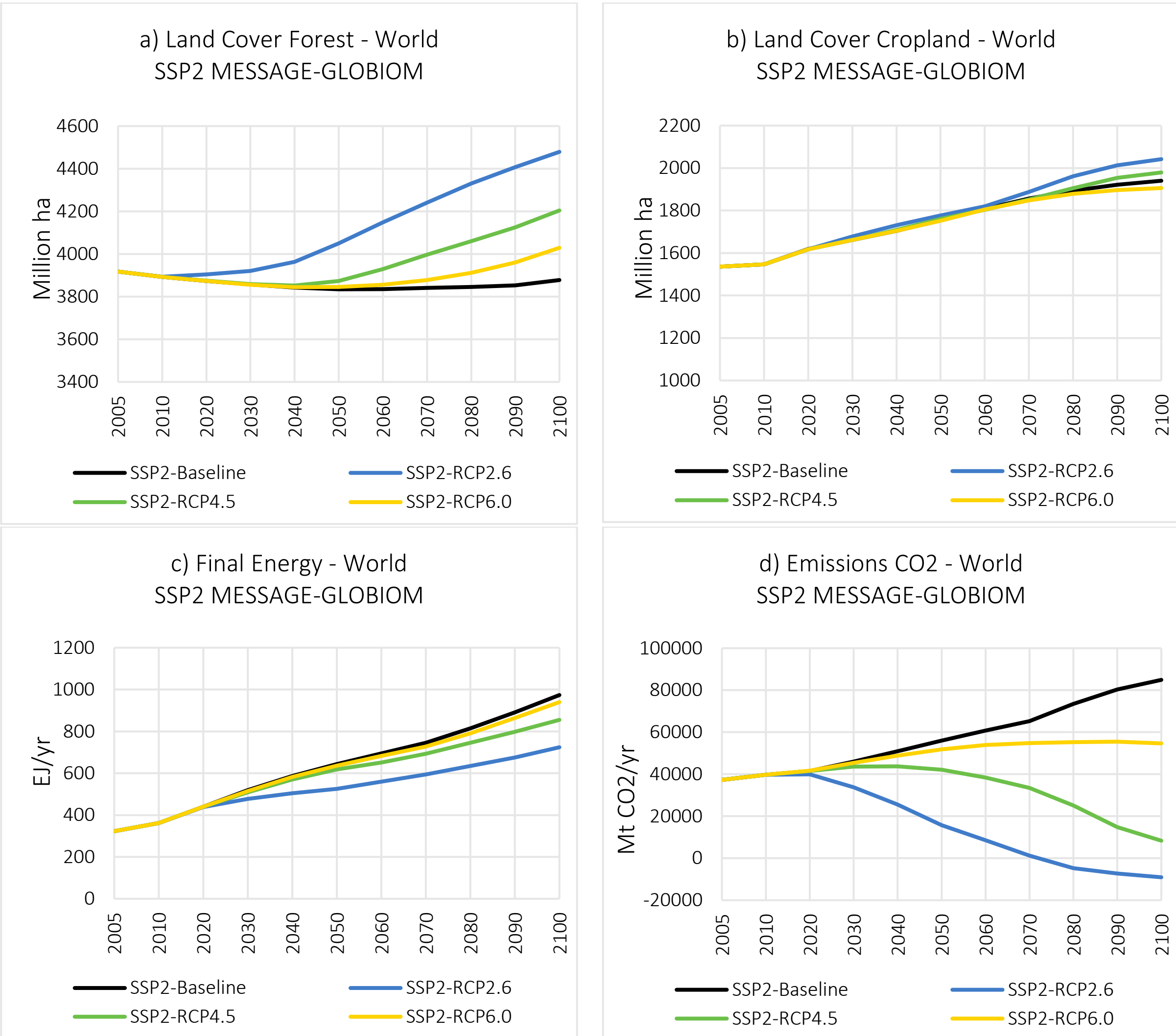


Figure 6. Results for SSP2 scenario marker for selected variables for the world: a) land use forest; b) land use cropland; c) primary energy; d) CO2 emissions (SSP Database).

The alignment of a particular SSP with a concentration pathway is possible through climate policy assumptions. Kriegler et al. (2014) introduce the concept of Shared Climate Policy Assumptions (SPA) as the elements that allow for the correspondence or coupling between RCPs and SSPs to be achieved.

RCPs and SSPs can be brought together into a two-dimensional matrix with the extra dimension of SPAs, as presented in Figure 7. The policy assumptions, interpreted as policy goals, instruments and obstacles to mitigation and adaptation challenges (Kriegler et al., 2014), ensure the consistency and overlap between the emissions trajectory (RCP) and the socio-economic context described in the SSP (van

Vuuren and Carter, 2014). Thus, each cell of the SSP-RCP matrix will correspond to a combination of mitigation and adaptation policies. To facilitate comparison across scenarios and models, similar policy assumptions for a specific scenario should be made, corresponding effectively to “shared” policy assumptions. Examples of mitigation policies include universal carbon tax and technology standards; while adaptation policy could be represented with international support for adaptation, adaptation finance mechanisms (van Vuuren et al., 2014). In addition, the timing of the implementation of the range of SPAs taken into account, the way and the actors of implementation are important aspects to take into account.

The matrix architecture facilitates the investigation of different research questions. For a given SSP, it allows the assessment of mitigation and adaptation costs for different forcing levels (analysis down the column). On the other hand, the implications and steps towards achieving a certain emission trajectory can be compared for different socio-economic development futures (analysis across rows) (van Vuuren et al., 2014). This is useful in the development of scenarios and their location in the matrix. It enables comparison across scenarios and, for the same scenario, the exploration of uncertainty if different modelling tools are used to investigate a similar set of conditions.

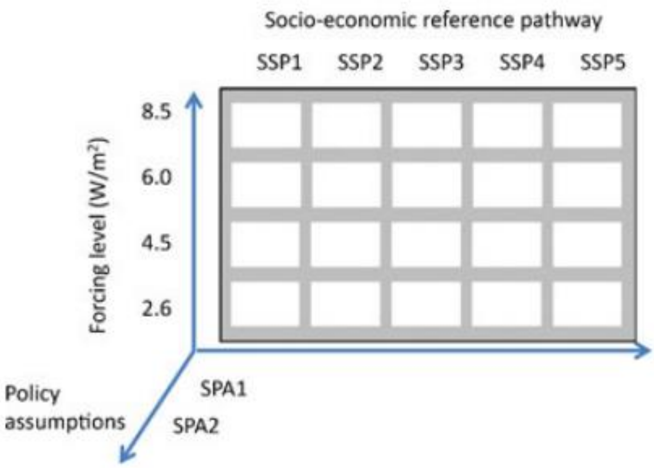


Figure 7. The SSP-RCP scenario matrix with the additional dimension of SPAs (van Vuuren et al., 2014).

Figure 8 illustrates the example of the impact in terms of costs (matrix on the left) and residual impacts (matrix on the right) of different levels of adaptation policies for SSP2 as a function of different forcing futures (Kriegler et al., 2014). Adaptation costs in a higher radiative forcing, for an aggressive context implementation of adaptation policies, will also be high because climate change impacts will be more severe; whereas in a similar policy context, but for a lower radiate forcing, adaptation costs will be lower since the corresponding residual impacts are also low because of the mitigation efforts. The SSP-RCP scenario matrix is presented by van Vuuren et al. (2014) as an “heuristic tool” that can be used, not only to produce new scenarios, but also to classify climate research studies developed in the past.

In SIM4NEXUS policy assumptions are used in the development of scenarios. The policies to be considered in each case study span across different sectors of the nexus domains; cover different regions and contexts, and may differ in period of implementation. In climate research, the climate policy assumptions extend over a longer period and have a wider spatial scale coverage. The latter may not be of particular interest or relevance to stakeholders whose action/operation focuses on smaller spatial and temporal scales. Although a mismatch exists in purpose and scope of scenario analysis of climate research and decision support, Kriegler et al. (2014) argue that complementary should be sought.

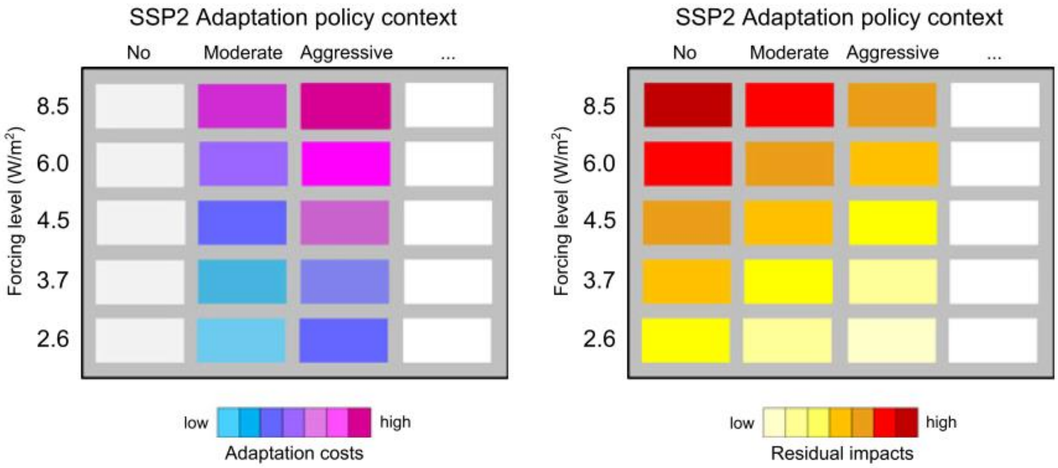


Figure 8. Example of analysis of the adaptation policy context (no adaptation, moderate and aggressive) for SSP2 and different radiative forcing levels. Adaptation costs are illustrated in the matrix on the left, and residual impacts on the right (Kriegler et al., 2014).

For most of the cases in SIM4NEXUS, the SSP-RCP combination corresponds to SSP2- RCP6.0. It will be crucial to clarify the baseline so to assist the development of the scenarios. This could imply distinguishing the type of policies at play from policies that affect socio-economic development with no implications to climate, from the policies that could have climate implications. This classification could facilitate the interpretation of the impacts of policy measures, at least, in the two broad categories of socio-economic development and climate adaptation and mitigation.

3.3. Selected application and use

The SSP narratives provide guidance in the identification of elements in models that can be affected by socioeconomic drivers, related to demographics, economy, human development; and other elements of the narratives linked to technological development and the environment. The transfer of the trends that characterize each pathway into different IAMs were used to derive corresponding projections for energy, land use and emissions, which constituted the baselines of each SSP. Additionally, mitigation scenarios resulting from the combination with RCP emissions trajectories, were also tested with different IAMs. **Error! Reference source not found.** illustrates this process.

Six IAMs were deployed in the quantitative translation of the SSP narratives: IMAGE (Netherlands Environmental Assessment Agency, PBL), MESSAGE-GLOBIOM (IIASA), AIM (National Institute for Environmental Studies, NIES), GCAM (Pacific Northwest National Laboratory, PNNL), REMIND-MAgPIE (Potsdam Institute for Climate Impact Research, PIK) and WITCH-GLOBIOM (Fondazione Eni Enrico Mattei, FEEM). A "marker" scenario, from the SSPs implementations in the different IAMs, was selected to represent the reference quantification pathway for each SSP. "Marker" scenarios were selected based on the IAM capacity of representing SSP characteristics and for the sake of internal consistency within all markers (Riahi et al., 2017). Not all SSPs scenarios were run by all the IAMs. Marker models and SSPs implemented by each IAM is summarised in Table 4 (Popp et al., 2017).

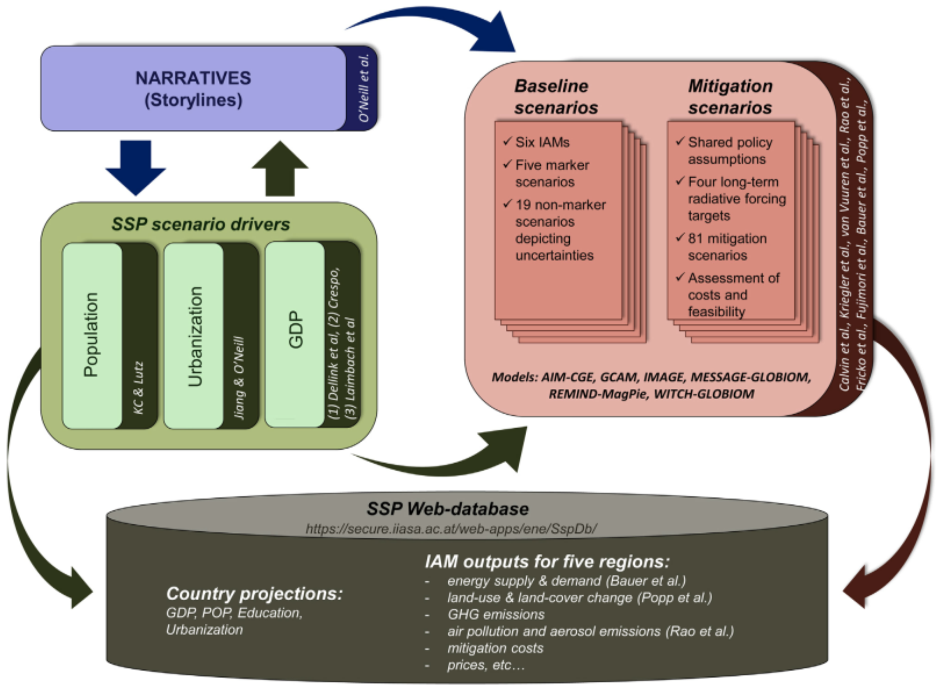


Figure 9. Main steps in the development of the SSP narratives and implementation in IAMs (Riahi et al., 2017).

Socioeconomic projections were produced at the country level (Riahi et al., 2017). Population data projections were prepared by (Kc and Lutz, 2017) and took into consideration factors such as age, sex and level of education. Global urbanization scenarios were produced by (Jiang and O'Neill, 2017). Economic growth pathways were investigated by three different teams: IIASA (Crespo Cuaresma, 2017), PIK (Leimbach et al., 2017) and OECD (Dellink et al., 2017). For the SSP scenario markers, Dellink et al (2017) GDP projections were used. For a summary of the methods used in the estimation of the socio-economic assumptions see the "Supplementary note for the SSP data sets" available from the SSP Database website (IIASA Energy Program, 2012).

Table 4. SSPs implementation in IAMs and marker scenarios (Popp et al., 2017).

SSP identifier	Descriptor	Marker model / Institution	Also computed by
SSP1	Sustainability	IMAGE-MAGNET (PBL, LEI)	All IAMs
SSP2	Middle-of-the-road	MESSAGE-GLOBIOM (IIASA)	All IAMs
SSP3	Regional Rivalry	AIM/CGE (NIES)	IMAGE, MESSAGE-GLOBIOM, GCAM (only baseline)
SSP4	Inequality	GCAM (PNNL)	AIM/CGE
SSP5	Fossil-fueled development	REMIND-MAgPIE (PIK)	AIM/CGE, GCAM

3.3.1. Global scale applications

Quantification analysis using the SSP narratives is frequently found in global and macro-region level analysis to support climate change mitigation and adaptation research. The extension of the global and "basic" narratives to smaller scale and/or sectoral contexts is starting to be explored. The extension of the global SSP narratives, and the RCPs, was produced in agricultural research as part of the Agriculture Model Inter-comparison Project (AgMIP) (Rosenzweig et al., 2013). We present examples of the use of the narratives in scenario analysis at global scale, with emphasis on SSP2-related findings. These include: an overview of the overall SSPs quantification exercise by (Riahi et al., 2017) in terms of energy, land use and emissions; the analysis of the narratives from the energy sector perspective for two mitigation scenarios by (Bauer et al., 2017); and lastly, a similar effort as the latter applied to land use by (Popp et al., 2017). Two examples of the extension of the narratives to smaller-scale contexts are also briefly discussed, both of which involving stakeholder participation.

An overview of the quantitative translation of the SSP narratives in a multi-model exercise is described in (Riahi et al., 2017). The focus of the analysis was the investigation of the implications of the narratives in term of energy, land use and GHG emissions. The development of the SSP scenarios to be used in the IAMs consisted of three main steps: 1) translation of the narratives into "input tables" for the quantitative representation of the key elements (for the latter, see Appendix A); 2) projections of key socioeconomic drivers (e.g. population, GDP, urbanization); 3) combination of the two previous steps and implementation in the IAMs. This quantitative interpretation of the narratives resulted in projections for energy, land use and GHG emissions of each SSP (Riahi et al., 2017). Total population estimates ranged from 7 billion people, in SSPs 1 and 5, and 12.6 billion people in SSP3. For SSP2, population reached 9.2 billion in 2050, peaked at 9.4 billion in 2070, and reaching the end of the century with around 9.0 billion. Urbanization increases in all scenarios, arriving to 60% (SSP3), 80% in SSP2 (in line with the UN projections) and 92% in SSPs 1, 4 and 5. In terms of economic growth, the projections are consistent with previous global scenarios studies. The highest GDP projection was obtained for SSP5 (fossil-fuelled economy) that considers rapid development and global convergence of income until the end of the century. Lowest projection was achieved for SSP3 (inequality), with world average income by 2100 estimated at 20,000 US$2005/year; in contrast with 60,000 US$2005/year in SSP2, and 140,000 US$2005/year in SSP5 (IIASA Energy Program, 2012; Riahi et al., 2017).

Key drivers for the energy system are identified to be assumptions made concerning technological change, economic growth, new energy services, energy intensity of services and in terms of costs and fuel resources reserves. SSP2 assumes the continuation of the use of fossil fuels and their dominance in the energy mix. In terms of energy demand, it doubles by mid-century and triples by the end of the century, in comparison to 2005. Land use dynamics are driven by agricultural and industrial demands (e.g. biofuels, timber, food, feed). SSP1 was the scenario in which land-use dynamics shifted the most from historical trends, with expansion of forests and natural lands; while in the remainder SSPs, changes were not so pronounced, with some variation in terms of cropland. GHG emissions are linked to the energy and land use trajectories. As expected, SSPs 3 and 5, correspond to the highest CO2 emissions due to the continued use of fossil fuels since these are the pathways with high challenges to mitigation. In contrast, SSP1 (sustainability) is the scenario with lower emissions and, consequently, radiative forcing. In SSP2, CO2 emissions double progressively until the end of the century. Major drivers for CH4 emissions include population growth and food demand; agricultural soil and fertilizer use in the case of N2O. The emissions trajectories will depend also on the assumptions taken in each IAM in the interpretation of each narrative. It was found that the baselines cover a radiative forcing range between 5.0 and 8.7 W/m2 by 2100. When analysing the consistency of the narratives, the authors conclude that an RCP8.5 future would only be feasible within conditions presented in the SSP5 narrative (fossil-fuelled future, high mitigation challenges). The radiative forcing in SSP2 baseline corresponds to 6.5 W/m2 in 2100 and a global mean temperature increase of 2.0 °C in 2050 and 3.8 °C in 2100.

Energy sector extension of the SSP2 narrative

Bauer et al. (2017) investigate energy futures for the five SSPs narratives (baseline scenarios) and two mitigation scenarios corresponding to end of the century radiative forcing levels of 2.6 and 4.5 W/m2. The quantification of the narratives from the perspective of the energy sector required the extension of the global "basic" narratives to sector-specific versions, even though the scope of the analysis remains global. The study introduces the five energy sector SSPs narratives. This type of exercise has the purpose of facilitating the harmonisation of assumptions across modelling frameworks, to the extent possible, and to streamline the translation of the specified elements in the parameters considered in the models. In the case of the energy system extension, considerations were made concerning final energy demand, energy conversion technologies and supply of fossil fuels. We present below the energy sector-specific narrative that corresponds to SSP2. Other narratives are reported at Bauer et al. (2017). Table 5 summarises description of SSP narrative elements of relevance to the extension of the SSP2 narrative to the analysis of the energy sector, and Table 6 provides an overview of results.

Table 5. Overview of narrative elements for the extension of the SSP2 narrative in the analysis of the energy sector (Bauer et al., 2017, including supplementary material).

General narrative elements	SSP2 interpretation in the perspective of the energy sector
Economy and lifestyle	semi-open globalized economy material-intensive consumption, medium meat consumption
Policies and Institutions	concern for local pollutants but only moderate success in implementation weak focus on sustainability uneven, modes effectiveness
Technology	some investment in renewables but continued reliance in fossil fuels medium carbon intensity; uneven energy intensity, higher in low income countries (LICs)
Environment and natural resources	no reluctance to use unconventional fossil resources continued environmental degradation
SPAs (not in baselines; only mitigation scenarios)	fragmentation up until 2020 thereafter, transition to globally uniform carbon price up until 2040
Energy sector narrative elements	**SSP2 description**
Energy demand side	In SSP2 service demand levels are intermediate (between SSP1 (modest demand levels) and SSP5 (high energy service demand) on a per capita level) and also energy intensity of services is intermediate across all end-use sectors.
Energy conversion	This is the world where energy intensity and fossil fuel dependency continue to decrease at historic rates. Both technology development and social acceptance for all conversion technologies are assumed to be 'middle-of-the-road' among the five SSPs.
Fossil fuel supply	SSP2 is the middle of the road scenario and therefore medium assumptions (between SSP1 – low availability, and SSP5 – high availability and use of fossil fuels) for the availability of fossil fuels are applied.
SSP2 extension to the energy sector	
Energy intensity improvements continue at global historical growth rates with a medium degree of regional convergence. Technological improvements are medium for all technologies and social acceptance does not shift markedly. This results in moderate growth if the energy sector, no remarkable shifts in the primary energy mix and continued modernization of the final energy mix.	

The results presented in the following table provide an example of what the narrative implies in quantitative terms. Modelling assumptions and modelling framework set-ups are related to the type of messages that can be derived from the exercise. Therefore, it is important to understand how to translate the narrative into modelling parameters and to be transparent in this implementation. For more details on the assumptions used in the different IAMs, the reader is advised to consult the supplementary material of Bauer et al. (2017).

Table 6. Overview of energy sector results for the SSP2 baseline in the marker scenario (MESSAGE-GLOBIOM) (Bauer et al., 2017)

Result category	Description
Global final energy demand	Similar trajectory to historical growth rates of 1.4%/year until 2050.
Regional trends in final energy demand	Historic coupling between GDP and energy is ongoing although GDP grows faster than energy demand. Final energy consumption in OECD countries increase by 20% by the end of the century, even though income per capita triples. Developing and emerging economies follow less energy intensive development pathways and energy demand and GDP coupling is stronger. Convergence in energy use is not achieved.
Final energy mix	Moderate modernization of final energy use with mixed contribution of traditional and modern energy carriers. Increased use of electricity., which doubles by mid-century and quintuples by 2100; but also increase in the use of coal, which also doubles by 2050 and triples by the end of the century (to power the industrial development in Asia, Africa and Middle East).
Primary energy supply – primary energy mix	Substantial growth in primary energy dominated by fossil fuels with a small increase in wind and solar. Oil supply peaks in 2050, and grows again at the end of the century with expanding non-conventional oil production. Coal and natural gas increase continuously throughout the century and show 50% and 125% higher production levels, respectively, from 2010 to 2050.
Primary energy supply – fossil fuel use	Over 85% of fossil energy in total primary energy in 2050 and around 80% in 2100. Energy sector emissions show moderate growth rates (1.2%/yr for the period 2010-50) which accelerate during the second half of the century with the increased use of coal.

Land use extension of the SSP2 narrative

The interpretation of land use implications of the different SSPs, in terms of changes in agricultural systems, food supply and prices and GHG emissions, is performed by (Popp et al., 2017). The approach is similar to the one of the energy sector, but the focus of the analysis of the IAM SSP scenarios is the assessment of changes to land use and land systems. Population growth, dietary preferences, income, agricultural trade, and demand for non-food products (such as biofuels and manufacturing) are key drivers to changes in land use. The study allows to understand dynamics of land use change and estimate ranges of different major land classes, in line with the SSP storylines. For example, it is found that in a SSP1 cropland area would not vary much, remaining around 1,500 million ha by 2100, or it could reach 2,300 million ha in a SSP3 future, considering only the baseline marker scenario results. The range of results varies even more when mitigation scenarios are explored, due to the dynamic response of land systems, their activities and associated emissions. In Table 7Table 5 summarises description of SSP narrative elements of relevance to the extension of the SSP2 narrative to the analysis of land use, and

Table 8 provides an overview of results.

Table 7. Narrative elements for the extension of the SSP2 narrative in the analysis of land use (O'Neill et al., 2017; Popp et al., 2017).

<table>
<tr><th>General narrative elements</th><th>SSP2 assumptions of particular relevance to land use</th></tr>
<tr><td>Economy and lifestyle</td><td>Moderate international trade;
Material-intensive consumption, medium meat consumption;</td></tr>
<tr><td>Policies and Institutions</td><td>Concern for local pollutants but only moderate success in implementation;
Weak focus on sustainability</td></tr>
<tr><td>Technology</td><td>Slow technological transfer and continued reliance on fossil fuels</td></tr>
<tr><td>Environment and natural resources</td><td>Continued degradation of the environment
Medium land use regulation lead to slow decline in the rate of deforestation
Medium pace of technological change in the agriculture sector; slow reduction in entry barriers to the agricultural markets</td></tr>
<tr><td>SPAs (not in baselines; only mitigation scenarios)</td><td>Carbon tax, changes in agricultural management, increased bioenergy production, afforestation</td></tr>
<tr><th>Land use scenario element</th><th>Description for SSP2</th></tr>
<tr><td>Land-use change regulation</td><td>Medium regulation; slow decline in the rate of deforestation</td></tr>
<tr><td>Land productivity growth</td><td>Medium pace of technological change</td></tr>
<tr><td>Environmental impact of food consumption</td><td>Material-intensive consumption, medium meat consumption</td></tr>
<tr><td>International trade</td><td>Moderate</td></tr>
<tr><td>Globalization</td><td>Semi-open globalized economy</td></tr>
<tr><td>(SPA) Land-based mitigation policies</td><td>Delayed international cooperation for climate change mitigation. Partial participation of the land use sector.</td></tr>
<tr><th colspan="2">SSP2 extension to land use (Popp et al., 2017)</th></tr>
<tr><td colspan="2">The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Land use change is incompletely regulated, i.e. tropical deforestation continues, although at slowly declining rates over time. Rates of crop yield increase decline slowly over time, but low-income regions catch up to a certain extent. Caloric consumption and animal calorie shares converge slowly towards high levels. International trade remains to large extent regionalized. In SSP2, international cooperation for climate change mitigation is delayed due to a transition phase to a uniform carbon price until 2040. In this transition phase, emissions from agricultural production are priced at the level of energy sector emissions, while avoided deforestation and afforestation are not incentivised before 2030.</td></tr>
</table>

Table 8. Overview of land use results for the SSP2 baseline in the marker scenario (MESSAGE-GLOBIOM) (Popp et al., 2017).

Result category	Description
Demand, production and trade	Population dynamics, per capita caloric consumption and animal calorie shares increase moderately, increasing moderately global demand for crops (plus 2860 million t DM in 2100) and livestock products (plus 235 million t DM in 2100), especially in Asia. Production remains regionalised and trade with agricultural goods grows slowly.
Trends in land use and agricultural intensification	The use of cropland for food and feed production increases moderately in SSP2 (plus 231 million ha between 2005 and 2100), due to relatively high demand for food and feed crops, combined with high yield (by a factor of 1.6 between 2005 and 2100). Pasture area increases strongly (plus 204 million ha until 2100). Agricultural expansion mainly happens in Middle East and Africa (MAF), and Latin America (LAM) because of medium demand for livestock products satisfied mostly through more extensive livestock production systems, with pasture land expansion happening at the expense of forest and natural land.
Projections of GHG emissions	Global CO2 emissions from land use change amount to 219 Gt CO2 cumulatively between 2005 and 2100. Annual CO2 emissions decrease steadily until the end of the century and are negative from 2080 onwards. Emissions occur mainly in MAF and LAM because of cropland and pasture expansion and the associated loss of forest and other natural land. Carbon uptake happens from mid-century onwards, mainly through the regrowth of vegetation in Asia. Annual CH4 emissions from agricultural production increase by 41 Mt CH4 between 2005 and 2050 and then remain fairly constant due to lower increases in demand, especially for livestock products, and more intensified livestock production systems associated with lower emission factors. Annual N2O emissions increase by 3.5 Mt N2O through 2100.
Food price dynamics	Major drivers for long-term changes in world food prices are changes in population, income, international trade, agricultural expansion and technological change.SSP2 (as well as in SSPs 4 and 5) show either flat or slightly falling world market prices for crops and livestock products by 2100, compared to 2005.

3.3.2. Regional and sub-national extension of the narratives

In this sub-section, we explore three examples of translation of the SSP global narratives to smaller scale levels, both in spatial and functional (or sectoral) levels. In each of the cases, the approach used in the formulation of the narratives is explained. Examples of the narratives are given to clarify the outcome of the process.

Extending the SSPs narratives to the agriculture, water and energy in the U.S. southeast region for the assessment of climate change impacts and adaptation

One of the first exercises of extending the SSP global narratives to a sub-national level is conducted by Absar and Preston (2015). In this study, sub-national and sectoral extensions of the global SSP storylines are developed to identify future socioeconomic challenges for adaptation for the U.S. Southeast. To achieve this, a set of nested qualitative socioeconomic storyline ‘elements’, integrated storylines, and

accompanying quantitative indicators were developed. Sectors investigated included agriculture, water and energy.
The 'one-to-one'[5] approach (see Figure 10, diagram A) and the FAS framework[6] (Kok et al., 2006) were used as means of developing embedded storylines for the current study based on the SSPs, with exception of SSP4 (Inequality). The FAS framework allows addressing the complexity of socioeconomic systems in a systematic and structured manner, by the identification and pre-selection of themes (factors), individuals and groups (actors), and social and economic sectors; which shape the scenario focus. Water availability, migration, demographics and land degradation are examples of "factors"; "actors" can be businesses, NGOs, civil society, scientists and /or governmental bodies; and "sectors", tourism, forestry, agriculture.

The first step in developing the nested storylines was the articulation of a core set of storyline FAS-related elements considered relevant across multiple spatial scales and to the study context. This step is followed by mapping the global SSP narratives to the FAS identified in the previous step, illustrated in Figure 11. For sub-national storylines, the factors and actors considered in storyline development remained the same as those for the national storylines; but for the sectors, the focus narrowed to energy, water and agriculture. The sub-national storyline elements were developed using national storylines and scenarios that contained sub-national detail as well as more state-based information.

The analysis was largely based on qualitative information; however, some quantitative indicators were developed (at the sub-national level) for state population and GDP to better understand the relative trends, magnitudes and dynamics of key factors within the region. Stakeholders were not involved in this study. For the projection of population and GDP trends at sub-national level (U.S. Southeast) in the different SSPs, scaling factors were applied to the national-level data available in the SSP database.

The development of storyline FAS elements at the global, national, and sub-national level across the four SSPs resulted in a database with details regarding each storyline element. Such database enables researchers to compare storyline elements across different SSP assumptions and scales. Using quantitative scenarios to explore the key driving forces of population and demography at the sub-national level in the U.S. Southeast provided a new context about the manner in which different socioeconomic pathways manifest in this region. Due to the large database of narrative elements and the associated difficulty in using it, a synthesis was conducted that focused on identifying the implications of each storyline element regarding challenges for adaptation. Additionally, the individual storyline elements at the sub-national scale were integrated to develop sub-national storylines that act as extensions of the global SSP storylines. The extension of the SSP2 narrative achieved for the U.S. Southeast case study is presented in Table 9. Highlighted in bold are the main narrative elements found in the global SSP narratives corresponding to demographics, economy and lifestyle, technology, human development, policies and institutions, and environmental and natural resources. For more details on the elements see Appendix B. For a comparison of storylines across scales, for the water sector, see Appendix C.

[5] In this approach, each storyline at a given geographic scale manifests at the next lower scale as a single storyline with fully consistent assumptions on drivers and scenario logics as the higher scale scenarios, but with enhanced context.
[6] In the FAS framework, a "Sector" represents a sub-component of a national or social system; an "Actor", an individual or organization of individuals with the capacity to effect and/or influence change; and a "Factor", an aspect of a social or natural system around which there are broad policy issues of particular interest.

Although global narratives were effectively downscaled to the sub-national context, Absar and Preston identify limitations in this process. The extension of the SSP narratives is limited by the ability of capturing all aspects of each storyline element, resulting in a generalized vision for the region. The storylines formulated do not explore the multiple ways a given global SSP could manifest at national level. As the study follows a literature review approach and participation of stakeholders was not part of the scenario development process. An important challenge in study related to the information gap and the lack of detailed data to better characterize the FAS elements more relevant for the elaboration of the extensions. The information gap challenge due to the lack of detailed information on some factors, actors, or sectors that may be relevant for SSP extensions.

Table 9. Sub-national version of the SSP2 "Middle of the Road" global narrative for the case of the U.S. Southeast region (in Appendix A "Sub-national narratives" (Absar and Preston, 2015)).

Sub-national SSP2 – Middle of the Road for the U.S. Southeast region
Gulf Coast states experience moderate rates of growth in GDP throughout the 21st century due to a rapid increase in population, employment, focus on alternative energy sources and efficient industrial processes. Increasing dependency on natural gas and alternative energy resources helps constrain emissions to moderate to high levels. Stringent federal, state and local regulations around building codes and product standards enable efficiency gains, lower externalities of urban sprawl drive additional investments in renewable energy resources. The relatively low cost of living and high quality of life attracts people to the region, increasing both international and local migration. National and regional investments in technology research and development contribute to increasing regional efficiency and reduced carbon intensity of economic activity. Regional land use trends are dominated by high rates of urbanization with significant urban sprawl around existing urban centers. Environmental consciousness leads to retrofitting processes with greener alternatives, efficient low energy buildings, use of biofuels and modest ecosystem restorations. The region experiences continued disparity in income and wealth between skilled and unskilled workers and, particularly, between urban and rural populations. The private sector seeks to respond to market opportunities created by consumer demand while civil society continues to play an important role in driving the pace of economic growth and technological change through patterns of consumption and demand for goods and services. Energy demand is concentrated in residential and industrial sectors whereas energy supply is increasingly comprised of clean coal and natural gas facilities with modest gains in renewables such as wind, solar and biofuels. Increased demand, competition, and privatization of water resources drive up the water withdrawals, which are offset by incremental improvements in water supply infrastructure. Regional crop portfolios and crop management practices largely remain stable. However, the sector benefits from incremental improvements in yields and increased production efficiencies.

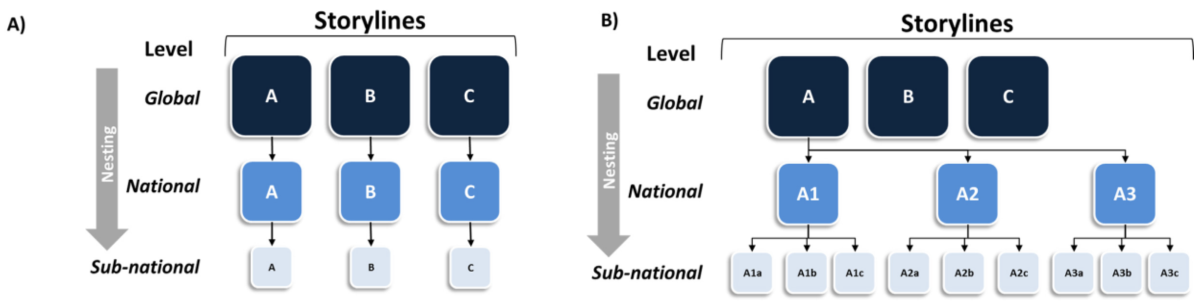


Figure 10. Comparison of alternative approaches to the development of nested socioeconomic storylines. (A) Represents a one-to-one nesting approach, where each global storyline is consistent with a single storyline at sub-global scales. (B) Represents a one-to-many nesting approach, where each global storyline is consistent with a range of alternative storylines at other scales.

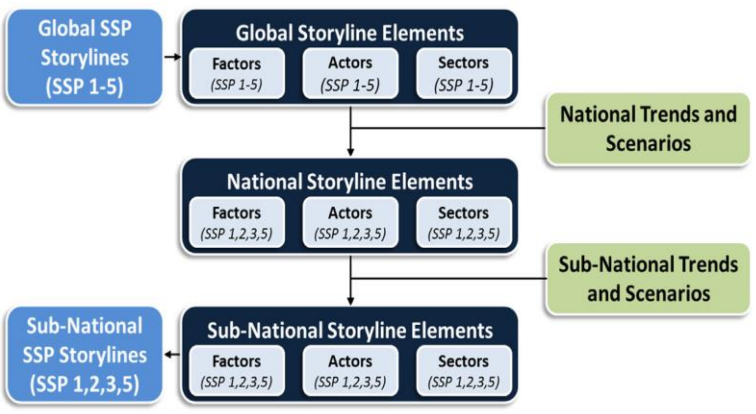


Figure 11. Illustration of SSP storyline nesting based on the Factor-Actor-Sector framework (Absar and Preston, 2015).

Participatory methodology for the extension of the global SSP narratives applied to the Barents region (Nilsson et al., 2017)

A participatory methodology for extending the global narratives to locally-relevant storylines is presented by (Nilsson et al., 2017) and applied to the Barents region[7]. The period of the storylines spans over one or two generations ahead and the focus is to understand what the economic, environmental and social impacts of the different SSPs mean to the region.

The development of the local narratives results from a stakeholder participatory process where the global narratives of SSPs 1, 3, 4 and 5 are qualitatively assessed from a regional perspective, and locally-relevant extended narratives are co-formulated with stakeholders. The study held four participatory workshops, in Norway, Sweden, Finland and Russia. Stakeholders and regional actors involved corresponded in the initiative included planners, public servants, sector representatives, and other experts (including NGO representatives), as well as researchers. See (Nilsson et al., 2015) for more details on the workshop process.

[7] The Barents region corresponds to several administrative regions in Norway, Sweden, Finland and Russia that share the coast to the Barents Sea.

The methodology is organized in two main steps: a first one dedicated to the identification of local drivers and subsequent classification in terms of impact and uncertainty using a voting approach; and a second for the characterization of how the drivers would evolve under the main conditions depicted in the narratives assessed. The workshops started with brainstorming activities to identify local drivers in the region. After identifying the local drivers with the highest impact, these were linked to the SSP narratives. The following question was used to guide the discussion: "*How could driver X play out at the regional scale in a world as the one described by SSPY?*" **Error! Reference source not found.** how the information collected in the participatory workshops was organised in a table format.

	SSP1: Sustainability : Taking the green road More inclusive global development and improved management of global commons, low global population growth and slower economic development, leading to relatively low resource and energy demand. Environmental technologies are favored. Global, national and regional institutions are strong and flexible, and human well-being has improved.	**SSP3: Regional rivalry: Rocky road** Resurgent nationalism, competitiveness, and security, along with weak global institutions. Other features are trade barriers, authoritarian governments and highly regulated economies. Economic development is slow but material consumption intensive.	**SSP4: Inequality: a Road divided** Increasing inequalities both between and within countries, concentration of power within a small elite, and moderate economic growth in the industrialized world with a large, vulnerable population on the rest of the planet. Technological development is uneven and global markets volatile due to prevailing political uncertainties.	**SSP5: Fossil-fueled development: Taking the highway** Competitive markets, innovation and participatory societies that produce rapid technological progress and development of human capital as a way to achieve sustainable development. It is a world of intensive fossil fuel development, high energy demand and rapid technological progress, but also characterized by a focus on health, education and institutions to enhance human and social capital.
Driver X	*Interpretation of driver X given global SSP1*	*Interpretation of driver X given global SSP3*	...	...
Driver Y	*Interpretation of driver Y given global SSP1*	...	...	...
Driver Z	...	...	...	...
...	...	...	...	...
	Extended SSP1	**Extended SSP3**	**Extended SSP4**	**Extended SSP5**

Figure 12. Structure used in (Nilsson et al., 2017) to establish the relationship between the global narratives and the interpretation of the drivers at local and regional level in the Barents region for each SSP narrative analysed in participatory workshops.

The identified interactions between local and global in the form of local interpretation of narrative drivers were set together to a coherent narrative (the extended SSP) for each of the SSPs analysed. The "new" narratives included social, cultural and political features that were particularly relevant for each of the workshop setting. Note that no quantification was performed in the study and the focus was to explore how the global narratives could be transferred qualitatively to a local context. Examples of the narratives are available in (Nilsson et al., 2015), based on the workshops in Pajala, Sweden; and in Kirosvsk for the Murmansk region (Russia) and in Bodø, region of Nordland in Norway see the report by (Oort et al., 2015). The summary of the narratives for the Murmansk region is presented in Table 10.

The implementation of the methodology highlights how the local and regional actor's engagement can bring nuance to the global narratives. In particular, highlight how locally or regionally specific dynamics related to social trends, economic structure, cultural characteristics, the natural environment, and political dynamics affect for the capacity to adapt to different future circumstances of global socio-economic development. The study finds that the global narratives can be elaborated in a way that incorporate local and regional dynamics. This is achieved by exploring, in a participatory manner, how local adaptive capacity is affected by a diversity of demographic trends, changes and volatilities in global resource markets (including energy markets) and power over decision-making.

While narratives are useful as provocation and motivation, the authors indicate that further work is necessary to develop complete local extended SSPs, supported by quantification and qualitative analysis of the trends described in the extended narratives. More work is also needed for using the results to “scale up” local insights into regional SSPs. One important step, in addition to conducting interactive workshops with regional actors within the public administration and relevant sectors, would be to link the locally informed analysis to the available published data and expert opinion at the national and sub-national scale.

Table 10. Summarised versions of the extended SSP narratives applied to the Murmansk region (Russia), part of the Barents region (Oort et al., 2015).

SSP narrative	Narratives summary
Extended SSP1 - Sustainability	The research and development sector providing environmental-friendly mining and waste treatment technologies will be an important driver of Murmansk region development in the world that follows the green road. Demands to find environmentally friendly solutions of development problems will force transferring decision-making process to the local level, and transition to participatory government of the Murmansk region. The welfare and wellbeing of society as a whole will be in focus of government, birth rate will increase by the reason of high life quality. Climate change will demand increase investments for infrastructure.
Extended SSP3 – Regional rivalry	While the global security situation worsens, the federal centre will amass a maximum of administrative powers and the Murmansk region will be developed as a military outpost of Russia in the Arctic and a point of the Northern Sea Route, which will link the Arctic zone of the Russian Federation. The mining will stay as the basis of economic development of the Murmansk region. The risk is in reducing of environmental protection costs for cheapening the cost of products and services.
Extended SSP4 - Inequality	In the divided world, the Murmansk region completely transformed into a raw materials appendage of the central regions of the Russian Federation. We will meet intense involvement in the operation of new mineral deposits that will reduce the areas available for traditional nature use (reindeer herding, picking mushrooms and berries, and fishing) and create difficulties with access for public recreations. The risks are in dividing of society and the emergence of nationalist political parties.
Extended SSP5 – Fossil-fuelled development	Fossil-fuelled development globally entail demand for advanced mining technologies, which will be a reason of decreasing job opportunities and outflow of population from the Murmansk region. At the same time, demands of qualification of labour force will be high which will force increasing of investment to education and human capital. Risks relate to fluctuation of international mineral market and low sense of place of people which coming to the Murmansk region to work and go back to the native region when job opportunities dry up. International cooperation will play a significant role.

Linking the SSPs and regional stakeholder scenarios for West Africa (Palazzo et al., 2017)

Palazzo et al. (2017) develop a qualitative and quantitative approach in the formulation of regionally relevant scenarios and subsequent quantification using IAMs (GLOBIOM and IMPACT) for the analysis of agriculture and food security in West Africa for different climate futures up until 2050. The region-specific scenarios resulted from a multi-stakeholder participatory process structured in three workshops. Evolution of key drivers in the narratives produced were then interpreted from a quantitative perspective later incorporated in the global models used. To establish the link with the global SSP narratives, drivers and scenario indicators were compared and linked, whenever possible, to key SSP drivers. The mapping exercise provides the analysis with a global perspective of the scenarios.
The production of the regional scenario narratives and initial quantitative interpretation of the storylines was developed with stakeholder participation in the three workshops. A group of 94 participants joined the workshops, with representation from governments (agriculture and

environment ministries, meteorological institutes), research organizations, national and regional civil society organizations (CSOs), international non-governmental organizations (INGOs), academia and the media[8]. Each of the workshops were planned to fulfil specific objectives. The first workshop served to gather information on the relevant drivers that could affect the future of agriculture, food security and climate change mitigation and adaptation in West Africa. The formulation of narratives was performed in the second workshop, which built from the outputs of the first workshop. The third workshop activities aimed at bridging the qualitative interpretation of the storylines with quantitative estimates of variables linked to the key drivers. This analysis was performed in collaboration with the modelling teams.

The four scenarios produced took in consideration two dimensions of uncertainty, reasoned as being the most relevant for the region. These were both found to be related to governance and corresponded to the level of involvement of the state and/or non-stat actors in regional development and to how the time-span of priorities influenced the policy-making process (i.e. short or long-term). The scenario narratives are presented in Table 11.

The quantification process of the qualitative interpretation of narratives and matching with global SSPs is illustrated in Figure 13. In the third workshop, stakeholders classified a list of indicators related to drivers, in terms of their logic and magnitude of change as +, = or -, for each of the four futures in respect to the food security, livelihoods and the environment. This process resulted in the selection of the most important indicators, which, once characterised in numerical terms, were used as drivers in the models. The linking of the regional scenarios with the SSPs results from the inter-comparison of indicators in the two analyses in terms of scope. The example of the comparison of "Gross Domestic Product (per capita)" is presented in Figure 14. In the analysis, the SSP drivers were used as boundary conditions and starting values for the analyses. However, the stakeholder trends definition was used to shape the evolution of these drivers throughout the model period.

In the mapping the regional scenarios to SSP narrative trends, authors find the following correspondence: "Self-determination" more aligned with SSP1; "Save Yourself" more in line with SSP3, although some of the narrative elements tend towards SSP3 and SSP4; "Civil society to the Rescue" sharing similarities with SSP2; and, lastly, "Cash, Control, Calories" mirroring SSP5.

Figure 13. Process of quantification of the regional scenarios and link with the SSPs (adapted from Palazzo et al. (2017)).

[8] For more details on the stakeholder process see (Palazzo et al., 2016)

Table 11. Stakeholder-generated regional scenario narratives developed for the West Africa region (Supplementary material of (Palazzo et al., 2017)).

	State Actors Dominate		
Short-term Priorities Dominate	Cash, Control, and Calories	Self-Determination	Long-term Priorities Dominate
	Governments playing a strong role in governing West Africa's food security and livelihoods, however, short-termism drives government policies. Governments are more focused on urban social stability and security than rural lives. Quick fixes, and fast gains and cash get priority. Quantity is emphasized before quality. The disregard of rural food security eventually leads to increases in the need for food aid and external safety nets such as urban to rural cash flows. Governments become very adept at mobilizing foreign aid money. Commercial, monoculture agriculture is implemented widely leading to environmental degradation and conflicts between agriculturalists and pastoralists. Resource mining for quick food production has destructive long-term effects. Regional integration plans do not last, and the lack of regional policies means that water conflicts occur regularly. On the other hand, vigorous efforts are made to follow the Millennium Development Goals through mass education and decentralization of power.	Governments, emerging out of a period of uncertainty to relative stability, drive the change through regional collaboration, better tools for effective government and a focus on longer-term investment into infrastructure and access to markets for rural populations, education and direct investments into agriculture. All of this has to be done on a small budget because donor funds have declined after the region's drive to self-determination has resulted in international disputes about outside influence. A measure of regional food self-sufficiency has been achieved by West African countries. However, agricultural intensification has a negative impact on rural employment. Also, increased agricultural productivity and extended land use have impacts on water availability and quality which produces challenges for the region's developments.	
	Save Yourself	Civil Society to the Rescue?	
	Non-state actors are the driving force of change, governments are passive, corrupt and unstable, playing a facilitating role for the short-term oriented, extractive actions of the private sector. Civil society organizations focus almost exclusively on emergency issues and longer-term development objectives are not part of societal debates. Extra-regional interventions to try and stabilize Mali have failed and instead led to great regional unrest. Hyper-liberal market policies have led to an increasing diversity of available food for the urban middle class, while at the same time the rural poor are highly food insecure due to the fiercely expansive presence of commercial agriculture. Rural livelihoods are decreasing and there are massive movements to urban areas in search of work, ungoverned by national governments. Environmental health has suffered greatly from a lack of policy in this domain and the scramble for new rural sources of livelihood.	Active private sector interests aiming for the large-scale commercial development of West Africa vie for influence with vibrant and powerful civil society organizations and NGOs who focus on a more community-oriented, sustainable future. This powerful civil society and the private sector collaborate as well as compete for influence, often for the better, for instance contributing to improved livelihoods and knowledge for rural communities. Gender relations have changed and amid the other tensions this transition has been a challenging one. Food security on the whole has improved through a combination of commercial investment in regional food systems which have raised urban food security and an increasing professionalization of relatively small-scale farmers. However, uncertainty around the control of land and resources has threatened the stability of incomes for rural communities.	
	Non-State Actors Dominate		

CCAFS ind.	Scenario	2010-2020	2020-2030	logic for change	2030-2050	logic for change	SSP	SSP ind.	SSP qualitative information	SSP ind.	SSP qualitative information
Col 1	2	3	4	5	6	7	8	9	10	11	12
Gross Domestic Product (per capita)	*Cash, Control, Calories*	++	=	Initial boosts are not sustained as long-term growth	+	Periodical boosts and plateauing; reactive	*SSP 5*	Growth (per capita)	High	Population growth	Relatively low
	Self-Determination	+	+	Some countries already involved in long-term transformation, others make an effort. Minerals exported/divide between countries, artificial way of changing GDP through services	++	Transition into services and secondary industry, agricultural production; processing	*SSP 1*		High in LICs, MICs; Medium in HICs		Relatively low
	Civil Society to the Rescue?	+	+	Increasing regional stability and strong civil societies stimulate investment, but governments are not able to facilitate investments well.	+	Population pressures increase; pressure on education; without governments it is difficult to bridge the growing gap between poor, middle class and rich. Climate change makes things worse for the poorest.	*SSP 2*		Medium, uneven		Medium
	Save Yourself	++	++	Open market competition with little state interference, but also forming of cartels, society overall is worse off	++	Dynamic growth continues to build though resources have become a constraint; large informal economies	*SSP 3*		Slow		High

Figure 14. CCAFS scenarios trend indicators compared with and mapped to SSPs and indicators – example for Gross Domestic Product (per capita) (Palazzo et al., 2017).

An interesting observation from the comparison of the previous examples is how they complement each other. Absar and Preston (2015) explore the possibility of formulating narratives that can fit under the umbrella of global narratives. This exercise does not involve stakeholders in the process, but it is valuably explored the possibility of producing narratives that are coherent with global development futures which are valid at smaller spatial scales and for specific sectors. Nilsson et al (2017) thoughtfully implement stakeholders' involvement and participation in the elaboration of narratives. The study involves different organisational settings as the region under focus spans across four different countries, whose similarities mostly relate to the extreme climate, type of settlements and activities in the Arctic latitudes. In this case, and although quantification was not part of the exercise, stakeholders are gathered to discuss implications of the global futures in the SSPs within the context of their region. Also in Palazzo et al (2017) stakeholders play a determining role in the design of narratives. In contrast with Nilsson et al (2017), where the SSPs were used at a starting point to the extension to the regional, Palazzo et al (2017) elaborate regional-specific narratives without SSPs framing and the matching exercise is established *a posteriori*. The study takes a step further in terms of using stakeholders' knowledge in the translation of the qualitative descriptions into drivers and indicators that can be used in models for the region, step that is performed in collaboration with modelling teams.

Overall, the examples show that the extension of narratives across scales and sectors is possible. Additionally, they confirm the importance of stakeholder engagement and participation to ensure the futures are plausible and comparable to the SSPs, but, most importantly, that portray and define the space covered by the narratives taking into account the historic and near and long-term expected socioeconomic trends of the region and its sectors.

3.4. Application to nexus assessments

The authors of this report could not find in literature nexus-specific studies that include the SSP narratives or the SSP-RCP matrix framework as is being done in SIM4NEXUS. Existing research focuses on the application of IAMs, which do not consider at the same extent all nexus domains explored in SIM4NEXUS. This is because the SSPs are used primarily for climate change research; therefore, the main systems influencing GHG concentrations are energy and land use. However, important lessons can be learned from the SSP development, SSP-RCP matrix framework and the role of the SPAs. Elements from the previous are of relevance to the studies under development in SIM4NEXUS and many similarities exits. These greatly relate to the characterization of systems, the definition of scenarios, and their implementation in multiple modelling tools that not always overlap in systems represented, but when they do, the architecture is differs. Main differences include:

- the scope of the analysis, which spans across nexus domains in SIM4NEXUS;
- the spatial resolution, which goes into national and sub-national scales in terms of case studies' boundaries;
- the audience, which apart from the research community includes multi-institutional, cross-sectoral and transdisciplinary experts as stakeholders;
- the purpose of the analyses, which aims at building capacity in the nexus with concrete case studies, explore the application of several thematic models, and assist in decision making.

The SSPs are, nonetheless, important references to global and wider-regional trends. In SIM4NEXUS there is the possibility of comparing smaller scale development futures of relevance to the case studies and, in an integrated manner, to the framing provided by the European and Global case studies. The process of formulation of the SSP narratives is presented in the next chapter, and the exercise of developing baseline narratives, can provide valuable assistance to the case studies in the conceptualization of the scenarios to be investigated in the coming months of the project.

3.5. Other scenario narrative methods

The translation of qualitative high-level narratives (or storylines) into modelling assumptions is a cumbersome task, especially in multi-tool modelling exercises covering different sectors. Although there is a large body of scientific literature around the narrative formulation topic, there is no established or standardized methodology. This is due to several reasons. Amongst the most important ones, is the fact that modelling assumptions are specific to modelling tools; in order for a methodology to fit different modelling tools it has to be generic. Apart from the difficulty of converging modelling approaches, there is the additional issue of lack of agreement on terminology across modelling teams.

Many modelling exercises start from re-defining the meaning of terms such as narrative, storyline, pathway, scenario or indicator. One generic storyline may be compatible with numerous (potentially infinite) sets and combinations of specific modelling assumptions. The process of scenario design followed in the Horizon 2020 project REEEM[9] faces similar challenges. The impact assessment spans across several sectors (economy, energy system integration, energy poverty, consumers behaviour, energy security, dispatch of electricity, health impacts, water and land resources use, climate change impacts and life cycle impacts) and is carried out with numerous independent modelling tools. Therefore, researchers in REEEM decided to rely on a semi-structured and flexible scenario design methodology, based on state-of-the-art scientific research and practices, experience of the partners, and stakeholder engagement and participation.

[9] The Horizon 2020 REEEM project (http://www.reeem.org/) investigates the impacts of transitions towards a low-carbon EU economy through a set of 15 modelling tools to a large extent linked with each other.

Table 12. Overview of the main steps of the scenario design methodology used in the REEEM H2020 project.

Internal agreement on basic terminology		A document is formulated including a short list of basic terms and a short definition for each. The document is not intended to establish a standard of interpretation in the community, but rather to provide a glossary for any external (and internal) reader approaching the exercise not familiar with the terminology.
First draft of a narrative	Short Description	Description, in one sentence (e.g. in a table-form), of the main characteristic of the narrative for each one of the following dimensions: Social, Economic, Environmental, Political, Technological and Global. This practice aligns with the SEEPT[10] framework described in (Maack, n.d.)The only difference is the addition of the Global dimension, necessary in REEEM given the clear separation between the impact assessment at the EU and global level; an example is shown in Appendix D.
	Expanded description	Expansion of the description for each dimension and statement of the main modelling assumptions chosen to represent it; an example is shown in Appendix D.
	Elaboration	Elaboration of a one-paragraph nuanced storyline that summarises the previous sub-steps in a qualitative fashion, understandable by a non-technical audience. This summary provides the 'identity card' of the scenario, and the version to be shown when presenting it in any context.
Collection of stakeholder inputs through workshops.		During a workshop organised within the project, stakeholders of different background (policy makers, industry and associations of consumers) provide comments and additions, primarily to the table created for the formulation of the "short storyline description".
Refinement of the narrative by the REEEM researchers.		The first draft is corrected with input received from the stakeholders, to the extent possible given the scope of the project and the modelling tools utilised.
Elaboration of model-specific numerical inputs.		This step is carried out by each individual team in a decentralised fashion. Teams are asked to collect modelling assumptions complying with the general storyline and to use the key assumptions stated in the "expanded description" step as far as these can feed directly into their models. It is not possible to harmonise all modelling assumptions, given the very different focus and structure of all the models employed. Nonetheless, the analyses are of significance and relevance in as much as 1) the assumptions of each model are open and transparent; 2) the modelling methodology and its limitations are described and 3) the main robust insights are drawn from the modelling exercise.

This methodology leaves space for refinements and iterations during the course of the project, but at the same time, it sets clear boundaries to the scenario design process. The step of drafting the narrative and especially its first sub-step take inspiration from the morphological analysis (MA) approach by Ritchey (Ritchey, 2011). Morphological analysis consist on structuring relationships between elements in complex and non-quantifiable problems (Johansen, 2018; Ritchey, 2011). This is usually performed using tables that state the parameters (or dimensions) of the problem in columns followed by

[10] SEEPT stands for Social, Economic, Environmental, Political and Technological framework for the identification of the external forces (drivers) that influence the SEEPT categories (Maack, n.d.).

description of its future state in rows. The comparison of the parameters descriptions enables the identification of consistent configurations of a solution that include all parameters. Thus, MA offers a structured way to build the essential elements of a scenario collecting inputs from expert roundtables or stakeholder workshops. The step of stakeholder interaction takes great inspiration from a management-oriented working paper by J.N. Maack (Maack, n.d.). This presents a state-of-the-art, step-by-step guide for project managers to carry out co-design of scenarios and it has wide applicability. An illustration of this process is provided in

Figure 15.

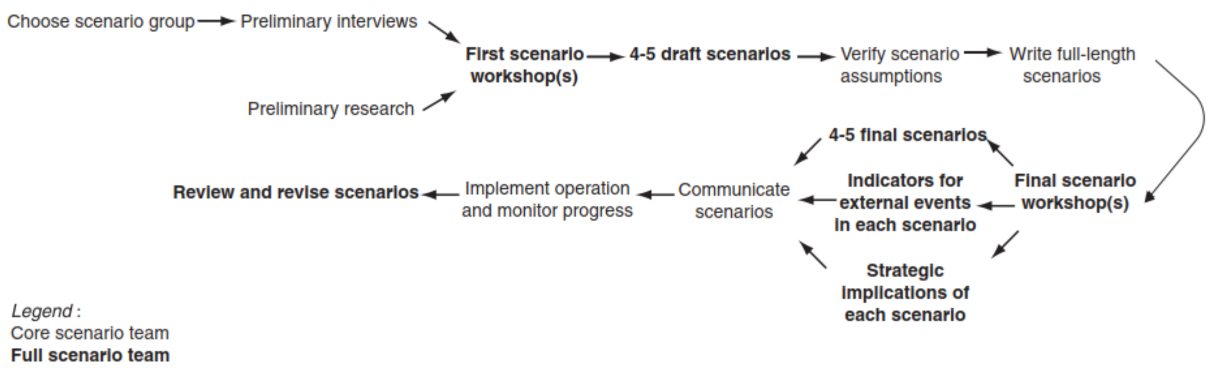


Figure 15. Scenario process diagram (Maack, n.d.).

The approach of REEEM builds on practices widely adopted in literature and demonstrates their feasibility within large and multi-sectorial modelling efforts. Mallampalli et al. review methodologies to design land use scenarios. In general terms, they refer to the Story-And-Simulation approach (SAS) as the most commonly used (Mallampalli et al., 2016). This resembles the one detailed for multi-sectoral decarbonisation scenarios in REEEM project and essentially consists of two phases: one where qualitative narratives are defined by experts/stakeholders and one where they are translated into quantitative parameters. The authors zoom into the translation methodologies, i.e. narrative to quantification, and identify 10 of them, each one having different ranges of applicability, advantages and disadvantages. A summary of these methodologies is presented in Table 13.

W. Weimer-Jehle introduces the Cross-Impact Balance approach (CIB), a method for systematically deriving internally consistent qualitative socio-economic scenarios. The CIB approach is useful when the number of stakeholders involved in the co-design of scenarios and the number of sectors included in the analysis is high. It may be seen as a more structured version of the morphological approach. The methodology consists of two steps. The first one consists in collecting and choosing the most important factors that have a significant direct or indirect influence on the object of the examination. The next step consists in building a matrix containing judgments that express the influence of each factor on each one of the other factors (the so-called Cross-Impact Balance Matrix, shown in Appendix D). The final step consists in creating scenarios by choosing from the matrix consistent and feasible combinations of factors. A limitation of this approach is that the size of the matrix increases rapidly as the number of factors and their potential values increase. For this reason, Schweizer and Kurniawan propose a methodology to disaggregated the Cross-Impact Balance Matrix into smaller matrices (Schweizer and Kurniawan, 2016).

Börjeson et al. try and categorise all of these views (Börjeson et al., 2006). They provide a synthesis of scenario types and scenario design techniques. Scenario types are divided into three commonly used categories: Predictive, Explorative and Normative. The categories differ by the type of question they answer to, respectively '*What will happen*', '*What can happen*' and '*How can a specific target be reached*'. Sub-categories are also mentioned. Scenario design techniques are divided into Generation, Integration and Consistency. Generation techniques include brainstorming-type techniques such as workshops, surveys and more or less structured questionnaires. Integration techniques refer to numerical modelling exercises. Consistency techniques mainly refer to the morphological approach and CIB analysis described above. State-of-the-art approaches to scenario design combine these techniques in various ways, as done in the REEEM project. One interesting consideration made by the authors is that the scenario type and scenario design technique depend on the *structure of the system under analysis* and the *models employed*. Both factors have to be taken into account, at least as soft constraints, when designing the scenarios.

Table 13. Main method-categories for scenario development and quantitative implementation (Guivarch et al., 2017).

Method		Description	Reference
Story-and-simulation (SAS)		Characterised as an "open" process that considers the involvement of in the development of the scenarios. It starts with the development of qualitative "storylines" by stakeholders and experts, followed by their translation in quantitative scenarios. The harmonisation of qualitative and quantitative interpretations of the scenarios is achieved through an iterative process. More in (Mallampalli et al., 2016)	Alcamo 2001, 2008. Application: MEA, IPCC-SRES, GEO-4 scenarios, SSPs
Consistency and diversity approaches	Cross-Impact-Balance (CIB analysis)	Tool used to validate the internal consistency of storylines and to identify the most internally consistent ones. The analysis is performed through numerical judgments from experts or stakeholders for state-dependent influences between drivers to construct cross-impact matrixes and identify internally consistent scenarios.	(Weimer-Jehle et al., 2016); applied by (Schweizer and Kurniawan, 2016)
	Modelling to Generate Alternatives (MGA)	Optimization method that generates a sequence of near optimal solutions that are very different in the decision space. It can be used to explore alternative solutions under conditions of deep uncertainty.	(DeCarolis et al., 2016)
	Multi-pattern approach (MPA)	Transition pathways are conceptualized as successions of elementary change patterns. The approach specifies the conditions under which those patterns may emerge, but acknowledges that those conditions do not exclusively determine what pattern will occur, as multiple potential futures are possible.	(de Haan and Rotmans, 2011)
Vulnerability and robust decision making	Robust Decision Making (RDM)	Results from a combination of scenario planning and computing to support decision-makers by assisting in the identification of potential strategies that are robust to future unknowns, characterize the vulnerabilities of such strategies, and evaluate trade-offs among alternatives.	(Lempert et al., 2006)
	Scenario Discovery	Computer-assisted method of scenario development that applies statistical algorithm to databases of simulation model results to characterize the combinations of uncertain input parameters values most predictive of specified classes of results (cluster	(Bryant and Lempert, 2010)

		analysis). Often used as a key step in RDM analyses, scenario discovery provides a systematic manner to find what combinations of the model input parameters that lead to specific "outcomes of interest", i.e. cases where output variables are located in specified areas of the results space.	
	Many Objectives Robust Decision Making (MORDM)	Decision making framework that enhances RDM with Multi-objective Evolutionary Algorithms (MOEAs) to help identify robust strategies that can achieve multiple objectives (Kasprzyk et al., 2013; Herman et al.,2014). MOEA uses a detailed simulation model of a system to characterize performance of solution alternatives, by generating trade-off sets that show compromises among the objectives sought.	(Kasprzyk et al., 2013)
	Crossover point	Crossover points are used to compare management alternatives, e.g. environmental, under uncertainty. Crossover point scenarios are combinations of values of variables where the preferred alternative will change, i.e. where several alternatives are of equal values in cost-benefit or other trade-off analysis frameworks.	(Guillaume et al., 2016)

4 Using SSP2 narrative and assumptions to investigate the nexus in the Case Studies

4.1. Application of the narratives in an nexus context

As discussed in the previous chapter, the SSP global narratives are "basic" in the sense that they are relatively broad even though they are very distinctive. Additionally, since they were designed to allow the investigation of mitigation and adaptation challenges, it can be argued that nexus domains are not represented equally. However, the purpose of the narratives was not the analysis of the nexus but the formulation of plausible descriptions of socioeconomic futures at global level. Particular combinations of elements, which include human development, demographics, economic growth, international cooperation, and technological change, derive these futures. These elements embed activities within the domains under analysis in the SIM4NEXUS case studies. This creates an interesting opportunity to transpose and extend these narratives to other sectors and components of the nexus domains, as is done in SIM4NEXUS.

Figure 16 describes the formulation process of the SSP narratives as presented by O'Neill et al. (2017). The construction of the case studies baseline narratives in SIM4NEXUS thus parallels this process. Information collected from existing deliverables and additional information from case studies is interpreted based on the steps in the diagram of Figure 16. As the case studies' scope of analysis spans across different nexus domains, the methodological steps are translated as follows:

1. ***Definition of the objective:*** the objective (or objectives) of the scenario (in this case the baseline) is postulated in an integrated manner, so that the key interactions between systems can be defined and accounted for.

2. ***Identification of key elements:*** key elements refer to systems' components that are at play in critical (relevant) biophysical interactions between systems. These interactions directly relate to the most relevant nexus link identified during the postulation of the shape of the local SSP2 narrative. (This could include findings from analysing ad-hoc model results, in particular the impacts, responses, states and pressures that result from the interlinked nature of the baseline's resource systems). The identification of key policy and societal pressures, states and challenges to be included - or not - in the models, are also identified in this step.
3. **Combination of elements:** Elements of the narrative are collected for each case study in tables in appendixes E (SSP2 assumptions in models), F (trade-offs, as impacts, responses, states and pressures, from baseline model runs) and G (scenario elements' tables).

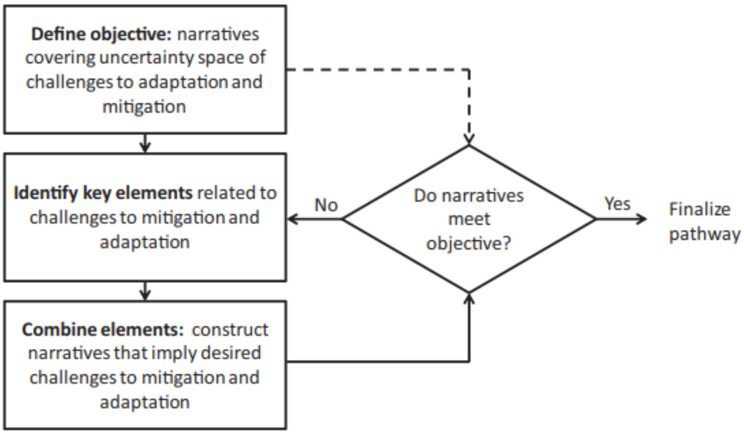


Figure 16. Flow diagram of process for developing SSP narratives (O'Neill et al, 2017).

In order to produce narratives, key elements need to be identified and then described. Table 14 presents the textual description of how each main element of the SSP2 narrative is interpreted. Note that the descriptions of the different elements are consistent with each other, and combined to form the narrative that introduced in the previous chapter. A similar approach is followed in this task to produce the narratives with some differences. An important difference is that the narratives in the case studies will detail how the future development of nexus systems is anticipated to unfold under the specific socioeconomic circumstances of the baseline scenario. Additionally, variances are expected in the detail of these descriptions. They will be related to the impacts, responses, states and pressures (as challenges) and interactions under investigation in each case study.

The baseline narrative, and scenario developed in the case studies in SIM4NEXUS is supported by assumptions related to SSP2. However, in some cases, the baseline may include case study-specific policies implemented until December 2015. The baseline does not include, for example, international climate agreements such as the Paris Agreement. In the majority of cases, with exception of Azerbaijan and to some extent the Global case study, the common Agriculture Policy (CAP) 2014 – 2020 is part of the baseline; as is the EU energy/climate package up to 2020 but not the new package, released in 2016, that sets goals until 2030.

Table 14. Description of the main narrative elements of SSP2 (supplementary material in (O'Neill et al., 2017)).

Narrative Element	Description
Motivating force	In this world, socio-economic development occurs at moderate rates on average, but with substantial differences on a regional level. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others do less well. Moderate corruption levels and limited access to the rule of law slows the effectiveness of development policies.
Policies, institutions and social conditions	There is moderate awareness of the environmental consequences of choices when using natural resources. There is relatively weak coordination and cooperation among national and international institutions, the private sector, and civil society for addressing environmental concerns. While local environmental concerns, such as air quality, rank high on the agenda of many countries, implementation lags behind the ambitions. Globally this leads to an intermediate pathway for pollutant emissions.
Human development:	There is some progress towards universal education, but education investments are not high enough to rapidly slow population growth, particularly in low-income countries. Access to health care and safe water and improved sanitation in low-income countries makes unsteady progress, with some countries benefiting from the resulting improvements to population health and productivity. Gender equality and equity slowly improve, particularly in countries with more sustainable development.
Economy and lifestyles:	Moderate rates of development are reflected in economic growth patterns, with high growth for some low-income countries. Emerging economies continue their rapid development for an initial period, but experience a slowdown in growth rates as their economies mature. High-income countries continue to grow at moderate rates. As a result, per-capita income levels grow at a medium pace on the global average, with slow convergence of relative income levels between the bulk of developing and industrialized countries. Most countries are politically stable and associated globally connected markets function imperfectly. The flow of information and global access to markets are rather well established in most countries, although entry barriers to agricultural markets are reduced only slowly. Consumption is oriented towards material growth, with growing consumption of animal products. Income distributions within regions improve with increasing national income, but inequities remain high in some regions. Poverty is a challenge for many disadvantaged populations conditions of extreme poverty particularly so. Tensions within and between countries periodically threaten to boil over, but do so only rarely, and never catastrophically. Conflicts over environmental resources flare where and when there are high levels of food and/or water insecurity coupled with political and economic instability.
Population and urbanization:	Population growth is moderate, with higher growth in low-income countries, slowing population growth in middle-income countries, and limited to negative population growth in most industrialized countries. Migration between countries continues at intermediate levels owing to the restriction of labour markets, but there are intermittent periods of greater international migration when populations are challenged by food insecurity, conflict, and other factors. Urbanization proceeds at rates and in patterns consistent with historical experience in different world regions. Urbanization is particularly transformative in East and South Asia and sub-Saharan Africa. The transformation of cities resulting from the introduction of sustainable energy technologies and associated design proceeds at differing rates, with the highest rates in developed or rapidly developing urban contexts
Environment and resources:	Fossil fuel dependency slowly decreases, but access to global oil and gas markets continues to play a large role in international relations. Growing energy demand and no reluctance to use unconventional fossil sources lead to continuing environmental degradation even with reductions in resource and energy intensity. There is less progress in low-income countries. Moderate regulation of land use leads to a slow decline in the rate of deforestation.

Technology:	There is some international cooperation and investment in research and technology on providing access to modern energy and promoting sustainable development. However, new energy and agricultural technologies developed in industrialized countries are only slowly shared with middle- and low-income countries, in part because of challenges to resolving intellectual property rights, legal rights, and other issues with technology transfer.
Challenges:	Mitigation challenges are moderate in this pathway with a semi-open globalized economy and only moderate transformation toward environmentally friendly processes. Limits to mitigative capacity include the continued reliance on fossil fuels, including unconventional oil and gas resources, limited progress toward an urban sustainability transition, the moderate pace of technological change in the energy and agricultural sectors, and challenges in global cooperation on environmental issues. Challenges to adaptation are moderate as global population growth, along with persisting income inequality (globally and within economies), societal stratification, urban growth in exposed and vulnerable locations, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes. Food and water insecurity continue to be problems in disadvantaged areas of low-income countries. There is only intermediate success in addressing air pollution or improving energy access for the poor as well as other factors that reduce vulnerability to climate and other global changes.

Since different thematic models are being used to represent different domains, comparisons may not always be possible. However, within the same case studies, for a common narrative the models incorporate the assumptions in different ways. To illustrate these inevitable differences see Figure 17, Figure 18 and Figure 19. They refer to IAM runs for the SSP2 scenario marker that combines SSP2 socioeconomic assumptions with the RCP6.0 climate future. The marker scenario corresponds to MESSAGE-GLOBIOM. Total energy use for the world throughout the century (Figure 17) is different across models; however, the trend is similar. When it comes to energy sources options, implicitly connected to the technological options available and considerations made, the composition of the final energy use is also different since the models are of different nature and/or structured in different ways. Similar reasoning applies to the land use profile for the world in Figure 19.

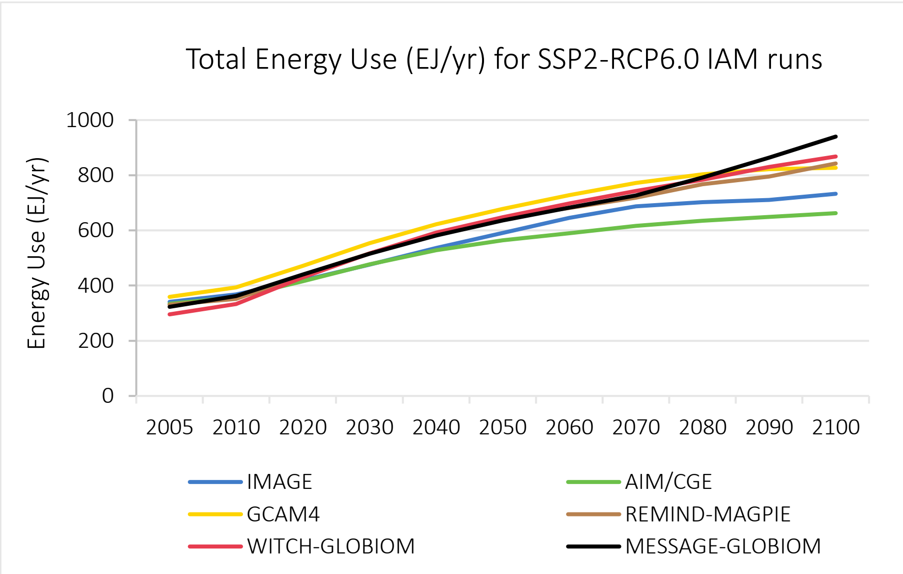


Figure 17. Total energy use for the world in the SSP2-RCP6.0 IAM runs (IIASA Energy Program, 2012).

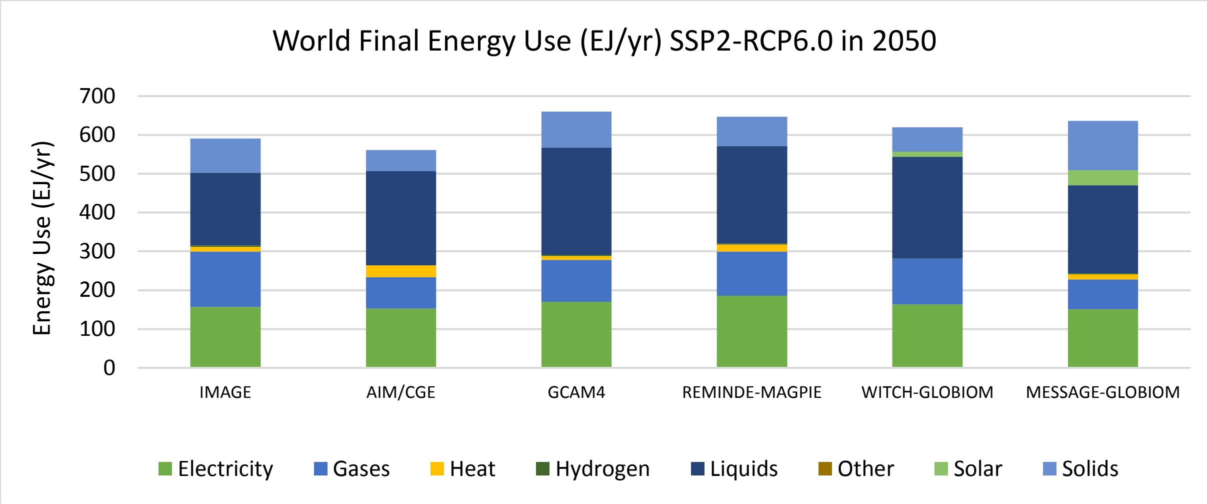


Figure 18. Final energy use for the world in 2050 from the SSP2-RCP6.0 IAMs runs (SSP Database).

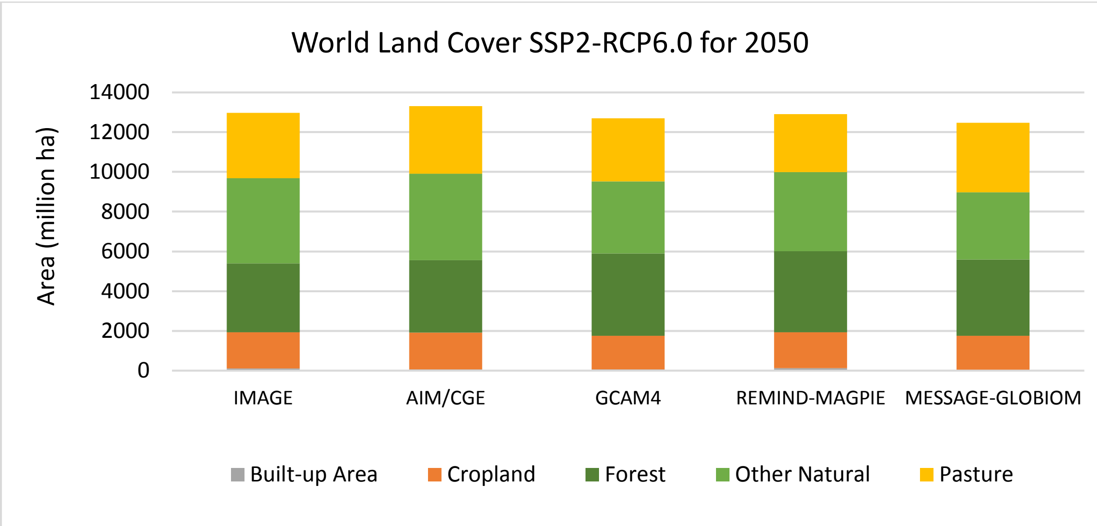
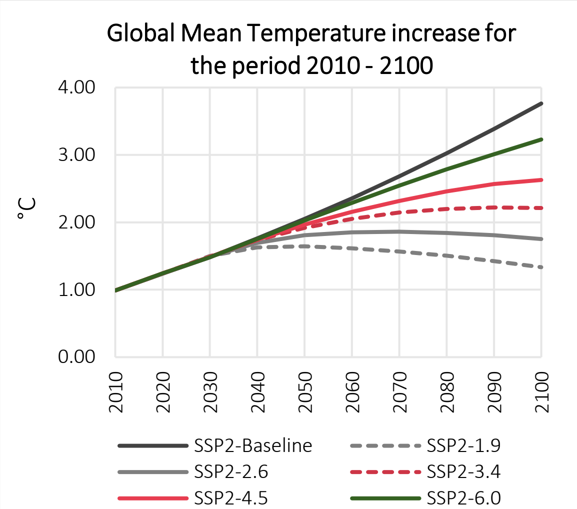


Figure 19. Land cover distribution for the world in 2050 obtained from the IAMs SSP2--RCP6.0 runs (SSP Database).

In the analysis of scenarios with different climate implications, it will be important for each case study to have an understanding of the total and/or sectoral GHG emissions produced in the baseline. In Chapter 3, Figure 6d shows the different trajectories of CO2 emissions for the SSP2 baseline and RCPs combinations, obtained with the respective IAM scenario marker. These trajectories result in different changes in global mean temperature. Although a SSP2-RCP2.6 corresponds to a drastic decrease in emissions from 2020, which turn negative around 2070, global mean temperature increases by 1.8 °C in 2050 remaining relatively constant until the end of the century. Figure 20 presents the scenario marker results for the global mean temperature in SSP2 baseline and RCPs 2.6, 4.5 and 6.0, until the end of the century (chart on the left) and until 2050 (right), according to the latest update of the SSP Database of December 2018. Global mean temperature increase is also presented for the new radiative forcing levels of 1.9 and 3.4. As expected, the RCP6.0 combination differs less to the baseline results, with the global mean temperature separated by only 0.028 °C in 2050. Differences in total emissions and in global temperature are more distinct from 2050 onward; a period not covered in the SIM4NEXUS case studies. However, it will be important to keep in mind that climate policies implemented in the previous decades, or earlier, are likely to have consequences on the emissions trajectories even after the period of analysis. A consistency-check in case-study assumptions that are likely to affect post-2050 emissions trends could be required in such cases, at least in qualitative terms.



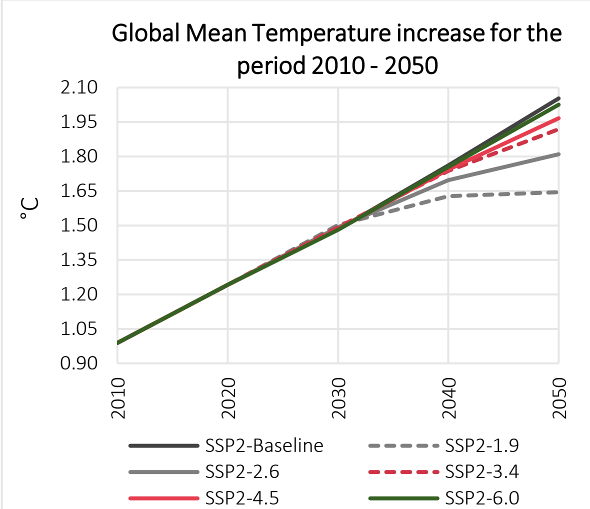


Figure 20. Global mean temperature for the SSP2 scenario marker results for the baseline and RCP 1.9, 2.6, 3.4, 4.5 and 6.0 runs. On the left: global mean temperature increase until 2100; and on the right, global mean temperature increase until 2050. Data retrieved from the IIASA SSP Database – Version 2.0 (Fricko et al., 2017; Gidden et al., 2018; Riahi et al., 2017; Rogelj et al., 2018).

4.2. Summary of implementation of SSP2 in the case studies modelling exercises

The formulation of the baseline narratives was informed by the contents of several outputs produced in the project[11]. In addition, case studies' consultation was performed in collaboration with WP5. The version of the narratives was also iterated with each case study and the final versions are presented in the next section of this chapter (4.3). Information was collected using different tables which are presented in Appendix E (SSP2 parameter assumptions per case study and model developed); Appendix F (Trade-offs identified in the baseline (SSP2) scenario runs); and consolidated in Appendix G (Summary of scenario elements per case study). Table 15 presents the template for structuring the information related to the narrative elements that refer to the baseline. The structure incorporates the main elements considered in the development of the SSP narratives and is expanded to include key elements that refer to the nexus domains investigated in SIM4NEXUS. In this way, we ensure the narratives are consistent with the nexus approach explored in SIM4NEXUS that combines the biophysical assessment of systems' interactions with the dimensions of society and economy. Narratives of the different case studies are still specific to the each context, yet comparable. Some cases studies provide descriptions of all sub-elements of the narratives in the table as the coverage of these elements varies with the specificities of each case.

[11] Deliverable 4.1 "Learning goals definition", Deliverable 3.1 "Report on "First Run simulation results of the thematic models: identifying gaps" ", Deliverable 5.2 "Nexus challenges in case studies", Milestone 17 "Thematic Models applied for all the case studies" and Milestone 18 "Conceptual Complexity Science Tools finalised".

The baseline narratives clarify and describe how a business as usual future would look like in each case study, considering the main nexus challenges and current approaches to the management of different sectors of the nexus. They are also important for the development of scenarios as they present a standard future to compare with.

Table 15. Description of the baseline narrative elements for one of the 12 case studies.

Major Elements for the narrative		Secondary narrative elements	Qualitative Description
Structural elements	Objective		
	Motivating forces / drivers		
	Key nexus interactions and Challenges		
	Critical Trade-offs from baseline runs		
Key SSP scenario elements	Policies, institutions and social conditions	• International Cooperation • Environmental Policy • Policy orientation • Institutions	
	Human development	• Education • Health Investments • Access to health facilities, water, sanitation • Gender equality • Equity • Social cohesion • Societal participation	
	Economy and lifestyles	• Growth (per capita) • Inequality • International trade • Globalization • Consumption and Diet	
	Population and urbanization	• Population (Growth, Fertility, Migration) • Urbanization (Level, Type)	
	Environment and resources	• Fossil constraints • Environment • Land Use • Agriculture	
	Technology	• Development • Transfer • Energy technological change • Carbon intensity • Energy intensity	
Nexus Domains Elements	Water	• Water demand • Wastewater treatment • Use of water for irrigation • Water availability • Water quality • Water policies and regulation	
	Climate	• Future trends in light of historic climate • Influence of climate on nexus systems	

	Energy	• Energy supply and production • Energy demand • Contribution of renewables • Carbon intensity • Energy dependence and security • International trade • Energy policies and regulation	
	Land	• Land use profile and regulation • Forest and forestry activities • Use of biomass • Land use change • Land productivity • International trade • Environmental impact	
	Food	• Food consumption and diets • Food waste • Environmental impact • International trade • Food policies	

4.3. Case study-specific SSP2 (baseline) narratives

In this section, we present the narratives produced for the baseline in each case study, under the SSP2 narrative assumptions and other considerations specific to the context of the cases. We start with the sub-national cases of Sardinia, Andalusia and South West UK, then the national cases of Greece, Sweden, The Netherlands, Latvia and Azerbaijan; followed by the transboundary cases of France-Germany and Germany – Czech Republic – Slovakia; and finally, the European and Global cases.

Sardinia

Sardinia, a large Italian Island in the Mediterranean, has currently around 1.65 Million inhabitants. All economic sectors are projected to increase their GVA between now and 2030. Total employment shows a small increase of 5%, between 2013 and 2030. However, this increase is not homogeneous for all sectors and, notably, employment in the agriculture, forestry and fishery sector is projected to decrease by 32%. This would be in line with the present trend that shows the decline in the number of farms but also an increase of the farm size. For the energy sector, the baseline scenario of E3ME does not project any major change for total energy production. However, the energy portfolio from different sources will see a marked shift towards renewable energy sources with an increase in energy production from wind (256%) and a reduction from coal (-45%) for 2030, compared to 2013.

It should be highlighted a strong uncertainty linked to the regional development of the industrial sector, which is particularly linked to large single industries with heavy demanding energy such as aluminium production oil refineries. The expansions or contractions of these industries are extremely volatile and erratic and depending on global market driving forces.

Under this scenario, and in agreement with the simulations performed for the development of the Regional Energy Plan, reduction of CO2 emissions will not meet regional targets. However, further simulations are planned to include the ongoing regional actions and also to test alternative pathways. The local government has ambitious targets to support the achievement of the Paris agreement that is aimed at with a mix of measures. In the narrative, water management is improved to 2030 to optimize food production and reduce competition for water among different sectors under climate change scenarios, also including inter-annual variability. The irrigated area in Sardinia shows a relevant increase between 2010 and 2030, according to CAPRI model outcome. The largest expansion of irrigated land by crop types is expected for vegetables, identifying several cash crops that can be promoted by high prices in the market. Furthermore, both rice and maize could encounter an expansion of their irrigated distribution, while the largest decreases in irrigated areas are foreseen for fruit trees and grapes. It is also explored how a more efficient use of water may reduce the energy consumption related to water pumping. Different policies for water management (new infrastructures, managing rules, water pricing) and policies to increase the share of renewable energies to increase the resource efficiency in the region, reduce emissions and increase resilience to climate change while guaranteeing livelihood and a sustainable economic growth are implemented to 2030. Key interlinkages considered in the modelling are how water availability affects hydropower and food production and how water pumping affects the energy sector.

Andalusia

This case study covers Andalusia, which is currently the most populated region of Spain. This region is characterised by a strong agricultural sector highly dependent on irrigation agriculture, which accounts for more than 80% of total water withdrawals and generates more than 64% of the agricultural production in the region. The industrial sector is mainly based on agricultural and consumer goods. The services sector, which dominates the regional economy, relies heavily on tourism. The narrative sees a reduction of diffuse emissions of 18% by 2030 combined with an increased resource use efficiency in agriculture. This is supported by an improvement of governance, transparency, and information. Agricultural and environmental policies are integrated to address pressures on land and water whilst promoting their sustainable use and economic development. Sustainable water management in agriculture is investigated to reduce trade-off between water use and food production. The role of energy efficient technologies and renewable energy potentials in agricultural systems are looked at. Finally, the potential impact of climate change on water availability and crop yields are explored.

South West UK

The UK Case Study covers the region of South West England, more specifically the counties of Cornwall, Devon, and parts of Somerset and Dorset. The region, with a population of about 1.7 million, receives around 11 million tourists during the peak summer season. The largest share of the population (55%) live in rural areas, and the remainder is distributed over 13 urban centres. Population is expected to grow at 0.6% rate up to 2030 and 0.4% until 2041. Regional Gross Value Added (Devon and Cornwall) has increased, on average, at a 3.1% rate in the period of 2010 - 2016. Tourism and agriculture are the main sectors in the local economy. These sectors are greatly dependent on water for their activities, with summer demands for water typically 10-15% greater than the norm. This seasonality in water demand creates challenges for water management, in-terms of both supply and wastewater disposal. South West Water is one of the largest energy consumers in the region as well as being a large energy importer to the national grid, through their own renewal power generation (wind/ solar/anaerobic digestions). The UK water sector is privatised and the water and wastewater services in the region are provided by South West Water. The government regulates the water sector through a group of three separate and independent bodies; which focus on economics, the environment and drinking water quality. It is thought that the low perceived value of water by users delays a behavioural change towards water conservation. In fact, water prices in the UK are forecast to be cheaper in real-terms in 2025 than 10 years previously, as companies continue to improve operational efficiency. Therefore, water efficiency initiatives focus around customer awareness of their usage through increased metering and engagement initiatives. The water industry market structure follows the traditional approach and the wholesale water market model is not implemented (in the baseline case). Increase in temperatures and longer periods of hot weather increase the demand for water from different users. The extreme variance in the UK weather, as experienced in 2018, is putting additional strain on the assets – with an increase in water mains burst and leakage reported by some other UK Water Companies in this year. It is envisaged that water supply and treatment will be further challenged towards the middle of the century due to the higher degree of urbanisation [EPR5] and increased seasonal water demand peaks, especially during summer months due to tourism. Upstream in the catchment, South West Water is working with local farmers to improve raw water quality as a way of reducing their drinking water treatment costs and improving the natural waterways in the region. Similarly, downstream in the catchment, the water company is promoting more sustainable drainage solutions that are often large in land area but provide amenity value. Bio-solids that result from the treatment of waste water are used for energy generation at some of the larger wastewater treatment works, where-as in rural areas these bio-solids are disposed of on land as fertilizers. There is only one nuclear power plant in the region and most of the electricity produced in the region is supplied by renewable energy sources. The source of water for cooling is outside the boundaries of this case study. No plans exist to develop thermal power generation infrastructure in the region.

Greece

After facing an economic downturn early in the 2010's decade, Greece economy recovers and debt levels decrease. GDP and GDP per capita nearly double by 2050. Population decreases moderately (About 1%) until 2050; and more around 85% of the population will live in cities, in contrast with 60% in 2010. The major economic sectors of tourism, agriculture and food processing, grow in the coming decades. In agriculture, olive oil exports, primarily from small farms, are expected to grow more than domestic consumption declines. As a result, olive oil production grows at a rate of 0.9% in coming years. Following current trends, cultivation of cotton increasingly relies in organic practices (more than half of Greek cotton yield was organic in 2016). However, a shift in the cultivation of cotton and other crops, to fodder is anticipated, with benefits to decrease soil erosion by 11%. The tourism sector continues expanding, so does its contribution to the GDP, which is higher than 20% by 2030. Greece is a country with diverse terrain, from high mountain regions to one of the world's longest coastlines, and thousands of islands - more than 200 of them populated. With this diversity, the predominantly Mediterranean climate is subject to large variations across the country both in terms of precipitation and temperature. As a consequence, water and land use strategies need to be diversified.

In recent years, water scarcity has been a recurring challenge to many Greek islands that now depend on water imports. Also in the mainland, groundwater abstraction is substantially exceeding the natural recharge. With the expected growth in domestic energy and food industries, water demands in these sectors increase in the coming decades - a development that poses challenges in light of decreasing total water availability. Limited land availability hampers the development of food and energy sectors. Although climate change is expected to lead to moderate decreases in precipitation, it is anticipated it will affect crop yields and energy demands - as well as extreme events. Further, improved water efficiency is expected in all sectors. This will be realized through a mix of technological development and the fostering of a water-saving culture (expected across Europe). The energy sector in Greece is heavily dependent on imports of fossil fuels (61%). Also domestic energy sources are largely fossil (natural gas?). Overall, less than 10% of total energy needs are covered by renewables. Low carbon energy is however growing in coming decades. On the demand side, electricity prices are high. Between 2010 and 2016 the cost of electricity has increased by 49% (mainly due to additional taxes and fees, which represent % of the tariff). If these do not decline in the coming years, the country's socio-economic development may be impacted negatively.

Sweden

Sweden follows a path with no major changes in recent trends at social, economic and technological levels. The forestry sector and the increase use of renewable energy sources continue to dominate the national agenda. The population is expected to increase by 33% in 2050. Although most of the population lived in cities in 2010 (85%), the urbanization rate will continue to increase reaching 92% by the mid-century. GDP will more than double by 2050 and average per capita income will also increase but at a smaller rate. Nonetheless, income is expected to reach 59 thousand US$2005 by 2050, more than 25% above the average European income. Hydropower and nuclear power are the backbone of the electricity system, providing reliable and relatively low energy costs in comparison to other countries in Europe and low carbon intensity (low emissions from electricity generation). Excluding taxes and levies, household electricity prices for electricity are lower than the EU-28 average. The long lifetime of hydropower plants secures partly electricity supply. On the other hand, expansion of this renewable technology is limited by law, as already ⅔ of the rivers in the country host this type of infrastructure. The fragmentation of river system has impacts to ecosystems, and because of that recently introduced legislation protects the only five major rivers not hosting hydropower dams thus no new large hydro dams can be constructed. Already now forestry by-products and waste are used for energy production, particularly for heating, and this will continue in the future. The increasing demand for bioenergy, in particular from the intensification of the forestry industry, may increase the share of managed forest land in forestry sector, and the area of energy forest of fast-growing tree species and use of fertilizers in agricultural sector. All these activities impact ecosystems and biodiversity, and also affect water quality. Wood and black liquor (a by-product of pulp processing) represent over 80% of the biofuel demand in Sweden, followed by densified wood and waste). Two thirds of the country's land is covered by forests and 55% by productive forest (i.e. producing at least 1 cubic meter wood per ha per year). The forestry sector continues to play an important role in the economy, although increased mechanization in the large-scale forestry leads to lessen the employment opportunities in the sector. Water is an abundant resource in the country, however vulnerable to changes in the climate. Precipitation and temperature are likely to increase in the future as is the risk of flooding and drought events. Drinking water supply in the south is likely to be affected more often by reduced water availability. As climate is a limiting factor in the agricultural production, most food production occurs in the South. There are 63,000 farms in Sweden, with average side of farm of 41 hectares. Swedish exports of food and agri-cultural products currently amount to EUR 5 billion, and is steadily increasing. Sweden has very ambitious targets when it comes to sustainability and values in food production and Swedish organic production is increasing and has more than doubled in the last ten years. The farmed land (arable land, pastures and meadows) used for organic production is currently 18 percent. In 2017, the Swedish Government set a target that certified organic production shall increase to at least 30 percent of the cultivated area by 2030.

The Netherlands

In the Netherlands, the population is expected to moderately increase by 2050 (approx. 10%). GDP is expected to nearly double, with GDP per capita rising by approximately 70%. While urbanization is already high in the country (around 80%), by 2050 it is expected to be over 90%, and by 2100 it is expected that nearly all population will live in urban areas, according to population density.

The Netherlands move towards a low-carbon and resource efficient economy by 2050. That is achieved with various measures such as energy efficiency and Carbon Capture Storage (CCS). Energy will be transformed both within the Netherlands and outside, and electricity trade with neighbouring countries is considered. The government supports these change with a number of policy instruments, such as financial incentives. To reach the ambitious target of 95% reduction of GHG-emissions by 2050 biomass is expected to play a key role. In some sectors such as air transport and freight shipping the only low-carbon option are biofuels. In 2015 only 3.6% (80 PJ) of the energy production was from biomass where the two main sources were waste and wood from various sources. The potential energy of biomass from the Netherlands is estimated to 200 PJ which is not enough to meet the low carbon economy target (800-1600 PJ) which means that imports of biomass is needed. It is of importance that the imports of biomass are sustainably produced. Within the EU Renewable Energy Directive (RED) II, criteria for defining such sustainable production is currently being developed. The target of decreasing the GHG emissions in 2050 with bioenergy can compete in food and fodder crops which can lead to higher prices for these products. In 2015 around 35% of the biomass used for energy production was from waste from both households and industry. There is also a potential of utilizing the sewage where algae and sludge can be extracted as bioenergy.

Latvia

Latvia is among the fastest growing economies in the European Union. The country joined the Eurozone in 2014 and the OECD in 2016, after a fast recovery from the financial crisis of 2008 - 2010. GDP will continue increasing and double by 2050 in comparison to 2010. GDP per capita is to triple over the same period, improving its difference to the average EU-28 from 50% to 20%. The population is projected to decrease by 20% in 2050, not surpassing 2 million inhabitants. Urbanisation rates will increase moderately, and eight out of 10 people will be living in urban areas by the mid of the century. Demographics dynamics related to migration and ageing population can interfere with the economic growth of the country. Agriculture, chemicals, logistics and woodworking, seconded by the textiles, food processing, machinery production and green technologies are the most prominent sectors to the Latvian economy.[12]

The share of RES in the energy mix is one of the highest in Europe, has increased from 30% in 2010 to 37.2% in 2016. Main renewable energy sources are wood (firewood, wood wastes, wood chips, briquettes and pelleted wood), followed by hydro and in recent year's wind. Concerns exist regarding the achievement of the 2020 RES target of 40% in gross final energy consumption. Natural gas and wood biomass are the main energy sources for electricity and heat production. There is no endogenous production of fossil fuels (e.g. oil and natural gas) in the country and although energy dependency has decreased over the last decade (up to 2017) imports still represent 50% of the total energy consumption. Due to the high share of RE, the carbon intensity of the energy sector is 15% lower than the EU-28 average of 2.09 tCO2/toe in 2010. Hydropower potential in the country makes this an attractive technology to further the decarbonisation of the energy sector, however, at the expense of potential negative impacts on the environment. About half of the country land area is covered by forests, and nearly 40% is agricultural land, leaving a small share of primary forest (less than 1%). The forestland corresponds mostly to the naturally regenerated forest (around 80%) in the result of forestry sector activities. No major changes are planned over the coming decades. Agriculture and forestry compete for the use of land. Latvia is located in a temperate climate region, and its location by the Atlantic sea result in mild temperatures. However, as observed in the previous century, the temperature has increased by 1°C, and changes to rainfall patterns were verified, including increased total precipitation. Water quantity and availability is not a challenge in the near future, due to low consumption and water efficiency measures implemented by the government, but rather water quality. Eutrophication of marine and inland surface water triggered by higher levels of phosphorus and nitrogen in river systems, caused by local and pollutants diffusion and pollution from the transboundary basins, is a major environmental problem. Pressure from anthropogenic activities on environment is

[12] http://www.latvia.eu/lv/economy

expected to increase over the coming decades negatively affecting the Baltic Sea. The food industry is one of the main industries in the country. Top food exports of Latvia include cereals, such as wheat and rapeseed, milk and oil products. Food production and processing are important economic sectors of the man economic sectors of the economy, with revenues in the order of 1.5 billion euros in 2010. The increasing demand for cereals exports, particularly wheat, requires the expansion cropland area until 2030. Subsequently, the use of fertilisers is expected to rise to secure productivity levels in lower fertility soils, which will exacerbate water quality issues.

Azerbaijan

Azerbaijan follows a path in which socio-economic and technological trajectories do not change significantly from recent historical patterns. The GDP is estimated to double by 2050 relatively to 2010, and surpass 100 billion USD, with GDP per capita increasing in 60% over the same period. Population increases 20% by the mid of the century to about 11 million people. Following a worldwide trend, the degree of urbanization increases significantly to 70% by 2050; while in 2010, five out of 10 people lived in urban areas. Diversification of the economy and investments in manufacturing, non-energy mining and also fuel refining, reduces the dependence on the extraction and production of fossil fuels, even though the latter still makes up the majority of the production by 2050. Employment increases in all sectors up to 2030 and 2050, except in the electricity and gas distribution sectors (decrease of -0.5% by 2030). Water security is an important challenge in Azerbaijan since over 70% of the water resources of Azerbaijan are transboundary. Agriculture continues to be the sector with higher water demand, representing more than 70% of the freshwater withdrawals, and food production is vulnerable to water availability and soil quality. Azerbaijan produces a wide variety of agricultural products and the sector employs 30% of the active population. Agricultural productivity increased in the recent years, in part due the increased use of fertilizers. Production of cereals and dried pulses increased between 2010 and 2016 by about 50%. However, soil erosion, salinization and poor waste management limit the amount of arable land effectively available for agriculture. More than half of the land area is used for agriculture, with nearly 50% of it under irrigation. Forests cover 12% of the land but are unevenly distributed and illegal logging is a problem. Although reforestation is a key priority to the country, due to the importance of forest cover to ecosystems services, hydrology and mitigation potential, no particular measures are taken to increase forest land. The eleven climate regions in Azerbaijan influence greatly agricultural systems' productivity, due to different precipitation and temperature patterns coupled with the geography of the watersheds. Economic growth and continued reliance on fossil fuels leads to an increase of 70% in carbon dioxide emissions by 2030 relative to 2010, doubling by 2050. The country relies mostly on domestic oil and gas for electricity generation. Oil power plants continue to be decommissioned and gradually replaced by more efficient natural gas power plants. Natural gas is the main fuel used for electricity generation by 2050. The economy continues relying in the extraction and production of fossil fuels, such as oil and gas, however, the contribution of fuel exports to GDP decreases slightly in the coming decades (from 38% in 2010 to less than 8% in 2050).

Transboundary France - Germany

The transboundary France-Germany case study is situated in the Upper Rhine region and covers the federal state of Baden-Württemberg (35,751 km²) on the German side and the newly formed Grand Est Region1 (57,800 km²) on the French side, with the (Upper) Rhine playing the role of physical and administrative border in its middle. The area along the Rhine is one of the most densely populated and highly industrialized areas of the European continent. In the narrative, this transboundary area strives to achieve the European Directives and policies (Common Agricultural Policy, Water Framework Directive, EU legislation on biofuels) as well as the transboundary agreements (climate adaptation plans). A central issue for that to be achieved is increased transboundary cooperation. France and Germany jointly work for achieving jointly set policy objectives in a more cost-effective manner - with a special focus on resource efficiency and the preservation of rivers functionalities.

Transboundary CZ – SK - DE

This transboundary region encompasses areas of Germany, the Czech Republic and Slovakia. A common policy is developed to minimize land use effects on water fluxes and water management in general. The agricultural landscapes are dominated by large monocultures with high shares of energy plants (e.g. maize or rape) cultivated on systematically drained field blocks of surface area up to several km^2. Rain water discharges fast from agriculture landscape in which water retention capacities like small flood plains, wetlands, wet meadows are missing. Maize, as a C4 plant adapted to higher temperature, does not grow until June and bare land overheats on sunny days. Rape and wheat grow fast in spring and after harvest in late June/July bare land overheats. In summer months, a large portion of agriculture fields is either not covered by growing vegetation or is covered by growing maize with optimum temperature over 30°C. Surface temperature of harvested agriculture fields (without catch crop) in summer reaches 50°C and consequently warm air (sensible heat, turbulent ascending air, thermic) moves up carrying moisture high into atmosphere from the surrounding landscape (lakes, ponds, forests). Such a mass of ascending air may block income of wet air from ocean. Organic matter in drained overheated soil mineralizes (decomposes) and total loses of organic matter results in substantial release of carbon dioxide which can be higher than amount of carbon recycled in biofuel cultivated on these fields. The narrative investigates how water systems impact land systems by either flooding or droughts, and also how they impact food and energy production. Decisions on land systems affect water storage capacity, local climate, bioenergy potentials, and the available land for agriculture. An innovation consists in an increase of water retention capacity of agriculture landscape (restoration of flood plains, wet meadows, ponds with littoral vegetation, catch crops etc) resulting in higher CO_2 sequestration in biomass, cooling effect of evapotranspiration, renewal of short water cycle, nutrient recycling and dumping of temperature extremes.

Europe

Europe follows a path with no major changes in historic trends at social, economic and technological levels. Population increases by 10% in 2050 in relation to 2010, reaching 672 million people. In the EU-28, the increase is slightly lower (7%), and the union's population represents 80% of the total in the continent. Migration to cities will continue to increase surpassing 80% by 2050, in comparison to 72% in 2010. GDP is expected to double in EU-28 by 2050 and a similar trend is expected for Europe. The average per capita annual income also increases significantly but not as much as the GDP, reaching, by 2050, 46 thousand US$2005 in Europe and around 49 thousand US$2005 in the European Union. International trade continues to be key to meeting the different demands. Energy intensity of the economy is expected to decrease because of the implementation of a series of EU-level policies (i.e. EU-ETS, Energy Efficiency Directive, and Renewable Energy Directive). This is linked to the decommissioning of traditional coal-fired thermal power plants, which contribute significantly to emissions and require water withdrawal for cooling systems. Most of the water use will continue to be allocated for agriculture sectoral, mainly to large irrigation systems. Water consumption in other sectors (industry, electricity generation, and municipal uses) is not expected to change dramatically. Competition for water could be an issue in the southern regions of the continent, characterised by an arid climate, where the duration of drier conditions is more prolonged. Water quality is affected due to the intensification of agriculture in Eastern Europe. On the other hand, the implementation of wastewater treatment regulation reduces the contamination of water bodies caused by urban settlements. Water availability is likely to reduce in Southern Europe and the population living in river basins with a high risk of water scarcity is likely to increase by 90% (or nearly double), affecting around 40% of the total population. Agricultural land area is expected to decrease throughout 2030 and 2050 with a corresponding increase in forest land. As more people move into cities, built up area increases marginally. Although forest area is expected to increase, increase in land for cultivation of energy crops (although marginal) and the urban area may reduce biodiversity on land by 20%. Irregular rainfall patterns and sea level rise increase the flood risk in Europe. The energy sector is the one that contributes the most to the GHG emissions, followed by AFOLU. However, the latter has the potential to provide mitigation opportunities. Depending on policies implemented, CO2 emissions could vary between 2 to 6 Gt CO2 in 2050, in comparison to 4 Gt CO2 in 2010. In 2010, food supply is slightly over 3,000 kcal per capita per day in Europe, compounded by 1/4 animal products and the remainder of plant-based products, which indicates sufficient access to food and a substantial amount of food being wasted in the households. An increase in the consumption of animal-based products is expected, however, the modest population growth rates attenuate food demand increase due to the larger share of the ageing population. Crop and livestock production is therefore expected to increase modestly until 2050. Critical challenges relate to water availability, quality and vulnerability to climate change (e.g. increased flood risk and droughts). Competition for water between resource users can be a challenge in regions prone to water stress. Use of land, e.g. bioenergy crops cultivation, and water, for irrigation and cooling systems, resources are likely to affect biodiversity negatively. Expansion of hydropower generation can affect water quantity and quality, due to flow regulation, and apart from the ecosystems impacts, affect the water provision of downstream water users. Potential conflicts related to food security may arise from the increased production of bioenergy crops, which at the same time can also lead to hampering afforestation initiatives.

Global

The world follows a path with no major changes in historic trends at social, economic and technological levels. GDP is expected to quadruple by 2050 relative to 2010, and GDP per capita to nearly triple in the same period, reaching around 27 thousand USD2005 by the mid-century. Population surpasses 9 billion people in 2050. Urbanization rates increases over 30% relative to 2010 and approximately 70% of the world population in 2050 will live in urban areas. Main drivers governing resources management and sectoral demands relate to population growth, and economic development, i.e. income per capita. Climate change is an acknowledged factor that impacts systems and influences drivers, creating an overall added pressure. Key global challenges include the ability of sectors to supply their demands. This is particularly relevant for water, energy and food security in developing countries, and changes to consumer behaviour (e.g. higher consumption of animal products, increase of losses in food supply chains). Ecosystems become more vulnerable due to pressures in the energy, water and land use sectors. Food and energy sectors compete for the use of land for cultivation of bioenergy crops, which can result in higher food prices. Food production is strongly affected by the developments in the other nexus systems, in particular by climate impacts, which affect productivity. Agriculture dominates water demand, especially by large-scale irrigation schemes, in comparison to demands from other sectors (electricity, industry and domestic supply). Water quality is also an increasing concern, affecting both drinking supply and ecosystems. Cropland areas continue increasing until 2030 and 2050. Changes to land use depend greatly on population growth, dietary options and income per capita. Higher meat consumption affects livestock production and, consequently, land area dedicated to pastures. Forest land decreases with the increasing competition from land from different sectors and if efficiency of agricultural production does not increase. Land and aquatic biodiversity decline due to eutrophication caused by changes to land use and hydrological disturbances as a result of water abstraction and reservoir infrastructure. By 2050, only 30% of biodiversity remains intact in temperate climate regions, and 50% in tropical areas. Changes in climate disrupt natural water systems further, both in terms of quantity (e.g. flooding events) and scarcity (e.g. droughts). Energy systems develop towards global and affordable energy access by 2030, which increases the overall demand for energy. This development requires the extended use of natural resources, such as water and land for biomass production, and fossil fuel extraction. Fossil fuels, such as coal, natural gas and oil, continue representing 70% - 80% of the primary energy supply by 2050. From the renewable energy sources, biomass is the most used followed by hydropower; with solar and wind energy contributing very little to global primary supply, in this year, is less than 10% in 2050. Greenhouse gases emissions increase throughout the mid-century. CO2 emissions are most dependent on the evolution of the energy system, which continues to rely on fossil fuels; whereas methane emissions are dictated to changes in land use, and nitrate oxide emissions influenced by agricultural management. Total CO_2 emissions could increase from 30 Mt/yr to close to 50 Gt in 2030, reaching between 50 and 60 Gt by 2050, CH_4 emissions could increase between 350 Mt/year and 400 Mt/yr; while N_2O emissions are estimated to range between 12 - 17 Gt/yr in 2030 to 14 Gt/yr -23 Gt/yr in 2050.

4.4. Developing narratives for scenarios

Based on the literature review of the formulation of SSP narratives and extension examples, we propose the following general methodology for the elaboration of storylines. This might be used for the consistent development of narratives that describe the different nexus futures to be analysed in the case studies – should they be needed. The method presented should not be interpreted as an additional task for the case studies but seen as a potential way of supporting the development of scenarios in the case studies. Better understanding is needed on the usability of the methodology and how it can be operationalized or incorporated with other ongoing tasks, i.e. policy cards and the development of the policy scenarios.

The methodology suggested can be deployed by experts leading the case study team in combination with the modelling teams, and /or be used in the forthcoming case studies' workshops. Harmonization of narrative elements and their selection process across the narratives may help facilitate their comparison and interpretation. And, in turn, help scenarios become relevant, plausible and consistent across settings. The proposed 7-step method is presented below:

1. **Identification of the main objective of the narrative.** Setting the purpose of the storyline. This step can be interpreted as a title of the scenario narrative that embodies its purpose and provides an overview what is at stake in a particular scenario. It can be revised after the development of the following steps.
2. **Identification of main drivers that are at play in the future.** Drivers can be selected from the narrative elements in the SSP narratives (see appendix B). These can be complemented with others that confer specificity to the case study investigation, and/or new categories added. The drivers selected should be comprehensive enough to explore their implications across nexus domains. The use of the Drivers-Pressure-Status-Impact-Response (DPSIR) framework could assist in the identification of drivers. Care should be taken to document the implications of the adoption of complementary drivers – *vis a vis* the 'big picture' SSP futures.
3. **Weighting the drivers:** drivers are classified in terms of relative importance to the development in the future. This can be done using a numeric scale, e.g. low importance (1) to high (score 5) or other suitable scale. Alternatively, a qualitative scale can be used, simply describing low, medium and high relevance. As this step is subjective and importance of the driver is based on tacit knowledge a first method of weighting might be via expert workshop. However, at a later stage drivers might be formally derived via parametric sensitivity analysis resulting from model runs.

4. **Description of evolution of drivers:** the next step corresponds to describing how drivers are expected to evolve under a specific scenario. Firstly, the sectoral evolution of is stated; and secondly, their potential cross-sectoral impacts across the nexus domains are postulated (at least the ones expected to be more impacted). Again, the process of expert elicitation followed by formal modelling may be a useful process.
5. **Identification and mapping indicators to drivers** is undertaken in parallel to steps 3 and 4. They relate what are often qualitative information from the SSPs to quantities that can be mathematically modelled;
6. **Preferable type of scenario approach for the quantification analysis** (see section 3.5). The objective of the narrative, its characteristics and the type of modelling tools or mathematical approaches used for its quantification process are important aspects to consider when selecting the type of scenario investigation method. It answers the question of how the scenario questions are investigated. This step might most sensibly be undertaken after the formulation of the qualitative aspects narratives. Particularly in the case stakeholders are involved in brainstorming elements of those narratives. The prior choice of a model could act so as to obscure important elements of the local situation that would otherwise be overlooked.
7. **Formulation of the scenario narrative:** lastly, the narrative is formulated based on the information collected in the previous steps. Depending on the stage of the case study, the narratives can be either developed along with stakeholders or by case study teams. In the latter case, the scenario storylines should be discussed and iterated with stakeholders. Then the above steps might be repeated or iterated as a function of resource and time available.

4.5. Integration in the SIM4NEXUS nexus assessment framework

The formulation of narratives is necessary to describe scenarios under analysis in each case study. The use of the SSPs – or consistent scenarios across domains – to calibrate scenarios has clear advantages. Firstly, more than one system is investigated as is the analysis of a combination of trends and cross-sectoral impacts. Secondly, the understanding and the definition of assumptions related to socio-economic drivers are key to define a baseline for comparison with the futures to be investigated. Lastly, several modelling tools are used, IAMs in the case of the SSPs, thematic models in SIM4NEXUS that vary in inputs, architecture, sectoral and system scope, temporal and spatial resolutions.

In Figure 21 we present the current version (November 2018) of the SIM4NEXUS framework for the assessment of the nexus in the case studies. The formulation of narratives (document box highlighted in blue) is part of the second step of the framework. Step 2 corresponds to the identification of nexus challenges and definition of pathways to be potentially analysed in the case studies. The formulation of narratives takes into account the biophysical and policy assessment of the nexus domains, and the identification of the key nexus challenges in each case study. This information, in combination with stakeholder input and feedback, will enable the case study teams to identify the key elements of the narratives and formulate the storyline for the baseline scenario. Simultaneously, it should assist in the development of the other scenarios, and subsequently, produce their correspondent narratives.

Another important guiding element in the development of scenario narratives is the use of the DPSIR approach, presented in Deliverable 1.7. The DPSIR framework assists in the characterization of the starting point of the case study and facilitate the information exchange with stakeholders. For example, it could be useful for a better understanding of the status of the systems in the base year, identify main challenges through the documentation of existing impacts and pressures, and, within this context, connect the key drivers that influence the systems' dynamics.

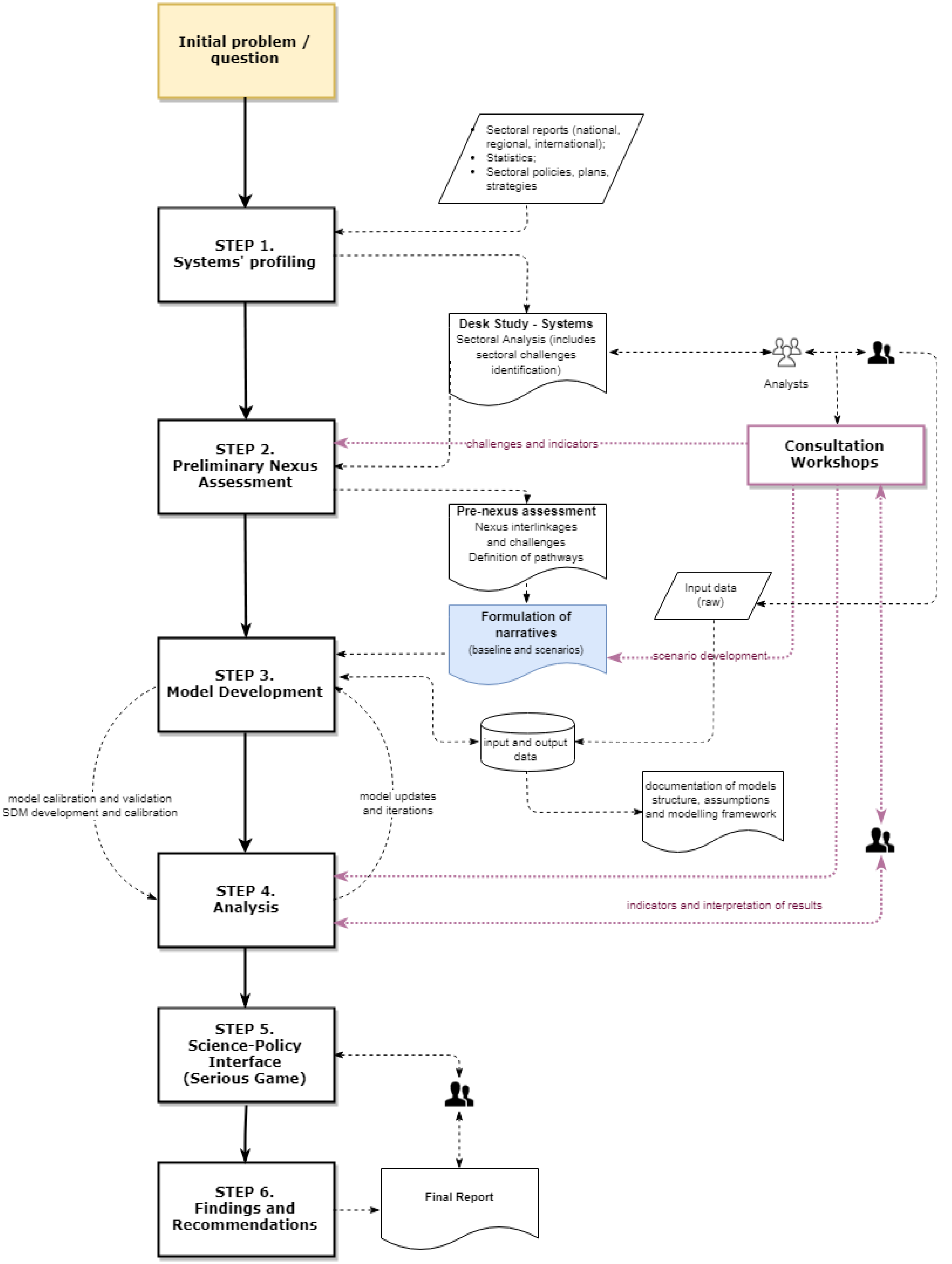


Figure 21. Simplified diagram of the SIM4NEXUS Framework for the assessment of the nexus in the case studies (version November 2018). The formulation of narratives (in blue in the diagram) is part of the activities in Step 2 (pre-nexus assessment) that results from the interpretation and definition of pathways and is informed by stakeholder participation. Note the diagram present here may not coincide to the final

version of the framework, which will be published in Deliverable 1.5 in Month 48 (May 2020) of the project.

5 Innovations and low-carbon options in the context of the climate, land, food, energy, water nexus

Here we consider an innovation new - or a new application of existing - technologies, policies, practice or combination thereof. A nexus Innovation is an innovation that takes advantage of linkages between domains. (As noted innovations need not represent something absolutely new. They can also be a novel way of applying existing technology or knowledge. For instance, a desalination plant might be used to produce fresh water, and use much electricity to do so. Yet an increased deployment of intermittent renewable energy might result in a surplus of power that is later curtailed/wasted. In response, the desalination plant might then be run during times of excess power – absorbing excess power – and lowering curtailment and waste. There is little new about the technology. Yet the operational policy is an innovative response to the pressure from the integration of the water-energy domains in the scenario described.)

An innovation is defined as some new or new application of existing technologies, policies, practice or combination thereof that is a Response to some: Driving force, Pressure, State or, Impact (DPSIR).
In SIM4NEXUS we consider a nexus Innovation, as an innovation that takes advantage of linkages between domains. We divide these into three categories: technical, policy/institutional and social.
Technological innovations refer to the introduction of new, or the new use of existing, technologies, methodologies and/or approaches. These tackle challenges solve problems or simply change something established following a less conventional approach, method, idea, etc. Examples include moisture-sensing technology as part of irrigation systems, Carbon Capture and Storage in thermal power plants. *Institutional and policy innovations* refer to the introduction of policies and governance structure to improve, for instance, the performance of a sector. Examples include the subvention of solar photovoltaic systems' instalment in rural areas, and the implementation of a transboundary flood alarm system. *Social innovations* refer to strategies, ideas or concepts that meet social needs, for instance working conditions or health service, with the aim to strengthen civil society. Fairtrade practices in the coffee sector to improve and sustain the life and livelihood of coffee farmers, CO2 labelling, biofuel mandates are examples of social innovations.

Many times innovations are implemented in silos in line with the common sectoral planning approach. We aim to identify here a pool of innovations, from which case studies can select interventions to include in the modelling analyses that are relevant for their cases. The transferability of such innovations needs to be discussed with modelling teams to assess how these can be included in the models developed with the thematic models.

The list of innovations and more particularly nexus innovations are to be produced in Task 1.6 over the next six months. Collaboration with WP5 is expected for the elaboration of the innovations inventory, which will largely derive from: a) case study input and feedback on innovations the case studies would like to include in the analysis; and, b) on background research by partners involved in the task of other potential innovations to address trade-offs identified in the baseline scenario runs. We present in this report a compilation of assumptions from each model classified in a similar manner to the categories of innovations (policy-related, technological and social). The analysis of innovations applied to the different case studies will be included in Deliverable 1.5, due on Month 48 of the project. Based on all innovations used in the case studies, the latter will also include an inventory of innovations which will be in accordance structure to the Deliverable 1.1 “Scientific Inventory of the Nexus” (Laspidou et al., 2017). In this way, technological, policy and social innovations are matched with system-to-system interactions.

It is foreseen that these innovations derived in one case study might be adopted or considered in another. Lessons learned from this exercise should produce insights for considering the implementation of selected interventions and a step toward policy coherence. The identification of innovations should also be discussed with stakeholders, ideally in the second workshop. This would allow for cross-validation of nexus challenges and/or the identification of potential implications arising from the implementation of “innovative” solutions.

5.1. Assumptions and Innovations in the Case Studies

A first step in the assessment of innovations is the understanding of assumptions considered in the baseline scenario, when these were transferred as quantitative interpretations by the thematic models. The summary of the key assumptions used in the baseline and 2-degree scenarios, per modelling tool, is compiled in Appendix H. The compilation considers similar categories as of the innovations and is based on information collected from the Milestone 17 “Thematic Models Applied to all Cases”. The next steps in this analysis are: 1) to complete the table with input from modelling teams and produce case-specific tables; and 2) distinguish the assumptions as “standard or conventional” option and/or solution; from “innovative”. Very important at this stage is to agreement on the interpretation of what innovations are and what the different categories of innovations are, in the context of the SIM4NEXUS project.

From the analysis of the table in Appendix H, it is seen that there is a higher representation of policy assumptions compared to other categories. Nonetheless, it is important to note that it does not mean there is an unbalance in terms of the types of assumptions but instead that policy options drive models and have a direct impact on the preferences for certain technological outcomes. Additionally, the models may already include a vast array of options that is far more comprehensive than what is relevant to the case. Hence, it is in better accordance to inform on the policy options than on extensively outlining details very specific to the models.

5.2. Inventory of innovations to address trade-offs in the case studies

The compilation of trade-offs (interpreted in the perspective of Drivers, Pressures, Impacts and States (DPIS)) from the baseline runs is ongoing and should be finalised in the first quarter of 2019. This will allow not only to refine the baseline narratives presented in Chapter 4, but also to investigate innovative solutions to tackle critical trade-offs identified in the baseline runs with the thematic models. Important to consider in this phase of the work is the collaborative work with WP5 and the liaising with modelling and case study teams. Participation of stakeholders will be crucial in the identification of potential solutions for the DPIS’s, once the results from the modelling effort are discussed. The inventory of innovations per case study to be produced is foreseen to include, when feasible, to the cross-matching when of categories of innovations per nexus domain, i.e., one policy innovation is linked to a (or more) technological interventions, and also to social-level actions. Combination of innovations, within and across nexus domains, will be assessed in terms of their potential to boost synergies between systems and sectors in the case studies. In this way, most innovative nexus sectors are identified in light of their capacity to strengthen nexus compliant practices.

6 Conclusions, recommendations and next steps

In this deliverable we explore the development and application of the global SSP narratives from the perspective of their usefulness to the nexus analyses under development in the 12 case studies of SIM4NEXUS. The "Middle of the road" SSP narrative (SSP2) served as a starting point for the baseline scenarios of the cases, particularly in the modelling component. In task 1.6 we transpose the quantification effort performed with the thematic models to their qualitative interpretation, with the aim of clarifying the meaning of the "middle of the road" scenario from the perspective of each case study. The latter we consider as the extension of the SSP2 global narrative to the cases in SIM4NEXUS, and respective storylines are presented in Chapter 4. The analysis of the SSP-RCP framework, as well as other narrative formulation methods, enabled the definition of methodological steps for the formulation of scenario narratives. Narratives, as textual description of scenarios, are useful not only for the case studies when presenting their work and investigating scenario options with stakeholders; but also provide an opportunity of checking the plausibility, consistency and relevance of the futures to be investigated in each case study. Additionally, narratives could be of use in the Serious Game in the form of summaries of a combination of options (if these match a combination of steps the player can choose).

The initial identification of trade-offs from the final versions of the thematic models runs for each case study, contribute to elaboration of the narratives and will contribute to the preparation of the list of innovations to tackle nexus challenges in the case studies. Trade-offs are interpreted in an integrated manner while narratives provide a description of a plausible and consistent future in each case, up to 2050, considering the biophysical dimension of the nexus, the economy and society.

Next steps on the work on innovations up to deliverable D1.5 include the revision of the contents of this deliverable and update of information in the different set of tables. Two updates are expected in 2019. The first will include the development of the section on innovations (chapter 5) and review of the baseline narratives; while the second will serve to improve and refine the contents to include in Deliverable 1.5.

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Appendix A: The "basic" SSP global narratives

Table 16. Global SSP narratives (O'Neill et al., 2017).

Narrative	Description
SSP1 (sustainability)	The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Management of the global commons slowly improves, facilitated by increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions, the private sector, and civil society. Educational and health investments accelerate the demographic transition, leading to a relatively low population. Beginning with current high-income countries, the emphasis on economic growth shifts toward a broader emphasis on human well-being, even at the expense of somewhat slower economic growth over the longer term. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Investment in environmental technology and changes in tax structures lead to improved resource efficiency, reducing overall energy and resource use and improving environmental conditions over the longer term. Increased investment, financial incentives and changing perceptions make renewable energy more attractive. Consumption is oriented toward low material growth and lower resource and energy intensity. The combination of directed development of environmentally friendly technologies, a favourable outlook for renewable energy, institutions that can facilitate international cooperation, and relatively low energy demand results in relatively low challenges to mitigation. At the same time, the improvements in human well-being, along with strong and flexible global, regional, and national institutions imply low challenges to adaptation.
SSP2 (Middle of the road)	The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. Technological development proceeds apace, but without fundamental breakthroughs. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Even though fossil fuel dependency decreases slowly, there is no reluctance to use unconventional fossil resources. Global population growth is moderate and levels off in the second half of the century as a consequence of the completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and to rapidly slow population growth. This growth along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development. These moderate development trends leave the world, on average, facing moderate challenges to mitigation and adaptation, but with significant heterogeneities across and within countries.

SSP3 (Regional Rivalry)	A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time, especially in developing countries. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards and provide access to safe water, improved sanitation, and health care for disadvantaged populations. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. The combination of impeded development and limited environmental concern results in poor progress toward sustainability. Population growth is low in industrialized and high in developing countries. Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply high challenges to mitigation. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act across regions, implies high challenges to adaptation for many groups in all regions.
SSP4 (Inequality)	Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour intensive, low-tech economy. Power becomes more concentrated in a relatively small political and business elite, even in democratic societies, while vulnerable groups have little representation in national and global institutions. Economic growth is moderate in industrialized and middle-income countries, while low-income countries lag behind, in many cases struggling to provide adequate access to water, sanitation and health care for the poor. Social cohesion degrades and conflict and unrest become increasingly common. Technology development is high in the high-tech economy and sectors. Uncertainty in the fossil fuel markets lead to underinvestment in new resources in many regions of the world. Energy companies hedge against price fluctuations partly through diversifying their energy sources, with investments in both carbon-intensive fuels like coal and unconventional oil, but also low-carbon energy sources. Environmental policies focus on local issues around middle and high income areas. The combination of some development of low carbon supply options and expertise, and a well-integrated international political and business class capable of acting quickly and decisively, implies low challenges to mitigation. Challenges to adaptation are high for the substantial proportions of populations at low levels of development and with limited access to effective institutions for coping with economic or environmental stresses.

SSP5 (Fossil-fuelled development)	Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary. While local environmental impacts are addressed effectively by technological solutions, there is relatively little effort to avoid potential global environmental impacts due to a perceived trade-off with progress on economic development. Global population peaks and declines in the 21st century. Though fertility declines rapidly in developing countries, fertility levels in high-income countries are relatively high (at or above replacement level) due to optimistic economic outlooks. International mobility is increased by gradually opening up labour markets as income disparities decrease. The strong reliance on fossil fuels and the lack of global environmental concern result in potentially high challenges to mitigation. The attainment of human development goals, robust economic growth, and highly engineered infrastructure results in relatively low challenges to adaptation to any potential climate change for all but a few.

Appendix B: Key elements in SSP narratives

Table 17. Categories of assumptions for the key elements that define the SSP narratives.

Demographic and Human development Elements	Economic and Lifestyle, Policies and Institutions	Technology, Environment and Natural Resources
Demographics	Economic and Lifestyle	Technology
Population • Growth • Fertility • Migration Urbanization • Level • Type	- Growth (per capita) - Inequality - International trade - Globalization - Consumption and Diet	- Development - Transfer - Energy technological change - Carbon intensity - Energy intensity
Human Development	Policies and Institutions	Environmental and Natural Resources
- Education - Health Investments - Access to health facilities, water, sanitation - Gender equality - Equity - Social cohesion - Societal participation	- International Cooperation - Environmental Policy - Policy orientation - Institutions	- Fossil constraints - Environment - Land Use - Agriculture

Appendix C: Comparison of extended SSP narratives across scales

Table 18. Comparison of narrative elements for the water sector across scales for SSP narrative 1 (sustainability) and 5 (fossil-fuelled development) (Absar and Preston, 2015).

		SSP Narrative	
		SSP1 - sustainability	SSP5 – Fossil-fuelled development
Scale	Global	Achievement of MDG enables global access to safe drinking water and sanitation	Global access to safe drinking water and sanitation through resource-intensive water system management.
	National	Increasing implementation of IWRM and ecosystem restoration strategies through public investment in water-use efficiency improvements and water distribution infrastructures.	Resource intensive water systems management including adoption of integrated watershed planning and management strategies. Improvements in water use efficiency due to water conservation strategies and end use technologies in residential, commercial and agricultural sectors.
	Sub-national	Regional investments in the sustainable management of available water resources increases water resource reliability despite growth and climatic variability. Increasing water use efficiencies across all sectors reduce water demand, consumption and losses. Water prices remain stable enabling equitable access and water quality remains high.	Population growth and economic development drive intensive investments in water resources managements including infrastructure to augment supply such as new reservoirs, and increased capacity for inter-basin transfers. Commoditization and privatization of water drive significant expansion of water trading and the delivery of water to sectors and activities that generate the greatest economic return per unit of water. Water demand grows across different sectors including domestic, agricultural, industrial, and energy sectors, despite investments in demand management and improvements in water efficiency. Growing demand, privatization, and investments to augment supply contribute to significant increases om unit cost of water.

Appendix D: Example of scenario formulation in REEEM

Base Pathway: *Coalitions for a low-carbon path*

This pathway was agreed upon as a useful base case for REEEM by the participants of the First Stakeholder Workshop held on October 6th in Brussels. The pathway narrative resembles features of the current EU context and one likely future course it could take.

In this narrative, economic growth in the EU restarts after the financial crisis, but at different speeds. Affinity on trade, labour, defence and energy security policy arises between groups of countries, depending on their geographic location, economy and domestic availability of resources. Despite the common general ambition to fulfil the Energy Union Strategy and the Paris Agreement, coalitions of more and less willing Member States emerge, setting more and less ambitious decarbonisation targets, respectively. A similar pattern is identifiable outside Europe, where countries being most affected by climate change extremes and/or having the means take on more climate change mitigation actions than others.

Even though the effects of climate change are also observed in Europe (especially with Southern regions becoming on average warmer and drier), consumers do not perceive it as likely to affect their lives significantly. Therefore, they mostly hold on to their current consumption behaviours and transition very slowly to more energy efficient end-use appliances. This, in turn, forces suppliers to take up larger part of the decarbonisation effort.

This narrative resembles characteristics of two of the five scenarios described in the 'White paper on the future of Europe' discussed by President Jean-Claude Juncker at the State of the Union 2017: 'Carrying on' and 'Those who want more do more'.

The narrative is broken down in dimensions and summarised in the following table.

Table 19. Scenario matrix for the REEEM sample pathway.

Political	Economic	Social	Environmental	Global
Stronger decision making / policy parallels within clusters of Member States	Growth at different speeds	Likely passive society in transition	Low availability of water (drying climate) and scarce resources	RCP4.5 - Global push to climate change mitigation driven by some regions / countries

Key underlying assumptions across dimensions

Economic dimension: *'Growth at different speeds'*

This is the entry point of the narrative. The EU economies re-start growing after the financial crisis. There is population and GDP growth, though uneven across the EU.

For the models, assumptions are based on The 2015 Ageing Report and the EU Reference Scenario 2016.

Political dimension: *'Stronger decision making / policy parallels within cluster of Member States'*

There is a common general ambition to comply with the Energy Union Strategy, even though with different commitment across Member States, according to the current socio-economic situation, the domestic availability of resources and the geographical location.

For the models, the key numerical assumptions for the near and longer term are based on current decarbonisation targets. They are reported in Table 20 below and summarised here:

- The existing binding decarbonisation targets set by the EU 2020 Climate and Energy Package and the 2030 Climate and Energy Framework are taken into account:
    - By 2020, 20% decarbonisation target for the ETS sectors in the EU as a whole, compared to 2005 levels;
    - By 2030, 43% decarbonisation target for the ETS sectors in the EU as a whole, compared to 2005 levels;
- The indicative 2050 decarbonisation targets, expressed in the EU Roadmap 2050 and in line with the Paris Agreement, are taken into account.
    - By 2050, 83% decarbonisation target for the ETS sectors in the EU as a whole, compared to 2005 levels;
    - Decarbonisation targets for 2020, 2030 and 2050 for the non-ETS sectors by groups of countries, according to the current socio-economic situation, the domestic availability of resources and the geographical location. Targets indicated here;
- The existing 2020 and 2030 binding targets of renewable share in gross final consumption for the whole EU are kept in consideration and complied with.

Social dimension: *'Likely passive society in transition'*
Consumers do not perceive climate change as likely to affect their lives. Therefore, change their consumption habits towards more efficient end-use technologies with high inertia and only in the medium to long term.
Constraints are added to TIMES PanEU as inspired by part of the results of surveys on consumers choices of heating technologies in the UK, Croatia and Finland. The shares of end-use technologies for this sector are fixed in the early years of the modelling in all EU countries and slowly changed towards greener habits from 2030 on. The user-defined constraints are added to allow for a slow transition between existing technologies and the mitigation technologies.
For the transport sector, disutility costs for different car technologies are calculated according to the results of the survey and these costs are added into the model for different car technologies as a part of the investment cost.

Environmental dimension: *'Low availability of water (drying climate) and scarce resources'*
The average temperature, which is positively correlated with evaporation, is projected to rise albeit at a varying level on a European scale. The regional variations include dryer regions of southern Europe becoming relatively warmer. At the same time, Southern Europe is likely to experience less yearly average precipitation resulting in a decreased net availability of water in already dry regions. In addition, although associated with a larger uncertainty, the variability is also projected to change into more extreme events concentrating e.g. rainfall to shorter periods where a larger share is lost through runoff as opposed less intense events supporting the build-up/recharge of water storage in soil and groundwater. Also, periods of droughts are likely to occur more frequently and for longer periods.
The assumptions on the climate are included in the analysis through the environmental models and databases: i.e. in REEEM the Cordex database feeding the Heating and Cooling demand changes analysis and the water and land resource use case studies.

Global dimension: *'Global push to climate change mitigation, driven by some countries / regions'*
There is an uneven push towards climate change mitigation, where certain regions will pursue more ambitious targets than others. In this context, at least two distinct groups are expected to rise outside of the EU:

- One of those having the economic means to decrease their emissions, or threatened the most by climate change, or both.
- The second group includes countries without the economic means to pursue more ambitious environmental targets or seeing the measures against climate change as an unnecessary burden.

Since the focus of the REEEM project is on the European countries, the main numerical assumptions made for this dimension are the GHG emission paths taken by each region outside of the EU. These paths were adopted from the Energy Technology Perspectives 2017, by the International Energy Agency, where a number of global GHG emission pathways based on different ambitions were created. For this work only two were utilised: Reference Technology Scenario (RTS), which considers only current and announced policies and commitments, and the 2°C Scenario (2DS), which takes into account the necessary emissions' reduction in order to reach the 2°C target consistent with the Paris agreement.
Table 21 below presents the reduction targets of the countries within the Regional Push, meaning that the remaining countries, who also aren't part of the EU-28, will continue following the current policies' emission path.

Table 20. CO2 emission targets by EU Member State.

	Targets for 2020 (compared to 2005)	*Targets for 2030 (compared to 2005) - Proposal*	*Target for 2050 (compared to 2005) – REEEM clusters*
EU-28 ETS	-21%	-43%	-83%
	Effort sharing decision (ESD)	Effort sharing decision (ESD)	Effort sharing decision (ESD)
France	-14%	-37%	-80%
Portugal	1%	-17%	-80%
Spain	-10%	-26%	-80%
Italy	-13%	-33%	-80%
United Kingdom	-16%	-37%	-80%
Germany	-14%	-38%	-80%
Netherlands	-16%	-36%	-80%
Belgium	-15%	-35%	-80%
Luxembourg	-20%	-40%	-80%
Austria	-16%	-36%	-80%
Denmark	-20%	-39%	-80%
Sweden	-17%	-40%	-80%
Finland	-16%	-39%	-80%
Ireland	-20%	-30%	-80%
Poland	14%	-7%	-50%
Czech Republic	9%	-14%	-50%
Bulgaria	20%	0%	-60%
Romania	19%	-2%	-60%
Estonia	11%	-13%	-60%
Latvia	17%	-6%	-60%
Lithuania	15%	-9%	-60%
Croatia	11%	-7%	-60%
Hungary	10%	-7%	-60%
Greece	-4%	-16%	-60%
Slovakia	13%	-12%	-60%
Slovenia	4%	-15%	-60%
Cyprus	-5%	-24%	-60%
Malta	5%	-19%	-60%
EU-28	-9%	-30%	-75%

Table 21. CO2 emission targets in regions outside the EU.

Region	CO2 emission targets in 2050	Rationale
USA	Halfway between 2 °C target and current policies	Despite Trump's presidency, an expressive number of an expressive number of states, cities, tribes, universities and business, including the states of New York and California, signed an open letter confirming their support to the Paris Agreement.
China	2 °C target	Although it doesn't have high GDP per capita, as EU or the USA, its economy is growing fast and it is also home to 7 of the 10 largest photovoltaic cell manufacturers and 4 of the top 10 wind turbine manufacturers.

Japan	Halfway between 2 °C target and current policies	Part of OECD, high GDP per capita and HDI. Would seek a higher ambition reduction target than the current policies, but its current high dependency on fossil fuels and lack of resources would undermine its willingness to pursue the 2 °C target
Republic of Korea	2 °C target	Part of OECD, high GDP per capita and HDI. Wouldn't have opposition to pursue the 2 °C target
Canada	Halfway between 2 °C target and current policies	Part of OECD, high GDP per capita and HDI. Would seek a higher ambition reduction target than the current policies, but as its economy also depends on production of oil, it is possible that they do not follow the 2 °C target
Mexico	Halfway between 2 °C target and current policies	Part of OECD, medium GDP per capita and HDI. Would seek a higher ambition reduction target than the current policies, as this ambition has already been shown through the creation of a long-term strategy to reduce emissions. However, due to its economy, it might end up not following the reduction cuts necessary for the 2 °C target
Australia	Halfway between 2 °C target and current policies	Part of OECD, high GDP per capita and HDI. Would seek a higher ambition reduction target than the current policies, but as its economy also depends on production of oil, it is possible that they do not follow the 2 °C target
Norway	80% reduction compared to 1990 levels	Would seek similar target to the EU's as it is also part of the EU ETS and an important partner
Switzerland	80% reduction compared to 1990 levels	Would seek similar target to the EU's as they signed and agreement in 2017 to link their emissions trading systems
New Zealand	2 °C target	Part of OECD, high GDP per capita and HDI. Wouldn't have opposition to pursue the 2 °C target
Iceland	2 °C target	Would seek similar target to the EU's as it is also part of the EU ETS

Appendix E: SSP2 parameter assumptions per case study and model developed

Table 22. SSP2 implementation in thematic models E3ME, MAGNET, CAPRI, IMAGE-GLOBIO (D3.1 and MS17).

	Thematic Model			
	E3ME	MAGNET	CAPRI	IMAGE-GLOBIO
Type of model	(D3.1) Global macro-econometric energy-environment/economy model	(D3.1) Global computable general equilibrium model. Covers the whole economy, focus on agriculture, food processing and bio economy.	Global agro-economic model	Integrated modelling framework of global environmental change
Spatial coverage / resolution	(D3.1) Global / National for EU-28 member states	(D3.1) Global / National (inc EU-28 member states)	(D3.1) Global / national and regional within the EU	(D3.1) Global / 30 or 5 arcmin grids
Case Studies	Andalusia, Sardinia, Southwest UK, The Netherlands, Greece, Latvia, Azerbaijan, France - Germany, DE - CZ - SK, Europe and Global	Andalusia, Netherlands, Sweden, Greece, Latvia, Azerbaijan, Europé, Global	Andalusia, Sardinia, Southwest UK, The Netherlands, Sweden Greece, Latvia, Azerbaijan, France - Germany, DE - CZ - SK, Europe and Global (all case studies)	Sweden, Greece, Europe, Global
Baseline preparation	(D3.1) No additional data needed to deliver the baseline.	(D3.1) No additional data needed to deliver the baseline. Builds on GTAP database.	(D3.1) No additional data needed to deliver the baseline.	(D3.1) No additional data needed to deliver the baseline.
General	(D3.1) - Many of the SSP features are outputs in E3ME. - E3ME baseline solution can be calibrated and made consistent to SSPs. - The baseline scenario is designed to be consistent with SSP2.	(D3.1) The SSP and RCP pathways have already been implemented and are currently being updated. Baseline is consistent with SSP2.	(D3.1) CAPRI has already been applied to assess the effects of climate change on agriculture using the SSP-RCP scenarios (Blanco et al. 2017, Martinez et al. 2015). (D3.1) The CAPRI baseline builds on the medium-term outlook for EU agricultural markets and income (EC 2014) and depicts the projected agricultural situation in 2030 and 2050 under the SSP2 scenario and a status quo policy setting.	(D3.1) IMAGE-GLOBIO used in the development of SRES and SSPs, also in GEOs, OECD Environmental Outlook (2012), Global SDGs, Global Biodiversity Outlooks (D3.1) Good coverage of all nexus domains, close link with MAGNET, and energy demand model TIMER, some feedback between water and crop growth is incorporated via LPJmL. (D3.1) The SSP and RCP pathways have already been implemented. (D3.1) qualitative descriptions of the SSP storylines (O'Neill et al., 2017) were quantified for IMAGE input parameters as described in several papers (Popp et al. 2017, van Vuuren et al. 2017, Doelman et al., in review). (D3.1) List of input variables and outputs online, as well as scenario drivers

Demographic and Human development				
Demographics				
Population (growth, fertility, migration)	EU population projections in line with Eurostat's 2015 Aging Report. Non-EU population projections in line with UN Population Projections.	M17: Population from KC and Lutz 2017, Dellink et al 2017.	M17: AGLINK for mid-term projections and GLOBIOM for long-term projections. Projections up to 2050 reflect the agri-food market development and socioeconomic drivers as defined in SSP2.	(D3.1) SSP2 population projections (KC and Lutz, 2017)
Urbanization (level & type)	n.s.	n.s.	n.s.	n.s.
Human Development		(D3.1) In few countries households split into urban and rural, and by income groups.		
Economic and Lifestyle, Policies and Institutions				
Economic and Lifestyle				(D3.1) SSP2 economic development projections (Dellink et al., 2017) (D3.1) Economic growth - key input variable
- Growth (per capita)	(D3.1) output: GDP GDP in line with SSP2 trends, with more detail for macroeconomic data taken from PRIMES assumptions.	(D3.1) SSP2, input; also output; outputs: GVA, employment, wages, self-sufficient rates M17: GDP from KC and Lutz 2017, Dellink et al 2017.	M17: AGLINK for mid-term projections and GLOBIOM for long-term projections. Projections up to 2050 reflect the agri-food market development and socioeconomic drivers as defined in SSP2 or 'middle of the road'	n.s.
- Inequality	n.s.	n.s.	n.s.	n.s.
- International trade	n.s.	(D3.1) Agriculture and trade policies (M17) Trade provided by Magnet to case studies	n.s.	M17: from Magnet
- Globalization	n.s.	(M17) Productivity of labour: Endogenously calculated to achieve the GDP projection (M17) consumption response to income: Linked to Population and GDP	n.s.	n.s.
- Consumption and Diet	n.s.	(D3.1) Inputs: Changes in patterns of consumption preferences such as a shift to a more meat based diet for example.	n.s.	(D3.1) Dietary preferences - key input variable
Policies and Institutions				(D3.1) Policy assumptions - key input variable
- International Cooperation	n.s.	n.s.	n.s.	n.s.
- Environmental Policy	n.s.	n.s.	n.s.	n.s.

- Policy orientation	(D3.1) Inputs: energy policy elements (regulations, FiTS, subsidies, taxes); energy and carbon prices/taxes; ETS; exogenous investment assumptions, optional exogenous energy technology scenarios. (M17) Tax rates remain the same as last year of historical data. Government final consumption expenditure is extrapolated, restricted to growth rates below 5% pa. Includes policies (Table 3 in M17): EU ETS, EED, RES2020, Transport Co2 Standards, Effort Sharing Decision, and several world assumptions	(D3.1) Inputs: Policy changes such as percent changes in taxes, subsidizes, tariffs, biofuel mandates, production quotas etc... (M17) Policy assumptions from Table 9 (include EU and World policies)	(M17) Energy and agriculture policies in table 15	(M17) Carbon pricing Starting in 2015: 100-150 $/tco2 in 2030, 370 $/tco2 in 2050, 900 $/tco2 in 2100
- Institutions	n.s.	n.s.	n.s.	n.s.
Technology, Environment and Natural Resources				
Technology				
- Development	n.s.	n.s.	M17: Own assumptions and IIASA studies.	n.s.
- Transfer	n.s.	n.s.	n.s.	n.s.
- Energy technological change	(D3.1) Inputs:	(D3.1) inputs. Biofuel mandates	n.s.	(D3.1) Key input variable (agricultural and energy system) (M17) Energy technology specifications Medium assumptions from IMAGE energy model (TIMER, van Vuuren et al., 2017) Energy demand: Medium assumptions from IMAGE energy model (TIMER, van Vuuren et al., 2017) Energy system policy No climate change mitigation policy
- Carbon intensity	(D3.1) output: CO2 emissions (M17) Learning rates are included in the model.	n.s.	(M17) Table 19 covers the mitigation technologies in Capri	(M17) from Magnet
- Energy intensity	(D3.1) outputs: Energy demand by fuel and fuel user; electricity generation by technology; electricity capacity.	(D3.1) output: energy produced and consumed (toe) for various fuels and clean energy sources	n.s.	n.s.
Environmental and Natural Resources				
- Fossil constraints	M17: Baseline global fossil fuel prices (coal, oil and natural gas) in line with PRIMES projections.	n.s.	n.s.	n.s.

- Environment	(D3.1) Input: CO2 prices/taxes	(D3.1) input: Emission data from GTAP database; outputs: CO2 emissions and market price for emission permits. (M17) Rice and Livestock Emissions N2O, CH4 from IMAGE	(D3.1) Environmental indicators(N and PO4 balances, NH4, GHG emissions, agricultural water use)	
- Land Use	n.s.	(D3.1) outputs: Land use change for cropland, pasture, total agricultural land (area). (M17) Land productivity & Feed Productivity From IMAGE and FAO agricultural outlook (2012). Land use per sector Endogenously calculated based on demand and total available land. (M17) protected land areas From IMAGE Medium – Protected areas are extended to achieve the Aichi target of 17% of the terrestrial area, gradually implemented from 2010-2050. These Aichi targets result in a 10% reduction of available land for agricultural use in Europe and 7% Globally between 2010 and 2050.	n.s.	(D3.1) In Popp et al, 2017 (?)

- Agriculture		(D3.1) 20 primary agricultural activities and processing activities. Includes crop, livestock, feeding, and fertilizer sectors. (D3.1) Yield from FAO. (D3.1) inputs: Changes in productivity of land, labour and capital as well as efficiency changes in the economic sectors themselves (in percent change).	(D3.1) outputs at regional EU NUTS level: Activity levels (crops, livestock activities, feeding activities, processing activities); supply indicators (production yields); demand indicators (food, feed, processing and biofuel demand). (M17) EU agri-food market: Trend estimates from EU Agricultural Outlook and national sources (mid-term projections). Lon-term projections derived with the GLOBIOM and IMPACT models. (M17) World agri-food markets: Trend estimates from AGLINK-COSIMO (mid-term projections). Lon-term projections derived with the GLOBIOM and IMPACT models. (M17) Irrigation trends from Impact model	(D3.1) In Popp et al, 2017 (?) (D3.1) GLOBIO - inputs: P and N emissions, climate (precipitations and evaporation, global mean temperature), land use and water maps, river dams (location and capacity) (M17) Yield increase: Exogenous tech. increase according to FAO agricultural outlook (2012), endogenous increase following MAGNET Irrigation: Irrigation area increases following the FAO agricultural outlook of irrigated harvested area, irrigation efficiency increases by 0.2%/yr for the share newly irrigated area Livestock intensification: Exogenous tech. increase according to FAO agricultural outlook (2012), endogenous increase following MAGNET Land-use change regulation: Medium – Protected areas are extended to achieve the Aichi target of 17% of the terrestrial area, gradually implemented from 2010-2050. Nitrogen fertilizer use: Following largely the projections by FAOs agricultural outlook

Table 23. SSP2 implementation in thematic models: OSeMOSYS, SWIM, MAgPIE-LPJmL, G-RDEM (Information collected from Deliverable 3.1 and Milestone 17)

	Thematic Model			
	OSeMOSYS	SWIM	MAGPIE-LPJML	G-RDEM
Type of model	Linear cost-optimisation model for long-term energy planning	Eco-hydrological semi-distributed model	Global land use allocation model (D3.1) Partial equilibrium model with exogenous demand, which is coupled to the grid-based dynamic vegetation model LPJmL, with a spatial resolution of 0.5°x0.5°.	(MS17) G-RDEM is a recursive-dynamic Computable General Equilibrium model for long-term counterfactual analysis and baseline generation from given GDP and population projections. (MS17) The core of the model is developed from the GTAP standard model.
Spatial coverage / resolution	Global / flexible (subnational, regional, national, multi-country)	(D3.1) Several river basins in Europe, Asia, Africa and South America / River sub-basins (typically 100–1000 km^2)	Global / detailed grids	(MS17) The G-RDEM model can provide macroeconomic results at the regional level for all European NUTS2 regions.
Case Studies	Greece, Azerbaijan, Global	Transboundary CZ-SK-DE; Transboundary FR - DE	Europe and Global	Andalusia, Sardinia, Southwest UK (used in the sub-national case studies where downscaling of SSP2 socio-economic variables is required)
Baseline preparation	case-study specific	case-study specific	(D3.1) No additional data needed to deliver the baseline.	(MS17) baseline uses exogenous GDP and population data from IIASA SSP2
General	(D3.1) flexibly accommodate constraints imposed by other systems, e.g. land use, water availability and climate change Alignment with SSP2 is possible during preparation of input data; and/or definition of model constraints (e.g.. CO2 target, cost of carbon); and in scenario development by transferring the qualitative narrative into a quantitative representation.	(D3.1) The Soil and Water Integrated Model (SWIM) is an eco-hydrological semi-distributed model integrating hydrological processes, crop/vegetation growth, nutrients and erosion at the river basin and regional scales. (D3.1) SWIM is coupled with GIS and has extensive data requirements. (D3.1) The model can partially be aligned with the SSP-RCP scenario framework; the SSP components only indirectly considered by the input data (e.g. land use scenarios).	(D3.1) Contribution to the development of the SSP Scenarios, AgMIP, among others (D3.1) Energy-system dynamics and the influence of other non-agricultural sectors are not included. (D3.1) Biophysical inputs from LPJmL (D3.1) The model is aligned with the SSP-RCP scenario framework. MAgPIE is part of one of 5 IA modelling teams that provide the quantitative estimates for the SSP database. (D3.1) baseline results for change in global land area (cropland, pasture, forestry, forest, urban and other), change in cropland for world region (10), and change in irrigated are for world regions.	Version 1.0 of G-RDEM, fully documented and open source, will be released soon. This has a number of notable features, specifically designed for the generation of long term economic scenarios. Baselines provided to subnational case studies: (Sardinia and Andalusia, possibly South West UK).
Demographic and Human development				
Demographics				
Population (Growth, fertility, migration)	From SSP2	n.s.	(D3.1) Input	From SSP2, exogenous

Urbanization (level and type)	n.s.	n.s.	n.s.	n.s.
Human Development	n.s.	n.s.	n.s.	n.s.
Economic and Lifestyle, Policies and Institutions				
Economic and Lifestyle			(D3.1) Inputs: socio-economic data; Income /inhabitant	(MS17) Assumptions: aggregate saving sates (endogenously linked to population structure and income per capita); Household consumption in the form of consumption shares (different and time-varying income elasticities); Foreign debt, as debt stock and interest payment (cumulative trade deficit or surplus).
- Growth (per capita)	n.s.	n.s.	n.s.	From SSP 2, exogenous
- Inequality	n.s.	n.s.	n.s.	n.s.
- International trade	n.s.	n.s.	(D3.1) included (M17) Agricultural trade barriers Based on historical self-sufficiency rates and trade based on competitiveness	n.s.
- Globalization	n.s.	n.s.	n.s.	n.s.
- Consumption and Diet	n.s.	n.s.	(D3.1) Population and Income/GDP used to calculate food demand and livestock share;	n.s
Policies and Institutions				
- International Cooperation	n.s.	n.s.	n.s.	n.s.
-Environmental Policy	n.s.	n.s.	n.s.	n.s.
- Policy orientation	n.s.	n.s.	(M17) carbon price	n.s.
- Institutions	n.s.	n.s.	n.s.	n.s.
Technology, Environment and Natural Resources				(MS17) informs on technological progress in terms of industrial activity. Consistent with GDP but differentiated by sector on the basis of GDP growth. (MS17) Technology input-output parameters (endogenous, based on a development index)
Technology			(D3.1) Technological change in agriculture	
- Development	n.s.	n.s.	n.s.	n.s.

- Transfer	n.s.	n.s.	n.s.	n.s.
- Energy technological change	n.s.	n.s.	(D3.1) input: bioenergy demand; output: bioenergy production (M17) Energy technology specifications 1st and 2nd generation bioenergy	n.s.
- Carbon intensity	n.s.	n.s.	n.s.	n.s.
- Energy intensity	n.s.	n.s.	n.s.	n.s.
Environmental and Natural Resources				
- Fossil constraints	Definition of energy demand from SSP2	n.s.	n.s.	n.s.
- Environment	n.s.	(D3.1) Inputs: groundwater table location; data on reservoirs (also energy domain), irrigation areas and water budget; bedrock or sediment transmissivities	(D3.1) outputs: GHG emissions; water usage, water shadow price	n.s.
- Land Use	(M17) Definition of land categories from SSP2 (M17) Land categories from Global Agro-Ecological Zones (GAEZ) database version 3.0 by FAO and IIASA (2010) (M17) land use change from Herman et al, 2012 and own assumptions	(D3.1) Inputs: DEM, DEM with man-made alterations of natural flow paths, Land use data (14 classes, usually CORINE land cover data), soil map with soil profile 2m depth.	(D3.1) See Popp et al, 2017. (D3.1) inputs: Historical land use patterns (D3.1) Land classes area (cropland, pasture, forest)	n.s.

- Agriculture	n.s.	(D3.1) Inputs: data on reservoirs (also energy domain), irrigation areas and water budget; Crop structure with fertilizer applications, sowing and harvesting dates (D3.1) List of output variables in Annex 1 of (D3.1) Some include River discharge at sub-basin outlet (time series)(environmental variable) and agricultural yield of chosen crops.	(D3.1) Inputs: biophysical crop yields, water use for crop production, production utilization balances, production costs (D3.1) one of the outputs is cropping patterns of the different crops, which are the basis for the calculation of water shadow prices. (D3.1) outputs: cropland and pasture are, corp production and corp utilization, water usage, irrigation area, livestock production, ood demand for plant products and for animal-based products. (M17) Yield increase: Endogenous estimates, based on CC-impacted potential yield patterns from LPJmL (Stevanovic et al 2016) and induced yield-increasing technological change (Dietrich et al 2014) Irrigation: Endogenous estimates based on investments into irrigation infrastructure (Bonsch et al 2015) Livestock intensification: Exogenous tech. increase and shifting feed mix in line with productivity increases according to estimates by Weindl et al (2017) Land-use change regulation: Accounts for protected forests according to WDPA categories I+II. Moreover, areas for forest plantations for wood production and built-up areas are fixed over time. Additionally, see NPI policies in Climate System Nitrogen fertilzer use: Determined endogenously based on Bodirsky et al (2012, 2014) (For references see Milestone 17)	n.s.

Appendix F: Trade-offs identified in the baseline (SSP2) scenario

Table 24. Compilation of trade-offs from the baseline scenario (SSP2 implementation). Case study names are abbreviated as follows: [SR] - Sardinia (information to be added); [AN] - Andalusia; [SWUK] - South West UK (information to be added); [GR] - Greece; [SE] - Sweden; [NL] - The Netherlands; [LT] - Latvia (information to be added); [AZ] - Azerbaijan]; [FR-DE] - Transboundary case France – Germany; [DE-CZ-SK] - Transboundary case Germany – Czech Republic – Slovakia; [EU] - European case; [GL] - Global (to be added).

	→ Starting activity, intervention, assumption that relates (primarily) to the domain of…						
↓ trade-off to the first (directly) implicated domain	WATER	ENERGY	LAND USE	CLIMATE	FOOD	SOCIETY	OTHER (e.g. ECONOMY)
WATER	[SR] Conflicts between different sectors for the same water resources [AZ] Country partially dependent on polluted rivers (mainly transboundary). More than 30% of the irrigated lands suffer from increased salinity, mainly attributed to the poor maintenance and consequently deterioration of the irrigation system. Discharge of sewage water [FR-DE] Impacts from WFD implementation + Rhine RBMP on water bodies status [EU] GLOBIOM (water quality) – for trade-offs between the system	[SE] Hydropower dams affect the entire downstream ecosystem, which also impacts on groundwater recharge, groundwater quality and the habitats for animals and plants [FR-DE] Impacts from EU legislation on biofuels + French law on energy transition for green growth + German energy package on water abstraction	[SR] Increase of irrigated area in order to reach food security and reduce water security. [GR] Highlighted but not specified [SE] an increased production/felling is based on felling operations and fertilizer (locally) that reduce surface water and groundwater quality [AZ] Use of pesticides and fertilisers affects water quality [DE-CZ-SK] Growing biomass will have implications to water use (particularly maize which is a water intensive crop).	[AZ] Climate change reduces precipitation [FR-DE] Impacts of the Regional Scheme for Climate Air Energy Alsace on water abstraction [DE-CZ-SK] There is no response of the climate for 20 or 30 years [DE-CZ-SK] Restoration projects (e.g. 100 km^2 (less 2% of landscape) decrease the carbon sequestration to thousand tonnes - equivalent to the emissions of the region.	[AZE] Inefficient agriculture practices reduce water availability [FR-DE] Impacts from CAP implementation on water quality and quantity		[FR-DE] Impacts of the Regional Scheme for Ecological Coherence Alsace on water status

	[EU] Trade-offs across systems, from MAGNET – and IMAGE						
ENERGY	[NL] Energy and climate if policy interventions are disregard. [FR-DE] Impacts from WFD implementation + Rhine RBMP on hydropower production [EU] E3ME (more, because they are close to the policies) and IMAGE	[NL] If growing biomass, indeed contributes to carbon capture. [NL] Trade-off in the acceptance and to implement CCS technology. [NL] Produce renewable energy or import electricity from non-renewable primary energy sources (nuclear, coal) [FR-DE] Impacts from EU legislation on biofuels + French law on energy transition for green growth + German energy package on energy balance [DE-CZ-SK] Carbon tax from E3ME: it might cause challenges in the energy market. Impact on power flows. It could happen to import nuclear. Transboundary trade-offs.	[GR] Highlighted but not specified [NL] Non-renewables, climate to energy. Hampering the decrease of emissions. [NL] The sustainability of biomass, is it really renewable and if it contributed to reduction of emissions.	[NL] Production of food and less land available for biomass for energy (competition for land use). [AZ] Hydropower affected by climate change. [FR-DE] Impacts of the Regional Scheme for Climate Air Energy Alsace on energy production	[NL] Consequences of consumption and production (not only for NL) but also at international level, e.g. feed imports, broader perspective – implications at global level) [FR-DE] Impacts from CAP implementation on energy consumption (to produce food) and energy production (from biofuels)	[NL] Resource efficiency by lowering emissions other than GHG emissions to water and land [NL] Whether or not import of bulk biomass will be needed.	[AZ] Dependence of the economy on fossil fuels hinders the shift to a decarbonised pattern [FR-DE] Impacts of the Regional Scheme for Ecological Coherence Alsace on development of energy production
CLIMATE		[SR] Increase in energy use generally implies higher GHG emissions. [SR] Use of coal, causes greater emissions, compared to renewable sources. [GR] Highlighted but not specified [AZ] Fossil fuel dependent energy mix leads to GHG emissions.	[EU] MAGPIE and CAPRI	[FR-DE] Impacts of the Regional Scheme for Climate Air Energy Alsace on GHG emissions	AN] Climate-induced changes in crop productivity that affect food production [FR-DE] Impacts from CAP implementation on GHG emissions		[FR-DE] Impacts of the Regional Scheme for Ecological Coherence Alsace on GHG emissions

		[FR-DE] Impacts from EU legislation on biofuels + French law on energy transition for green growth + German energy package on GHG emissions						
LAND USE	[SR] Missing water resources decrease the quality and function of aquatic systems	[AZ] 5% increase in bioenergy crops cultivation by 2050, in comparison to 2020, results in a reduction of 10% in available land area for vegetable cultivation in the same period [FR-DE] Impacts from EU legislation on biofuels + French law on energy transition for green growth + German energy package on land use dedicated to biofuels		[SE] The aim of reducing emissions can cause a conflict between land use for food production and fuel crops [FR-DE] Impacts of the Regional Scheme for Climate Air Energy Alsace on land use change	[GR] Highlighted but not specified [FR-DE] Impacts from CAP implementation on land-use to grow food		[SE] Protecting forest biodiversity limits the production of forests; older forest is needed for biodiversity but not for production [FR-DE] Impacts of the Regional Scheme for Ecological Coherence Alsace on land use change
FOOD	[AN] Increased water use in irrigation	[AN] Growing renewable energy use in agriculture [FR-DE] Impacts from EU legislation on biofuels + French law on energy transition for green growth + German energy package on food production		[AZ] Climate change reduces food production.	[FR-DE] Impacts from CAP implementation on food production	[AZ] Top-down governance - local issues such as low food production due to lack of resources frequently overlooked	
SOCIETY								
OTHER (e.g. ECONOMY)		[SE] The increasing demand for bioenergy, may increase the share of managed forest land and the area of energy forest of fast-growing tree species (forestry sector) and use of fertilizers in agricultural sector leading					[EU] trade-related trade-offs

		to negative environmental impacts [AZ] High revenues from fossil fuels boost the economy significantly					

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

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Appendix G: Summary of scenario elements per case study

Add a note on the documents consulted to produce these tables and that case studies revised their contents.

Table 25. Compilation of narrative elements for the Global case study.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	The objective of the global case study is to identify and assess nexus issues at the global scale. The focus of the global case lies on nexus issues that are represented by the thematic models being used in the case study.
	Motivating forces / drivers	Population growth, income per capita, sectoral demands, climate affecting dynamics and creating added pressure
	Nexus-induced Challenges	Food: meeting global food demand (food security in developing countries, change in diets in high-income countries, reduce waste / losses in the supply chain (particularly at household level))
	Key nexus interactions	(W -> E) Power production sector (W -> F) Irrigation (L -> W) Water requirements for industrial, urban and other activities (L -> E) Land availability for bioenergy or renewable energy expansions (L -> C) Afforestation (E -> L) Land requirements (E -> F) Bioenergy competing food security (E -> C) Bioenergy as mitigation option to CO2 removal (C -> W) Increasing water temperatures (C -> L) Increasing temperatures affecting ecosystems (both land and in water) (C -> F) Climate change mitigation may cause food prices to increase, e.g. afforestation causes land and water to becomes scarce
	Critical Trade-offs from baseline runs	(In the food intro): Food production may in the future strongly compete with the cultivation of bioenergy, which is one of the climate mitigation options to remove CO2 emissions from the atmosphere. Finally, food production will also be strongly affected by the developments in the other Nexus elements, in particular by climate impacts. Thematic models used: E3ME-FTT (CE), MAGNET (WEcR), CAPRI (UPM), IMAGE-GLOBIO (PBL), OSeMOSYS (KTH) and MAgPIE (PIK). (Needs to be updated)

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Key SSP scenario elements	Policies, institutions and social conditions	Information to be added if available.
	Human development	Information to be added if available.
	Economy and lifestyles	GDP is expected to quadruple by 2050 relative to 2010, and GDP per capita to nearly triple in the same period, reaching around 27 thousand USD2005 by the mid-century. (based on SSP2 data)
	Population and urbanization	Population surpasses the 9 billion people in 2050. Urbanization rates increases over 30%, and close to 70% of the world population in 2050 lives in cities / urban areas. (based on SSP2 data)
	Environment and resources	See description in sections dedicated to the nexus domains.
	Technology	No specific information provided on technology trends. To be added.
Nexus Domains Elements	Water	Agriculture dominates water demand, especially by large-scale irrigation schemes, in comparison to demands from other sectors (electricity, industry and domestic supply). Water abstraction and use (e.g. reservoir management) affect aquatic and land biodiversity. Water quality is also an increasing concern, affecting both drinking supply and ecosystems. Climate change will disrupt further natural water systems, both in terms of quantity (flooding events) and scarcity (droughts). Thematic models estimated water demand for irrigation and, due to the uncertainty, starting values vary. IMAGE shows a modest increase from 2010 to 2050, which is partly due to limited increases in irrigated area and the SSP assumption that climate change impacts are not taken into account. MAgPIE shows a stronger increase, especially from 2020 to 2050 due to larger increases in irrigated area. OSeMOSYS shows a much stronger increase up to four times current levels due to strong expansion of irrigation. Water demand for industrial and electricity sectors is expected to rise significantly fuel to the increase in energy demand and industrial production. Household water demand is projected to increase due to population growth and increasing GDP per capita (IMAGE is the only model informing on this). Water quality and biodiversity are covered by the IMAGE-GLOBIO model. The model projects a further decrease of aquatic biodiversity intactness in 2050 to, on average, about 70% of the natural value in the temperate climate regions and 50% in the tropical realms. This decline is for about ¾ due to direct and indirect effects of land-use changes (including eutrophication) and for ¼ to hydrological disturbances like dam construction and water extraction. Eutrophication will increase the number of lakes with harmful algal blooms above the WHO standard and increasing algal bloom problems in coastal waters e.g. leading to fish kills. Increase in water temperature due to climate change will aggravate these problems.
	Climate	"The baseline CO_2 emission trends are also very similar across models, when looking and energy-related. Total CO_2 emissions could increase from 30 Mt/yr to close to 50 Gt in 2030, reaching between 50 and 60 Gt by 2050 (considering E3ME, IMAGE, MAGNET results). CH_4 emissions could increase from 350 Mt/year to over 400 Mt/yr (over 800 on the case of MAGNET results). Whereas N_2O could vary between 12 Gt/yr

		and 17 Gt/yr in 2030 to 14 Gt/yr -23 Gt/yr in 2050. No explanation is given about the dynamics in emissions."
	Energy	The development of the energy system towards global energy access by 2030 (access to affordable, reliable, sustainable and modern energy for all), will increase the overall demand for energy, which will foster the use of natural resources (e.g. water and land for biomass production) for enabling the system to meet this demand. Increased demand for biofuels and food production costs relate to an increase in food prices. Allocation of land for biofuel production has shown to impact agricultural production (e.g. crops such as wheat and maize) and, consequently, food prices. Total Primary Energy Supply (TPES): increase reported by all models in the long term (2030 and 2050). This seems to drive the system towards investing on power generation coming from renewable energy sources, namely biomass, hydropower, solar and wind energy. However, a large share of production (over 70 or even 80%) is still expected to rely on fossil fuels such as coal, oil and gas. (D5.2, p.10). From the renewable energy sources, biomass is the most used followed by hydropower. Solar and Wind are more expressive in the mix in 2050 and their contribution to global primary supply, in this year, is less than 10%.
	Land	The baseline scenario for all models show an increase in cropland in 2030 and a further increase in 2050. The models show varying results for the changes in other type of land use however. Of the three models that report changes to pasture land, IMAGE and MAGNET show an increase in pasture land as production rises to meet the increase in demand. MAgPIE reports a significant decrease in global pasture land. In Figure 2 showing global agricultural production MAgPIE reports little or no increase in the production of livestock. Therefore an increase in the livestock efficiency with respect to land would account for the reduction in the use of pasture land. Similarly IMAGE and OSeMOSYS report a decrease in the forest cover and other land while MAgPIE reports an increase.
	Food	In order to meet the demand of a growing and increasingly wealthy world population, food demand can be expected to strongly increase in the coming decade. This will be a challenge to provide in particular the least developed countries with sufficient food security (SDG2: No Hunger), but also to change diets in high-income countries from unbalanced to healthy diets (SDG3: Good Health and Wellbeing), and to avoid wasting behaviour in households and the supply chain (SDG12: Responsible Consumption and Production). Food demand dynamics varies across regions and development levels. Population and income growth are lead to an increase in food demand at global level, food demand could stagnate in high income countries with lower fertility rates and ageing population. High level of per-capita food demand indicates that food waste in households will further increase as it exceeds plausible intake rates. IMAGE and MAGNET assume a stabilization of global per-capita calories after 2030. To meet the increase in crop and animal products demand, agricultural production doubles by 2050 relative to 2050 (triple for climate change mitigation - competition for bioenergy crops cultivation).

Table 26. Compilation of narrative elements for the European case study.

<table>
<tr><th colspan="2">Major Elements for the narrative</th><th>Qualitative Description</th></tr>
<tr><td rowspan="6">Structural elements</td><td>Objective</td><td>Europe follows a path with no major changes in historic trends at social, economic and technological levels.</td></tr>
<tr><td>Motivating forces / drivers</td><td>The per-capita demand is one of the main drivers of the agro-food system. Agricultural production also driven by population growth, feed demand, bioenergy demand and material demand, and is strongly determined by international trade.</td></tr>
<tr><td>Nexus-induced challenges</td><td>Water problems in Europe include water scarcity, water quality and flood risks. Several studies indicate water scarcity as a key environmental problem.</td></tr>
<tr><td>Key nexus interactions</td><td>(L -> F) Land-use change from agricultural to, for instance, bioenergy land
(L -> C) Afforestation
(E -> W) Decreasing water quality and quantity as results of bioenergy, hydropower production
(E -> L) Deforestation as result of bioenergy production
(E -> F) Increasing bioenergy demand conflicting food security
(L - > C) GHG emissions</td></tr>
<tr><td>Critical Trade-offs from baseline runs</td><td>- Increase production of bioenergy, including biofuels, can cause potential conflicts with food security, and prevent indirect land-use change and enhancing forest cover (afforestation).
- Likewise, preventing ILUC (e.g. converting previously cultivated land into a source for bio-energy land could have a negative impact on the provision of environmental public goods to the agricultural sector. Other trade-offs exist with goals of reducing water abstraction, improving water quality and the ecological status of water bodies.
- Potential conflict between the goal of increasing hydropower production and ensuring good quality of rivers and floodplain water, as well as the provision of environmental public goods to the agricultural sector.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="6">Key SSP scenario elements</td><td>Policies, institutions and social conditions</td><td>Information to be added, if available.</td></tr>
<tr><td>Human development</td><td>Information to be added, if available.</td></tr>
<tr><td>Economy and lifestyles</td><td>GDP is expected to double by 2050. No major differences between EU-28. Average per capita annual income also increases however more moderately, reaching 46 thousand US$2005 in Europe and 49 thousand US$2005 in the EU-28.</td></tr>
<tr><td>Population and urbanization</td><td>Population increases by 10% in 20150 in relation to 2010, reaching 672 million people. In the EU-28, the increase is lower (7%), however population represents 80% of total Europe. Migration to cities will continuing increasing surpassing 80% by 2050, in comparison to 72% in 2010.</td></tr>
<tr><td>Environment and resources</td><td>Information on biodiversity in the nexus domain of “Land Use” and “Water”</td></tr>
<tr><td>Technology</td><td>No specific information provided on technology trends. To be added if available.</td></tr>
</table>

Nexus Domains Elements	Water	"Agriculture as the largest water consumer due to large irrigation systems and is one of the most vulnerable sectors to the risk of water scarcity. Other sectors such as electricity, industry and municipal also have substantial water demands, however withdrawals are not expected to change significantly. The decommissioning of traditional coal-fired power plants decreases the cooling water demand for thermal electricity generation. Competition for water is an issue in southern regions of Europe, where climate is drier. The intensification of agriculture in Eastern Europe is expected to impact water quality due to the increase of eutrophication; however the implementation of water treatment regulation of urban wastewater prevents further deterioration of water sources. Water demand is expected to decrease due to changes in climate especially in Southern Europe. The number of people living in water stress river basins could nearly double by the end of the century (146 million to 274 million), reaching over 40% of the total population. Aquatic ecosystems are to be affected marginally in respect to current state, where 50% of water bodies remain a high biodiversity intactness."
	Climate	Irregular rainfall patterns and sea level rise increase the flood risk in Europe. The energy sector is the one that contributes the most to the GHG emissions, followed by AFOLU - were negative emissions can be achieved. CO2 emissions levels are expected to increase (IMAGE and MAGNET) and a decrease with E3ME (due to the implementation of EU policies). Depending on policies implemented, emissions could reach 2 - 6 Gt CO2 in 2050, in comparison to an average of 4 Gt CO2 in 2010.
	Energy	"The implementation of EU-level policies, such as the EU-ETS, Energy Efficiency and Renewable Energy Directives, leads to a decrease in primary energy demand, contributing to the reduction of energy intensity in economic sectors. Demand for coal for electricity generation is also expected to decrease. Primary energy demand is expected to increase in IMAGE and decrease in E3ME (policy driven). IMAGE estimates an increase in primary energy demand for coal."
	Land	Agricultural land is expected to decrease throughout 2030 and 2050, and corresponding increase in forested land. As more people move in cities, built up area increases marginally. Although forest area is expected to increase, increase in land for cultivation of energy crops and urban area may reduce biodiversity on land in 20%.
	Food	In 2010, food supply is over 3,000 kcal per capita per day in Europe, compounded by 1/4 animal products and 3/4 of plant-based products, which indicates sufficient access to food and substantial amount of food being wasted in the households. A further increase in the share of animal-based products in the diet is estimated by CAPRI, MAGNET and IMAGE. MAgPIE estimates a decline due to income-saturation demand and ageing population. Crop and livestock production increases modestly until 2050 (IMAGE, MagPIE, MAGNET; no increase in CAPRI), and cultivation of bioenergy crops remains marginal.

Table 27. Compilation of narrative elements for the transboundary Germany – Czech Republic - Slovakia case study.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	The case study domain are Central European landscapes sharing a common economic history under socialist rule. It consists of Eastern Germany (the former GDR), the Czech Republic and Slovakia (which had been united as Czechoslovakia back then). An important objective is the economic stability in front of the background of an area dominated by agriculture given the minimal and still diminishing share of agriculture in GDP. Governing trends are the abandoning of lignite mining (formerly important in some sub-areas) and the furthering of bio-energy instead.
	Motivating forces / drivers	Large and powerful agricultural businesses, economic and environmental politics on different levels, probably the EU and the regional levels are more important for the actual development than the national parliaments.
	Nexus-induced challenges	The main issues in this case study are land use effects on water fluxes and the The main issues in this case study are land use effects on water fluxes and the water management in general. How power supply can be secured reliably. Biogas plants have at least the advantage of relatively stable power generation; this cannot be stated for renewable sources currently challenging the grid capacities especially in Germany, because of the intermittency of photovoltaic and wind energy supplies: PV and wind cause big pressures on grid stability, because there are hardly any storage possibilities for electrical energy, and the strong natural fluctuations in radiation and wind have to be buffered by fossil fuel power plants. Issue between land, energy, and food is the recently extended production and use of bioenergy crops like rape and silage maize, contributing to the landscape effects on the regional climate. Photovoltaics (PV) and wind power are problematic, too. Valuable crop land has been lost to PV installations which are sealed surfaces contributing to sensible heat emissions. Wind power requires huge installations with negative impacts on the amenity quality of the landscape and probaby also bird and insect communities
	Key nexus interactions	(W -> L) Flooding, droughts (W -> F) Food production demanding water (W -> C) Cooling effects from water bodies (L -> W) Water storage capacity (L -> E) Bioenergy (L -> F) Land availability for agriculture (E -> F) Competition between food and bioenergy crops (F -> W) Reduced evapotranspiration from ripe cereals, increasing sensible heat (C -> E) Wind and energy potential
	Critical Trade-offs from baseline runs	Possible trade-offs emerge wherever water is redirected towards other purposes, e.g. maintaining minimum water levels in rivers or the flooding of lakes in post-mining landscapes. These activities may cause drought events harming cereal growth and food production. More land devoted to bioenergy production means less land for food production. Concurrence in growing/harvesting area between food and bioenergy crops.

		Increased generation of electrical energy from solar radiation and wind requires a powerful grid with many nodes capable of absorbing short-term input variations caused by cloud shadows or wind gusts. Thematic models used: CAPRI (UPM), SWIM (PIK).
Key SSP scenario elements	Policies, institutions and social conditions	See the very comprehensive reports on Nexus-relevant policies in the transboundary, national, and regional case studies (SIM4NEXUS Deliverable 2.2, available via https://www.sim4nexus.eu).
	Human development	Information to be added, if available.
	Economy and lifestyles	Information to be added, if available.
	Population and urbanization	The case study covers the eastern part of Germany most of which had been the domain of the GDR until 1991 and both the Czech Republic and Slovakia. This area (236,736 km², around 32 million inhabitants). Persistent trends can be found in urbanisation – each day, the area of several football fields is sacrificed to urban development, usually involving sealing.
	Environment and resources	See description in the nexus domains' fields.
	Technology	No specific information provided on technology trends, apart from the technological options in the energy sector. To be added if available.
Nexus Domains Elements	Water	River runoff has been massively impacted where open-cast lignite mining landscapes emerged. On the other hand 2.5 billion m³ of water have been accumulated in former open cast mines. The water developed high quality (transparency several meters) owing to water depth and targeted fish stock management and can be considered as a strategic reserve. Apart from that, there are many reservoirs in the case study area, these are partly used for drinking water supplies, generally contribute to reduce flood waves, and increase runoff during drought phases. The average level of river runoff decreased around 1990, the year of the political and economic system change. This might have been an effect of the so-called re-dimming: Many old industries with massive aerosol emissions were shut down, the skies became brighter, evapotranspiration increased driven by the surplus radiation reaching the ground, and river discharge consequently decreased. The effect of increased sensible heat released from drained areas (spoil heaps, harvested fields, urban areas and stores) of heat islands should be also taken into account as drought phases seem to occur more frequently also due to climate change. In summer, small streams in agricultural regions have low water flow and many of them even dry out. In many regions underground water level decreased which results in water shortage of local rural sources.
	Climate	The global warming trend is also observed in the case study region. Since the end of the 19th century, average temperatures have risen about one Kelvin with most of the increases taking place after the Second World War. Although there has recently been a hiatus decade of a stagnant temperature trend it is very likely that the region will experience another Kelvin of warming within the next three to four decades. Droughts are more pronounced in agricultural lowlands with large drained fields. Regional studies show a decrease of small precipitation events and longer periods without rain during the vegetation period. The number of so-called tropical days is increasing. Except of the general trend of global warming, spring frosts occurs and results in losses of crop, fruits and vegetables and even traditional local products like blueberries. Precipitation has not changed very much regarding the long-term trend of annual averages. However, Germany and the Czech Republic experienced major flood

		events in the Elbe River basin in 2002 and 2013, and there are increasing numbers of heavy thunderstorms causing flash floods, hail storms, and tornadoes. In Slovakia, decreasing precipitation trends have been observed in the lowlands during summer while respective increases – connected to higher thunderstorm frequencies – have been reported for the mountainous areas.
	Energy	The general direction of electricity exchange between these countries has been swapped in the recent years: Historically, the Czech delivered (cheap nuclear) power in a one-way relation to Germany, but during the last years more and more renewable energy (especially wind) pushed the balance into the opposite direction. There are neither more hydropower nor more wind power potentials in the Czech Republic, therefore biomass production (biofuel, biogas) is supported. Fast growing woods are cultivated only on 3000 ha in CZ; agroforestry has a potential in drained agricultural landscape for its ecological functions. The former dominance of fossil energy sources, especially the lignite from within the area has already been confined by political decisions in favour of renewables. It remains however unclear which development path will be taken when the last fossil fuel power plants are being phased out: - the hydropower potential is small and already largely tapped, but other options are possible. - Bioenergy, which is currently stabilizing on an already high level may be further pushed at the expense of food production. - Photovoltaics and wind seem to continue their massive development in recent years, but this sets the stability of the grid at stake. More wind machines and high-voltage pylons are also about to cause protests from opinion groups. Either route seems to cause problems and conflict, but nuclear energy seems no sustainable alternative given the inherent risks of this technology, too. All three countries have negative energy balances when we consider the import of primary energy sources, especially crude oil and natural gas.
	Land	Typical and current agricultural landscape: Average farm sizes, measured in total (agricultural) area in the year 2013, are 130 (81) ha in Slovakia, 193 (133) ha in the Czech Republic, and 241 (229) ha in Eastern Germany – about five times larger than average farms in Western Europe (EUROSTAT 2017). In Slovakia, there are historically small farms (1–5 ha) which in total cover only approximately 10% of the farmland. This is reflected in the lower average size of Slovak farms albeit most of Slovak farmland are managed by large enterprises. There is no trend of reversing the big block structure of the agricultural areas inherited from the collectivisation period. The socialist co-operatives had just been taken over by larger companies. Persistent trends can be found in urbanisation – each day, the area of several football fields is sacrificed to urban development, usually involving sealing.
	Food	The agricultural primary production (everything grown on the fields, without cattle breeding) includes approximately 32 million tons of grain production – which equals more or less 1 ton/inhabitant and year (EUROSTAT 2017). Approximately 45,000 km² of the agricultural land (approx. 82,000 km² in total) are currently used for this output, however approx. 22,000 km² are used for growing silage maize and rape, both typical bioenergy crops. There is an overproduction of plant biomass in the Czech Republic and Slovakia whereas pork, beef, milk, cheese, and vegetables are imported for about 50% of the internal consumption of these countries.

		In 2016, rape was cultivated on 10% of agricultural land (400 000 ha, i.e. 5% of the Czech Republic's area), maize (241 500 ha) to 6% (i.e. 3% of the Czech Republic's area). Farmers are motivated by the high purchase prices of these commodities, no matter what burden these crops have for the landscape. In addition, there is no crop rotation. In the Czech Republic, more or less only four crops rotate – maize, rape, barley, and wheat – covering 82% of the areas used in agriculture. To restore nutrients load in the soil ten to fifteen different species would be needed.

Table 28. Compilation of narrative elements for the transboundary France - Germany case study.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing BAU trends up to 2050.
	Motivating forces / drivers	To be added.
	Nexus-induced challenges	The morphological integrity of rivers and aquatic ecosystems are influenced through various factors. Straightening of the riverbanks of the Rhine (to protect human settlements from floods, to produce hydroelectricity or to improve navigation) changed the flow rate of the water thus affecting the natural dynamics of sediments erosion and deposits in the river and the floodplain. Hydroelectric power generation plants influence the river discharge and therefore flooding (Integrated Rhine Programme) through regulated flows up- and downstream of the plants. Climate change also affects river discharge and temperature, potentially creating disruptions in the energy power generation or navigation. For the production of biofuel, agricultural land is used. This land can no longer be used to produce food. In some cases fertilizers are used to increase the yield of energy crops, which may increase eutrophication and therefore indirectly affect water quality and life. Burning fossil fuels for electricity production, transport or food production emits greenhouse gases. Nuclear power plants use stream water for cooling purposes; but the process may shift the thermal status of river discharge. Former potash salt mining increased salination of the groundwater and indirectly alters the ecological integrity of groundwater fed ecosystems.
	Key nexus interactions	(W -> L) Flooding threatens settlements, water bodies work as purification and control of water; (W -> L) Ecosystems – Water: Aquatic ecosystems depend on water quality and quantity; are influenced by infrastructure (e.g. hydropower plants, cooling systems, navigation). (W -> E) 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) (W -> E) Flow regulations (flow regime, hydropower operation, cooling-related withdrawals). (W -> F) Irrigation demand, aquaculture, quality of water factor for quality of food; (W -> F) Water for food processing and production: industry (processed food), cattle (meat) and irrigation (crops, vegetables, fruits). (W -> C) Aquatic ecosystems play a role in the C cycle. (L -> W) The land use (e.g. urbanisation) influences the water balance (runoff / infiltration); (L -> E) Land requirements for the energy sector activities; (L -> F) Availability of land for agriculture (food production); (L -> C) Emission and sequestration of CO_2, cooling effect through land cover, albedo effect. (E -> W) Energy is needed for water abstraction, purification and treatment (raw water -> drinking water &waste water -> raw water);

		(E -> L) Occupation of land for resources extraction and power technologies. (E -> F) Competition between food security and biofuels; (E -> C) GHG (energy generation from coal, sludge, distribution and consumption). (F -> W) Water needs to grow food; (F -> W) Contamination from food production, processing and consumption; (F -> L) Cropland requirements as response to food demand. (F -> L) Food production generates pollutants and erosion (intensive farming only) to the land. (F -> E) 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. (F -> C) CO2/CH4/N2O « GHG » emissions from food production (food crops' cultivation and livestock); (C -> W) The climate influences the water balance (run-off, evapotranspiration, infiltration), as well as the water temperature; (C -> E) Wind and solar potential, heating and cooling demand, (Socio-Economic -> W) Water demands (withdrawals, discharge, net consumption); demand is influenced by climate condition; (Socio-Economic -> E) Energy demand (regional, national, and international (neighbouring countries); (Socio-Economic -> L) Human settlements and activities influence land use and management. (Socio-Economic -> F) Food demand and consumer choices influence the food sector (both locally and internationally via the food trade).
	Critical Trade-offs from baseline runs	Thematic models used: E3ME-FTT (CE), CAPRI (UPM), and SWIM (PIK)
Key SSP scenario elements	Policies, institutions and social conditions	The area is historically intertwined and cooperation beyond borders in the Upper Rhine institutions is viewed to be essential. The International Commission for the Protection of the Rhine has published its adaptation strategy in 2015. The Water Agency has published its adaptation strategy in 2017. Research and industry consortium are being formed to adapt to climate change (cf TRION network).
	Human development	Population growth was strongly uneven between rural areas (population decrease) and urban areas (about +50% to +115% in the Rhine valley over 50 years). The Grand Est region had 5,5 million inhabitants in 2015 (representing app. 8,7% of the metropolitan French population). About 80% of the population lives in an urban area. The average population density is 97 inhabitants per square kilometre.
	Economy and lifestyles	Both the French and German parts of the Upper Rhine region are highly industrialized. Baden-Württemberg's economy is dominated by small and medium-sized enterprises: in 2003, there were almost 8 800 manufacturing enterprises with more than 20 employees, and 384 with more than 500. Baden-Württemberg is also home to large enterprises' headquarters8. The Grand Est region also has an important industrial past. Today, 25.3 % of the added value comes from the industry and construction sectors (19.6 % at national scale). However services make up the highest share of GDP in Baden-Württemberg (61.7% in 2007).
	Population and urbanization	The transboundary France-Germany case study is situated in the Upper Rhine region and covers the federal state of Baden-Württemberg (35 751 km^2) on the German side and the newly formed Grand Est Region1 (57 800

		km²) on the French side, with the (Upper) Rhine playing the role of physical and administrative border in its middle. The area along the Rhine is one of the most densely populated and highly industrialized area of the European continent. The main urban agglomerations are Karlsruhe, Mulhouse, and Basel.
	Environment and resources	22,400 ha (French side) and 25,100 ha (German side) designated natural habitats, reserves and protected wetlands. Riparian forests playing a major role in floods protection. Major habitats for migrating species.
	Technology	Information related to energy infrastructure, flood protection (etc) is given is respective nexus domains.
Nexus Domains Elements	Water	The Rhine river underwent heavy straightening of the watercourses in the 19th and 20th centuries which cut off of old meanders. In the late 1950s, the Rhine canal was built between Basel and Breisach. The canal runs parallel to the Rhine, is 50km long and is used for the hydropower generation. Over the years the straightening led to a lower groundwater table declining by 2 - 7 m in the lowlands on the both sides of the Upper Rhine since the establishment of the canal. At the moment there are ten hydroelectric stations and one nuclear power plant which receives cooling water from the canal, all are run by the French energy utility company EDF. The Rhine aquifer is one of the biggest in Central Europe and an important source of drinking water. It supplies ¾ of the drinking water to the area between Basel and Strasbourg. Half of the industrial water demand is also met in this highly industrialized region by the 45 billion m³ aquifer. *Water quality:* Pesticides and most importantly nutrients are still present in spite of stronger regulations. Half of water bodies do not reach the good chemical status required by the WFD. Micro-pollutants are a new threat. *Water quantity:* Groundwater levels are decreasing in strategic areas due to the combined effects of increasing abstractions and decreasing infiltration. Drought situations are occurring more frequently, putting a threat on aquatic life. *Aquatic ecosystems and river morphology:* Continuity of the river is still not reached due to large dams and sluices on the Rhine and its tributaries. The migration of fish species is limited and efforts to reintroduce the Salmon fish are jeopardized. *Flood hazards:* Expensive projects are implemented to recreate floodplains in order to mitigate the impacts from major floods and protect human settlements. 85% of the former alluvial area of the Rhine was lost to urbanisation and digging. In Région Grand Est, ¼ of cities and 10% of the population are located in flood prone areas. *Navigation:* Navigation is a particular sector to be considered in this case study, due to its importance in the economy of both French and German regions as well as for the associated infrastructures.
	Climate	In the Rhine catchment, considerable knowledge is available on the effects of climate change observed during the 20th century on the discharge pattern of the Rhine and the development of water temperatures since 1978. According to climate projections, the development until 2050 is characterized by a continuous rise in temperatures which, for the period 2021 to 2050, compared to the period 1961-1990, will amount to an average of +1 to +2°C for the entire Rhine catchment.

		Simulations for the near future indicate that, compared to the reference situation and in periods of low flow, the number of days with water temperatures above 25 °C will increase up to the double. In the distant future, there will be a strong rise in the number of days with temperatures above 25 °C. For the distant future, this is also true of temperatures above 28 °C.
	Energy	France: In 2010, the total final energy consumption in Région Grand Est was 18,550 ktoe. There is a decreasing trend since 2005. The decrease is even more important than planned (objectives to achieve carbon neutrality by 2050), especially in Lorraine where the decrease objective was 4% and the real decrease was 30% over 10 years. In 2010, the sector with the largest share of final energy consumption was the residential and service sector (38%), followed by industry (36%), transport (24%) and lastly, the agriculture sector with 2%. The main energy fuels of final energy consumption are petroleum products, gas and electricity, which provide respectively 34%, 27% and 21% of the final energy consumption in 2010. Germany: So far nearly one-third of the electricity supply in Germany comes from renewable sources such as wind, solar and biomass. Nuclear power will phase out completely by 2022.
	Land	Overall, around 37% of the URR area is used by agriculture. Arable land is concentrated on the flat of the Rhine valley. Permanent grassland is generally located in the mountainous regions and along the rivers. Between 2000 and 2010, the Région Grand Est lost 15% of permanent meadows surfaces (to urbanisation or crop land). Viticulture represents only 2% of the total surface, but remains an important economic sector for the URR. Forests cover the highest percentage of the land, with about 43% of the total URR area. Broad-leaved forests are relatively rare in the Black Forest with 10% land cover, but more extensive in the Vosges with 19%. Conifer forests are inversely more important in the Black Forest (18%) than in the Vosges (9%). Though heavily urbanised and populated, many initiatives have managed to secure natural habitats, reserves and protected wetlands on the Upper Rhine basin: 22,400ha on French side and 25,100ha on the German side.
	Food	Agricultural production is distinctively different in the two countries. Crop production from arable land is dominant in Alsace with around 70% arable land of total French UAA. In comparison, the lowest share of permanent grassland has Alsace with only around 23%. Permanent cultures, such as wine and fruit-growing orchards are quite important in the German URR part (11% of German UAA), also important in Alsace (around 5% of French UAA).

Table 29. Compilation of narrative elements for the case study of Greece.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing BAU trends up to 2050.
	Motivating forces / drivers	The main issues in this case study are land use effects on water fluxes and the water management in general. GDP development, mainly driven by growth in agricultural and tourism sectors, urbanization
	Nexus-induced challenges	Reoccurring water scarcity, both on islands and in mainland, leads to costly water supply (to islands) and excessive groundwater abstraction (in mainland). Increased domestic electricity and agricultural production and climate change are anticipated to pressure the available water resources further
	Key nexus interactions	(W -> L) Flooding, droughts (W -> F) Food production demanding water (W -> C) Cooling effects from water bodies (L -> W) Water storage capacity (L -> E) Bioenergy (L -> F) Land availability for agriculture (E -> F) Competition between food and bioenergy crops (F -> W) Reduced evapotranspiration from ripe cereals, increasing sensible heat (C -> E) Wind and energy potential
	Critical Trade-offs from baseline runs	Critical trade-offs related to the interactions between land use and the water and energy domains; between energy and climate; and food and land use. - Increasing domestic energy vs. Water availability - Increased agriculture (also for exports) vs. Water availability
Key SSP scenario elements	Policies, institutions and social conditions	(see nexus domains below)
	Human development	Information to be added, if available.
	Economy and lifestyles	Tourism and agriculture are the main sectors in the economy. GDP is increasing post the dramatic recession around the turn of the decade (decline by 23.22% between 2007 and 2015) GDP per capita in 2015 was 16.200€. Unemployment is (still) very high but declining (-1.3% in 2016)
	Population and urbanization	Overall population is experiencing a slight decrease in coming decades (10.8 million people in 2016, projected to decrease to 9.9 million in 20309. Urbanization is however positive. Currently approximately 355 of population lives in Athens.
	Environment and resources	Highly varied terrain, resulting in varied micro-climate. See description in the nexus domains' fields.
	Technology	No specific information provided on technology trends. To be added if available.
Nexus Domains Elements	Water	85% of available freshwater is used by the agricultural sector, 3% is used in industry and remaining 12% for domestic uses. For domestic use, water tariffs increase with higher consumption. Water resources are classified in 14 water districts.

	Climate	The Greek climate is typically Mediterranean, but micro climates vary with terrain. Climate change has already impacted the country, primarily by decreased precipitation and more intense storms.
	Energy	The domestic sector is the largest energy consumer in Greece. Domestic electricity production is primarily coal fired, followed by renewables (29% of national production). However, a large share of energy is imported. As a result, less than 10% of energy demands are met by renewable energy. A 2020 target for renewable electricity generation is set at 40%. From 2030 a CO2 emissions cap is set. Electricity prices have increased in recent years (49% between 2010 and 2016) European directives on energy are translated to national goals ("20%20%20% by 2020")
	Land	Prevailing land uses in Greece are cropland, woodland and broadleaved woodland. More than 25% of total area of Greece is registered as Natura2000 sites.
	Food	Olive oil exports are expected to grow (while domestic consumption decrease slightly). Increase fodder production is expected. The Common Agricultural Policy (CAP) dictates the development in the agricultural sector. Mountainous regions/varied terrain has resulted in much agriculture being relatively small scale.

Table 30. Compilation of narrative elements for the case study of Latvia.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing BAU trends up to 2050.
	Motivating forces / drivers	Focusing on low-carbon development Latvia is seeking for possibilities to reduce energy dependency from imported fuels, increase sustainable use of renewable energy sources and ensure economic development while reducing greenhouse gas emissions.
	Nexus-induced challenges	Expansion of agricultural activities to support food industry and food exports (e.g., cereals) puts pressure on land use by increasing use of fertilisers consecutively increasing emissions of nutrients (water quality) and GHG (climate change); Intensive exploitation of biomass for energy production puts pressure on forests (forest felling), land (monocultures, fertilisers), consecutively increasing emissions of nutrients (water quality) and reduction of carbon sequestration potential (climate change).
	Key nexus interactions	(W -> F) Water quality affecting food production (L -> W) Nutrient leaching to water courses. Water conservation and protection (L -> E) Land availability for bioenergy (W -> E) Hydropower production (E -> L) Bioenergy requirements (E -> C) More Renewable energy technologies will reduce GHG (F -> L) Land requirements to meet food demand (F -> E) Food waste for energy usage (C -> E) Heating and cooling demand
	Critical Trade-offs from baseline runs	Information not available. To be added if available. Thematic models used: E3ME-FTT (CE), MAGNET (WEcR), CAPRI (UPM)
Key SSP scenario elements	Policies, institutions and social conditions	Information to be added if available.
	Human development	Information to be added if available.
	Economy and lifestyles	GDP will increase more than double by 2050 in comparison to 2010. Average per capita income is to triple over the same period, improving its difference to the average EU-28 from 50% to 20% below. (based on SSP2 data)
	Population and urbanization	Population is projected to decrease by 20% in 2050, not surpassing the 2 million inhabitants. Urbanization rates will increase moderately and 8 out of 10 people will be living in urban areas by the mid of the century. (based on SSP2 data)
	Environment and resources	See description in the nexus domains' fields.
	Technology	No specific information provided on technology trends. To be added if available.
Nexus Domains Elements	Water	Latvia is rich in water resources but having different quality. It is assessed that freshwater resources far exceed present and future requirements for water consumption.

		The Water Exploitation Index (WEI) is one of the lowest in the European Union and it has decreased from 0.013 in 1990 to 0.007 in 2005, due to economic and institutional changes and water saving and water efficiency measures. The main concerns are related to the water quality.
	Climate	Latvia is in the temperate climate zone, it climate conditions are influenced by the vicinity of Baltic Sea and the transfer of air mass by the atmospheric circulation from the Atlantic Ocean, thus creating mild climate. During the 20th century the average air temperature in Latvia has risen by 1oC. During the past 100 years, there have been fluctuations in annual rainfall, which tended to rise from the beginning of the second half of the 20th century.
	Energy	The total consumption of energy sources during 2005-2015 has not changed significantly: 192.1 PJ in 2005 (4.3% more than in 2015). Latvia is not rich in local energy sources and is dependent on imported energy. Nevertheless, the dependence on imported energy resources reduced from 63.9% in 2005 to 40.6 % in 2014 due to the increased gross consumption of renewable energy sources. Renewable energy sources (RES), particularly wood fuels and hydro energy, along with the oil products and natural gas imported from various countries play the most important role in energy balance of Latvia. The remaining share in the primary energy structure of Latvia is comprised by electricity import, peat, coal, and waste. Latvia has the second highest share of RES in the energy consumption in the EU; in 2014 Latvian indicator constituted 38.7 % (EU average – 16.0 %). Latvia is rich in forests (forests covered 3260 th ha in 2014) and respectively wood fuel is an important local fuel used in centralized, local, and individual heat supply, as well as in co-generation. It is estimated that the amount of biomass used in energy sector will increase, although in general, significant changes in primary energy structure are not envisaged until 2020. Main renewable energy sources are wood (firewood, wood wastes, wood chips, briquettes and pelleted wood), followed by hydro and in the recent years wind. The share of RES in the energy mix is among the highest in Europe, having increased from 30% in 2010 to 37% in 2016. Concerns exist regarding the achievement of the 2020 RES target of 40% in gross final energy consumption. Natural gas and wood biomass are the main energy sources for electricity and heat production. There is no endogenous production of fossil fuel in the country and although energy dependency has decrease over the last decade (up to 2017), imports still represent 50% of the total energy consumption.
	Land	The total area of Latvia covers 64.6 thousand sq.km where 62.1 thousand sq.km is land, including 30.6 thousand sq.km forest and 23.5 thousand sq.km agricultural land. Inland waters cover the area of 2.5 thousand sq.km.
	Food	Food processing is one of the oldest and most important industries in Latvia. The food production sector has a steady and stable growth over an extended period. Dairy farming, meat production, beverages, fish processing, growing of fruits and vegetables are the largest agricultural sectors in the country). The food industry is traditionally oriented to the internal market. However, many food products are exported abroad e.g., cheese, butter, milk and milk powder, canned fish, fruit and berry preparations, pickles, various grains, meat products, confectionery, and alcoholic and non-alcoholic beverages.

Table 31. Compilation of narrative elements for the case study of The Netherlands.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing current trends – BAU up to 2050.
	Motivating forces / drivers	Economic growth, population developments, switch to renewable energy sources, scarce land availability (competing claims).
	Nexus-induced challenges	Climate: In low carbon economy the target is to achieve 95% GHG reduction. Biomass together with CCS will play a key role in this transition. Land: Biomass for energy has several implications on agriculture as it can compete with food, fibre and fodder crops. Water: The water subsystem affects fossil energy production (cooling water), ag ricultural production (irrigation) and energy from biomass production (biogas from sewage sludge). It is affected by climate (water availability), agriculture (exploitation of fresh water resources) and land (nutrient emissions from runoff). Energy: The energy system consists of two subsystems, Renewable energy and Non-renewable energy. The non-renewable energy system has the following sub-systems large-scale biomass and small-scale biomass. Large scale biomass energy is generated from large scale biomass imports. Small-scale biomass energy is from existing sources of biomass produced in the Netherland. The energy from biomass system affect agriculture (energy use such as biogas) and the socioeconomic system (transport). It is affected by agriculture (biomass/bioenergy), water (biogas from sewage sludge) and the socioeconomic system (waste from households and industrial waste for incineration). The energy from fossil fuels and other renewable energy types are affected by the available land for solar and wind and the socioeconomic system (drivers of total energy demand/consumption including duel for transportation). It affects climate through GHG emissions from energy production from fossil fuels, agriculture and (supply of energy).
	Key nexus interactions	(W -> L) Shortage of fresh water limits the productivity of land (W -> E) Water is a production factor for energy production (e.g. biomass) (L -> W) Agriculture impact on water quality (L -> E) Availability of land for food crops and fibre (L -> F) Availability of land for food crops (E -> W) Water pumping, cooling water, energy for water management, fertilizers and pesticide in biomass production (E -> L) Land use for energy production, ILUC (E -> F) Competition between biomass and food production (E -> C) GHG emissions (F -> W) Water footprints of food consumption in the NL (F -> L) Changes in diets (protein) affect land use; Land footprint (F -> E) Energy used for food production; food crops for renewable energy. (C -> W) Availability of fresh water
	Critical Trade-offs from baseline runs	**Between the Water and Energy domains:** Energy and climate if policy interventions are disregard. Energy saving and how this is done in SSP2. **Within the Energy domain:**

		Sensitive domain. Growing biomass, does it contribute to capture. Trade-off in the acceptance and to CCS technology. Trade-offs of certain decisions (import electricity from nuclear) **Between Land use and Energy:** Non-renewables, climate to energy. Hampering the decrease of emissions. Biomass really renewable and if it contributed to reduction of emissions. **Between Climate and Energy:** Production of food and less land available for biomass (competition for land use). **Between Society and Energy:** Resource efficiency (water and land) Consequences of consumption and prod (not only for NL) but also at international level (e.g. feed imports, broader perspective – implications at global level) Whether or not import of bulk biomass will be needed on that. Thematic models used: E3ME-FTT (CE), MAGNET (WEcR), CAPRI (UPM)
Key SSP scenario elements	Policies, institutions and social conditions	Current setting of politic and institutions are expected to exist in the future.
	Human development	Information to be added in D1.5, if relevant.
	Economy and lifestyles	GDP is expected to double in EU-28 by 2050 and a similar trend is expected for Europe. The average per capita annual income also increases significantly but not as much as the GDP, reaching, by 2050, 46 thousand US$2005 in Europe and around 49 thousand US$2005 in the European Union. International trade continues to be key to meeting the different demands (based on SSP2 from the IIASA SSP database).
	Population and urbanization	Population increases by 10% in 2050 in relation to 2010, reaching 672 million people. In the EU-28, the increase is slightly lower (7%), and the union's population represents 80% of the total in the continent. Migration to cities will continue to increase surpassing 80% by 2050, in comparison to 72% in 2010 (based on SSP2 from the IIASA SSP database).
	Environment and resources	See description in the nexus domains' fields.
	Technology	Energy transformation can take place both in the Netherlands and outside the Netherlands. As we consider the energy mix in the Netherlands, we can also import secondary energy from hydropower from Norway or renewable energy from Germany, for instance.
Nexus Domains Elements	Water	Water availability will remain sufficient, although there are more periods of droughts and floods anticipated
	Climate	Future trends in light of historic climate: 95% reduction is planned by 2050 in low carbon economy.
	Energy	Energy demand: 800-1600 PJ of biomass for 95% GHG emissions reduction by 2050. International trade: Biomass imports are needed to meet the demand as only 200 PJ is available domestically. Energy policies and regulation: In Low carbon economy 95% GHG emissions reduction is targeted. CCS, energy efficiency measures as well as biomass are seen as critical parts to achieve this.

	Land	Use of biomass: Netherlands is expecting to increase energy use of biomass from 80 PJ to 800-1600 PJ. International trade: Imports of biomass is expected as the domestic potential is only estimated to 200 PJ.
	Food	Food production is still expected to grow (including exports), but the land available for food production will gradually decline (more intensive). Diets are not expected to change dramatically.

Table 32. Compilation of narrative elements for the case study of Sweden.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing current trends – BAU up to 2050.
	Motivating forces / drivers	Population growth, which leads to increasing food and energy demand. Climate change, which adds pressures and creates opportunities for some sectors. Reduction of GHG emissions to fulfil ambitious climate policies Increasing demand for biofuels to reduce GHG emissions and to meet the growing energy demand. Food security to meet the increasing food demand of a growing population. Intensification of forestry and agricultural production affect water quality and quantity. Increasing risk of flooding and drought events due to climate change
	Nexus-induced challenges	Land: The forestry sector is subject to alterations in the light of developments in energy, governance and land use systems, climate politics, and taking account of an increasing competition between economic, environmental and recreational functions (Sandström et al., 2011)[13]. The growing demand for bioenergy has led to an intensification of the forest industry (Helmisaari et al., 2014)[14], in particular through extensions of managed forest land and introduction of fast-growing tree species. Climate: extended growing seasons from warmer temperatures, more areas will potentially become attractive to forestry and agriculture. Water: key research questions in the water sector relate to how future climate change, streamflow shifts and changing forestry practices might affect (drinking) water availability and quality. Energy: As the market for biofuels further grows, the question arises as to whether the supply of forest biomass for energy can further be increased. The competition between forests, water and energy resources and their impacts on biodiversity is further intensified by changing climate conditions. Knowledge gaps and considerable uncertainties on how environmental systems will change and on their impacts are major challenges. Swedish law prohibits hydropower constructions in four of the biggest streams and a number of smaller rivers, and, thus, limits further expansion of hydropower. Large uncertainties remain in terms of the effect of future seasonal shifts in water availability (e.g., more streamflow during winter, but expected longer drought period during summer) on hydropower, which highlights the need for further research.
	Key nexus interactions	(W -> L & E) Intensification in extreme hydrological events (L -> W) Forestry/agriculture practices can diminish quantity and quality of water (E -> W) Hydropower production demand (E -> L) Bioenergy demand (E -> C) GHG

[13] Sandström, C., Lindkvist, A., Öhman, K. and Nordström, E.-M.: Governing Competing Demands for Forest Resources in Sweden, Forests, 2(4), 218–242, doi:10.3390/f2010218, 2011.
[14] Helmisaari, H.-S., Kaarakka, L. and Olsson, B. A.: Increased utilization of different tree parts for energy purposes in the Nordic countries, Scand J Forest Res, 29(4), 312–322, doi:10.1080/02827581.2014.926097, 2014

		(C -> L) Increasing temperature will affect forestry/agricultural practices (e.g. planted tree/crop types) and forestry production as well as agricultural output
	Critical Trade-offs from baseline runs	Not specified / To be added. Thematic models used: E3ME-FTT (CE), CAPRI (UPM), IMAGE-GLOBIO (PBL)
Key SSP scenario elements	Policies, institutions and social conditions	Not specified / To be added, if available.
	Human development	Information to be added, if available.
	Economy and lifestyles	GDP will increase more than double by 2050, and average per capita income will also increase but at a smaller rate. Nonetheless, income is expected to reach 59 thousand US2005 by 2050, more than 25% above the average European income. (based on SSP2 projections)
	Population and urbanization	Population is expected to increase by 33% in 2050. Although most of the population lived in cities in 2010 (85%), the urbanization rate will continue to increasing reaching 92% by the mid-century. (based on SSP2 data)
	Environment and resources	See description in the nexus domains' fields.
	Technology	No specific information provided on technology trends.
Nexus Domains Elements	Water	In a changing climate, shifts in meteorological conditions are expected to perturb regional hydrology, and thereby also the occurrence, frequency and duration of both floods and droughts. Annual water availability in general is expected to increase as a result of increasing precipitation. There are, however, large seasonal and spatial variations. Climate models project that extreme floods are expected to occur less often in northern inland Sweden and the northern coastal areas, while most the rest of the country is likely to suffer from more common extreme floods in a future climate (Eklund et al., 2015)[15].During summer months, water availability is likely to decline as a results of increasing evaporation rates in large parts of the country (Eklund et al., 2015)[16]. In southern Sweden, water shortages during summer increasingly affect the drinking water supply, both in terms of quality and quantity. Increasing temperatures, shifts in seasonality and more streamflow (especially during winter) are likely to cause higher nutrient loads in Swedish boreal rivers (Teutschbein et al., 2017)[17]. In addition, a continued intensification of the forest industry (Helmisaari et al., 2014)[18], in particular extensions of managed forest land, may increase the risk of nutrients leaching from watersheds (Sponseller et al., 2016)[19].

[15] Eklund, A., Mårtensson, J. A., Bergström, S., Björck, E., Dahné, J., Lindström, L., Nordborg, D., Olsson, J., Simonsson, L. and Sjökvist, E.: Sveriges framtida klimat - underlag till dricksvattenutredningen (en: 'Sweden's climate - a basis for investigating drinking water), Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden. [online] Available from: http://www.smhi.se/polopoly_fs/1.96078!/Menu/general/extGroup/attachmentColHold/mainCol1/file/klimatologi_14.pdf, 2015.
[16] Ibid.
[17] Teutschbein, C., Sponseller, R. A., Grabs, T., Blackburn, M., Boyer, E. W. and Bishop, K.: An ensemble approach to assess the effects of climate change on riverine inorganic nitrogen loading in Sweden, Global Biogeochem Cy, In review, 2017.
[18] Helmisaari, H.-S., Kaarakka, L. and Olsson, B. A.: Increased utilization of different tree parts for energy purposes in the Nordic countries, Scand J Forest Res, 29(4), 312–322, doi:10.1080/02827581.2014.926097, 2014
[19] Sponseller, R. A., Gundale, M. J., Futter, M., Ring, E., Nordin, A., Näsholm, T. and Laudon, H.: Nitrogen dynamics in managed boreal forests: Recent advances and future research directions, Ambio, 45(Suppl 2), 175–187, doi:10.1007/s13280-015-0755-4, 2016.

	Climate	Temperature and precipitation are projected to increase more in high-latitude regions such as Sweden than in the rest of Europe. Extreme events are projected to become more intense. Regional and seasonal environmental responses of high-altitude ecosystems could be altered by new climate conditions.
	Energy	Despite a large per capita energy consumption, Sweden's economy is today one of the least dependent on fossil fuels and has one of the lowest carbon emission rates. Sweden's total energy supply in 2015 was 557 GWh. The most important energy sources are nuclear fuel (33 %), crude oil and petroleum products (24%), biofuels (23%) and hydropower (12%). For the past decades, Sweden has invested heavily in alternative energy sources and is now in the front line of renewable energy use. Biofuels play a major role in industry, district heating, and to an increasing degree also in electricity production and transport. The biofuel market in Sweden is presently growing at a rate of 3 TWh per year, which equals 1.5x106 m3 of wood (de Jong et al., 2014)[20]. At present, the two leading biofuel sources are undensified wood (41%) and black liquor (33%), followed by densified wood (8%) and municipal waste-bio (7%). The increasing use of biofuels for electricity and heat production has caused a rising demand for wood fuels (Energimyndigheten, 2016)[21], which has been satisfied through increased extraction of forest biofuels (de Jong et al., 2014). The market is expected to grow further in the near future (Energimyndigheten, 2013)[22] and the supply of forest biomass for energy could potentially increase by 70% (Andersson, 2012)[23]. Sweden is the largest hydropower producer in the EU and the tenth biggest in the world, generating on average 67 TWh of electricity per year. In the last 15 years it varied from 53 TWh (2003, drought year) to 79 TWh (2000, particularly wet year). Swedish hydropower provides a valuable source of renewable energy and is able to balance the national electricity grid (Rudberg, 2013)[24]. However, about three quarters of the largest river systems are affected by fragmentation from water regulation (Rudberg, 2013)[25], causing negative ecological consequences. Swedish law prohibits hydropower constructions in four of the biggest streams and a number of smaller rivers, and, thus, limits further expansion of hydropower. Large uncertainties remain in terms of the effect of future seasonal shifts in water availability (e.g., more streamflow during winter, but expected longer drought period during summer) on hydropower, which highlights the need for further research.
	Land	More than two thirds of Sweden are currently covered by forests, of which the majority is subject to forestry. The country has a long history of using its natural forest resources, while also protecting and developing them (Andersson, 2012). Total forest industry output was approximately 23 billion Euros in 2011 (Skogsstyrelsen, 2014)[26], while the

[20] de Jong, J., Akselsson, C., Berglund, H., Egnell, G., Gerhardt, K., Lönnberg, L., Olsson, B. and Stedingk, H.: Consequences of an increased extraction of forest biofuel in Sweden - a synthesis from the biofuel research programme 2007-2011: Summary of the Swedish Energy Agency report no. ER2012:08 (in Swedish), IEA Bioenergy., 2014.
[21] Energimyndigheten: Energy in Sweden 2015, Swedish Energy Agency, Eskilstuna, Sweden., 2016.
[22] Energimyndigheten: Comprehensive assessment of the potential for exploiting high-efficiency cogeneration, district heating and district cooling, Swedish Energy Agency, Eskilstuna, Sweden., 2013.
[23] Andersson, K.: Bioenergy, the Swedish experience: how bioenergy became the largest energy source in Sweden., 2012.
[24] Rudberg, P. M.: Sweden's evolving hydropower sector: renovation, restoration and concession change, Stockholm Environment Institute, Stockholm, Sweden., 2013.
[25] Ibid.
[26] Skogsstyrelsen: Swedish Statistical Yearbook of Forestry, Swedish Forest Agency, Jönköping, Sweden., 2014.

		export value of forestry and the forest products industry was 13 billion Euros. The total number of employees in large-scale forestry has declined significantly in recent years, while, at the same time, the role of forest entrepreneurs (and their employees) has become increasingly important (Skogsstyrelsen, 2014).
	Food	Sweden is to some extend limited by climate, thus most food production happens on the South. There are 63000 farms in Sweden, with average side of farm of 41 hectares. Swedish exports of food and agri-cultural products currently amount to EUR 5 billion, and is steadily increasing. Sweden has very ambitious targets when it comes to sustainability and values in food production, such as animal health, animal welfare, restrictive use of antimicrobials and pesticides. Swedish organic production is increasing and has more than doubled in the last ten years. The farmed land (arable land, pastures and meadows) used for organic production is currently 18 percent. In 2017, the Swedish Government set a target that certified organic production shall increase to at least 30 percent of the cultivated area by 2030. Compared to other EU countries, Sweden has the second largest proportion of organic farmed land in the EU. Eggs, cattle, milk and grain are the largest sectors in organic production.

Table 33. Compilation of narrative elements for the case study of Azerbaijan.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing current trends – BAU up to 2050.
	Motivating forces / drivers	Shift a more sustainable pattern and a more diversified economy
	Nexus-induced challenges	High dependency on transboundary water resources as the downstream country of the Kura and Aras river basins. Wastewater treatment is practically non-existent. Water re-use is being investigated for irrigation purposes. Alternatives to conventional water supply could be interesting to analyse. Irrigated land is located in the lowlands, characterised by less precipitation. The climate is arid, the region is prone to floods and climate change is likely to affect water availability in the future - study options of improved irrigation systems/new irrigation technologies; and/or crop adaptation. Potential role of renewable energy sources in decarbonising energy generation (one of the aims of the country) and analysis of emissions reduction from the industry, transport and energy sector.
	Key nexus interactions	(W -> E) Water for cooling, hydropower, fuel extraction and production (W -> F) Irrigation requirements (E -> W) Irrigation, water supply, water/waste water treatment (E -> C) GHG emissions (F -> W) Fertilizers and intensive agriculture affect quality (C -> W) Water availability (C -> F) Crop production and yield
	Critical Trade-offs from baseline runs	Not available. To be added. Thematic models used: E3ME (CE), MAGNET (WEcR), CAPRI (UPM), OSeMOSYS (KTH)
Key SSP scenario elements	Policies, institutions and social conditions	Information to be added, if available.
	Human development	Information to be added, if available.
	Economy and lifestyles	Major industries include the extraction of crude oil and gas, and fields spread all across the country. Oil and gas products represent over 90% of the country exports, 65% of which to European countries, with the top importers being Italy, Germany and France (MIT Observatory of Complexity). E3ME: The GDP is forecasted to keep increasing at a reasonably steady rate with an average annual growth rate of 4% over the forecast period, from 30 billion (thousand millions) EUR2005 to over 100 billion (thousand millions) EUR2005 in 2050. The forecast to 2022 matches that of the IMF growth rates. MAGNET: Gross Domestic Product (GDP) is estimated to increase from almost 66 billion US$ (2011) to reach 120 billion US$ in 2050. SSP2 database: Increase from 81 to 150 billion US$2005 (PPP) (doubles); GDP per capita: 9 to 14 thousand US$2005/capita (1.6x, 60% increase). E3ME: The country's fossil fuel exports make up a significant contribution to the country's GDP. In 2010, fuel exports represented 38% of the GDP, with this figure decreasing to 17% in 2015 (IMF 2018; WITS Data 2015). The

		contribution to GDP of fossil fuel exports is forecasted to decline slightly by 2030 in comparison to 2015. E3ME: In 2010 oil and gas extraction made up the vast majority of total output, around 72%. However, this is forecasted to decrease by 2030, to about 42%, as Azerbaijan diversifies its production with the share of basic manufacturing, non-energy mining, but also fuel refining increasing. Although this is a significant change, as shown in Figure 15, extraction still makes up the majority of production in 2050. E3ME: It is forecast that in all sectors employment increases from 2010 to 2030 expect that of electricity and gas distribution. It is expected that there will be higher growth in sectors such as accommodation and food, professional activities, real estate, and financial activities.
	Population and urbanization	Azerbaijan is located in the southern Caucasus region (Figure 1). It is bordered by the Russian Federation, Iran to the North, and Georgia; with the Caspian Sea to the East. The Republic of Azerbaijan has a territorial area of 86,600 km2 and a population of 9.81 million people. Not much difference exists between the share of rural and urban population, with 52% living in urban areas in 2011.
	Environment and resources	See description in the sections dedicated to the nexus domains.
	Technology	No specific information provided on technology trends. To be added.
Nexus Domains Elements	Water	Only ¼ of the country's renewable water resources is generated in the country, which makes it vulnerable to the quantity, quality and timing of upstream countries. Water losses are an issue. Agriculture is the most water-intensive sector and accounted for more than 70% of freshwater withdrawals in 2014. Agricultural land represents 57% (2013) of the land area and nearly half of it is under irrigation. Over 70% of the water resources of Azerbaijan are transboundary. Water is a key resource to agriculture and dependence on external water resources increases the vulnerability of the food production sector.
	Climate	Azerbaijan is vulnerable to climate change, with the arid climatic region likely to expand affecting the agriculture sector that provides employment to 40% of the population. E3ME: Carbon dioxide emissions in Azerbaijan are forecast to grow with a 1.4% annual average growth rate over the forecast period with electricity generation and households being the largest emitters. New emissions trends: 7Mt in 2010, 12 Mt in 2030 and 14 Mt in 2050. E3ME: Demand for gas remains the largest for the fuels over the forecast period. Comparing with the CO2 emissions figures, it indicates that emission levels from the energy sector will not vary expressively and that the increase in emissions should have another source than energy-related.
	Energy	The country relies mostly on domestic oil and gas for electricity generation. Over the past years oil power plants have been decommissioned and replaced by natural gas power plants. Similarly to current trends seen in electricity generation in Azerbaijan, the model suggests that further investments in gas technologies would result in the least-cost option for electricity generation, with electricity produced from natural gas representing more than 80% of the generation in 2050. E3ME: The country's fossil fuel exports make up a significant contribution to the country's GDP. In 2010, fuel exports represented 38% of the GDP, with this figure decreasing to 17% in 2015 (IMF 2018; WITS Data 2015). The

		contribution to GDP of fossil fuel exports is forecasted to decline slightly by 2030 in comparison to 2015. MAGNET: In addition to the increase in the volume of production of crude oil, petroleum and gas, global prices are also expected to increase by approximately 74% from 2011-2050. Taking this price rise into account the real production value of crude oil is expected to more than double in 2050, in comparison to 2011 values and reach around 89 billion 2011-USD. In a similar trend, exports are foreseen to increase from 30.9 billion 2011-USD to 43.9 (or 76.3 when considering the change in price) billion USD in 2050. MAGNET: exports of oil, gas and petroleum to the EU remain constant, and increase in exports to non-EU countries. Increase in exports of electricity, chemicals, industry, gas distribution and transportation to non-EU. IMPORTS: In terms of imports, Azerbaijan does not import any oil, petroleum or gas and is not expected to. Imports of other goods from the EU will remain almost constant until 2050 will those from other trade partners will increase by 117% from 2011-2050.
	Land	Forests cover 12% of the land but are unevenly distributed and illegal logging is a problem. Reforestation is a key priority to the country, due to the importance of forest cover to ecosystems services, hydrology and mitigation potential.
	Food	Agricultural activities are highly diverse in Azerbaijan with a wide range of agricultural produce, including cereals and dried pulses, cotton, potatoes, vegetables, melons, fodders crops, fruits and berries, and grapes. Total area of agricultural crops exceeds 1.5 million ha, and a wide diversity of crops is grown. Climatic and hydrological conditions are highly variable across the country. Agricultural crops are mainly produced using irrigation and rain-fed production systems. Agricultural production increased in the recent years, mainly through increase of yield. Production of cereals and dried pulses increased between 2010 and 2016 by about 50% (Table 3), while the sown area of cereals and dried pulses showed inter-annual variation of some 10%. MAGNET, Sep 2018: Production volume of wheat and other grains is estimated to increase by some 48%, and production volume of horticulture (vegetables, fruit and nuts) is estimated to increase by some 36%.

Table 34. Compilation of narrative elements for the case study of Andalusia.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing current trends – BAU up to 2050.
	Motivating forces / drivers	Urbanization and intensification of farming
	Nexus-induced challenges	Major pressures on land and water – as a result of urbanization and farming intensification, over-allocation of water resources, and inadequate consideration of the linkages between water saving technologies and energy use.
	Key nexus interactions	(W -> L) Irrigation needs, soil erosion and salinization ; (W -> E) Water for hydropower production ; (W -> F) Water for irrigation (W -> C) Evaporation (L -> W) Competition of water resource between sectors (L -> E) Land availability for energy production (L -> F) Competition of land availability, e.g. agriculture and urban areas (L -> C) Carbon sink (E -> W) Desalination, pumping of groundwater, pressurise irrigation systems (E-> L) Renewable energy instalments (E -> F) Energy efficiencies in agricultural practices (E -> C) GHG emissions (F -> W) Groundwater overexploitation, fertilizer pollution (F -> L) Soil pollution and productivity losses (F -> E) Energy requirements (irrigation, etc.) (F -> C) Emissions and absorption of GHG (C -> W) Water availability (C -> L) Soil erosion (C -> E) Solar and wind potential (C -> F) Crop yields
	Critical Trade-offs from baseline runs	Climate-induced changes in crop productivity Increased water use in irrigation Thematic models used: E3ME and CAPRI.
Key SSP scenario elements	Policies, institutions and social conditions	Regional Government (Junta De Andalucía) has legislative powers in Agriculture, Water, Land Planning, Environment and Tourism. Split in 7 provinces. Policy incoherence across nexus sectors over the last years has led to over-allocation of water resources, increasing competition for water among sectors, growing energy dependence in the agricultural sector, raising greenhouse gas (GHG) emissions, soil erosion and environmental degradation.
	Human development	Information to be added, if available.
	Economy and lifestyles	Agriculture and Tourism are major economic sectors (representing 5.3% and 76.2% GDP in 2015). Andalusia has become one of the main fruit and vegetables suppliers to the European market and global exporter of olive oil. Unemployment rate in the region reaches 30%.

	Population and urbanization	Most populated region in Spain (8.4 million inhabitants, 18% of total population, 55% living in rural areas).
	Environment and resources	See description in nexus domains below.
	Technology	See description on water and energy domains.
Nexus Domains Elements	Water	Andalusia encompasses six River Basin Districts (RBD), three of them at the intra-community level (Tinto, Odiel, Piedras RBD; Guadalete, Barbate RBD; and Andalusian Mediterranean RBD), two of them at the inter-community level (Guadalquivir RBD and Segura RBD) and one transnational (Guadiana RBD). The Guadalquivir RBD is the main river basin of Andalusia with a watershed area that represents 58.8% of the geographic area of Andalusia and encompasses over 85% of the total irrigated land in the region. Water availability in the main river basins varies strongly over the years depending mainly on precipitation. Agriculture is the main water user representing 80% of total water consumption in the region. Irrigation water is allocated to olive trees, arable crops, fruits and vegetables. 74% of the irrigated land uses localised irrigation systems, with an average irrigation efficiency over 80%. CAPRI projects a 2.5% increase in total irrigation water use in Andalusia in 2030 driven by the expansion of olive and fruit trees irrigated land.
	Climate	The geographical location of Andalusia makes the region particularly vulnerable to climate change. According to the Spanish Agency of Meteorology, forecasts from different climate models under different Representative Concentration Pathways (RCPs) show long-term variations in average maximum temperatures in the region that range between -1 and 7C. Climate change will affect water availability in the region leading to a reduction of 8% by 2027, according to the different River Basin Management Plans.
	Energy	Around 20% of energy demand is produced internally. Main energy resources in Andalusia include coal production in the area of the Valle del Guadiato, natural gas extraction from deposits in the Gulf of Cadiz and Valle del Guadalquivir, and renewable resources mainly located in Seville (solar energy), in Cadiz (wind energy), and in Jaen and Cordoba (biomass production). Andalusia has no own oil reserves and is highly dependent on oil imports. The region has excellent natural resources for wind, solar and biomass energy. Considerable growth of wind industry in the last decade as well as the use of small PV for rural electrification. The region is leader in national biomass energy production. Hydroelectric energy less developed than the others due to high demand of water for other uses (irrigation, urban use). Renewable and non-renewable energy production trends provided by the E3ME model show an increase in renewable energies over the next years (particularly for solar energy), while non-renewable energies tend to decrease The total renewable installed capacity in Andalusia is 6 119 MW and 39% of the electric energy comes from renewable sources.
	Land	The region spans over 87,000 km2 (17% area of Spain). This region is characterised by a strong agricultural sector highly dependent on irrigation agriculture, which accounts for more than 80% of total water withdrawals and generates more than 64% of the agricultural production in the region.

		Andalusian land contains mainly of natural and forest areas (50% of the total surface) and agriculture (42% of the total). Constructed and altered areas represent 4.6% of the total surface and water areas represent 3.6% (Figure 13). Among natural and forest areas, scrublands with trees and without trees are predominant (24.0 and 22.7% respectively), followed by pasture lands with trees (18.5%). Within the agricultural areas, olive trees are mainly used, representing 46%, followed by cereals (14%), vegetables (12%), fruit trees (13%) and other crops (15%). Over the period 2005-2011, natural and forest areas have decreased by 4%, while agricultural areas have increased by 3%. The most substantial change is observed in constructed areas that have enlarged by 13%. CAPRI baseline for 2030 highlight a significant decline in the area allocated to cereals, while an increase in the area devoted to olive and fruit trees is expected. Focusing on irrigated agriculture, olive will remain the main crop in terms of total water use, followed by fruits.
	Food	See description in the “Land” nexus domain.

Table 35. Compilation of narrative elements for the case study of Sardinia.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing current trends – BAU up to 2050.
	Motivating forces / drivers	Tourism and agriculture are the main sectors in the economy. The main issues in this case study are the needs to support water services for tourism and agriculture sector, in order to achieve effectively food and economic security, while guaranteeing environmental flows for aquatic systems Another major issue is determine the right mix of energy sources to reduce energy costs and emissions.
	Nexus-induced challenges	Poor communication between sectors in the development of policies for each sector (silos thinking). In this sense, the main societal challenge can be seen as promoting coordination among nexus sectors to exploit the possible synergies and an overall need to substantially increase awareness. Stakeholders agree that water sector plays a central role with a shared objective of reaching a resilient system able to satisfy all demands. It is followed by the energy sector which must reduce the costs of energy, while reducing CO2 emissions.
	Key nexus interactions	(W -> E) Hydropower production (W -> F) Water resource limitation limit food production (crop yield) (W -> L) 1) Minimum Environmental Flow needed to sustain aquatic systems; 2) limitation or expansion of irrigated vs rainfed agriculture, by crop type (E -> W) Water pumping/distribution (E -> C) GHG emissions (F -> W) Irrigation systems and types of schemes, regulate water demand (C -> W) 1) Run-off and evapotranspiration rates, 2) Crop water requirements (C -> E) 1) Heating and cooling energy demand, 2) Wind and solar energy potential production (L -> C) Carbon sinking/stocks (L -> W) Effect of Land use/cover on reservoir recharge
	Critical Trade-offs from baseline runs	Sensitivity of water resources to climate, which affects their availability. Water is required for irrigation, domestic supply (including both consumption specifically for resident population and for tourism), and for hydropower generation, and ecosystems. Improvement of irrigation efficiency (water domain) could lead to reduction of water demand from agriculture and increase in land area under irrigation (land and food domains). Amount of water stored in reservoirs and its management determines the potential to expand irrigation and crop production (yield). Continued use of coal for energy production beyond 2025 and subsequent relevant emission of CO2, shift to renewable energy sources in the future may limit CO2 emission Urbanization plan in the coastal areas for tourism: increasing revenues to the sector, exacerbating water supply issues; impact on the environment by altering the natural landscapes (which is one of the main attraction to tourists). Thematic models used: E3ME-FTT (CE), MAGNET/GTAP (WEcR), CAPRI (UPM)

Key SSP scenario elements	Policies, institutions and social conditions	Region with a special statute by the Italian Constitution that grants the Region of Sardinia with a higher degree of legislative and financial autonomy. The Charter of the Autonomous Region of Sardinia established that the Regional administration has legislative authority over public water rights, agriculture and forests, and tourism. The regional government has set a number of objectives and policies for the energy, water, and agriculture sectors. Although, these objectives, especially those for the energy sector, mention climate change mitigation strategies and are designed to reduce CO2 emissions in line with EU targets, as of 2018 there was a lack of policies or plans directly addressing a climate change mitigation or adaptation strategy. In 2019, the Regional Government published a Regional Adaptation plan to Climate Change for the agriculture, forest, water (supply and demand) and hydrological risk. Low, but growing quickly in the last 5 years, degree of awareness. lack of inter-sectoral coordination
	Human development	Information to be added, if available.
	Economy and lifestyles	(From E3ME baseline run) In general, all economic sectors are projected to increase their GVA. Total employment shows a small increase of 5%, between 2013 and 2030. However, this increase is not homogeneous for all sectors and, notably, employment in the agriculture, forestry and fishery sector is projected to decrease by 32%. This would be in line with the present trend that shows the decline in number of farms but also an increase of the farm size.
	Population and urbanization	Population is projected to decrease and age. The present urbanization plan is under discussion as it allows for the expansion of buildings also along the coast. This would have an uncertain effect on the tourist flows and the economy of the tourism sector.
	Environment and resources	See description in the fields dedicated to the nexus domains.
	Technology	See description in the energy and water nexus domains.
Nexus Domains Elements	Water	Many of the reservoirs are connected and the water management has improved thus increasing the resilience of the system. However, repeated consecutive years with low precipitations the reservoir system was not able to satisfy all demands, with water shortages not only for crops but also for domestic use and hydropower production. Policies insist on improving the drop for crop ratio, but these policies do not account for the fact that increased water efficiency in agriculture may actually have a positive effect on the expansion of irrigated areas thereby cancelling the purpose of the policy itself in the long term.
	Climate	Climate influences basin run-off and thus the amount of water stored in reservoirs. It also has an influence on crop irrigation requirements and on evaporation from open bodies. It influences the destination and season choices of tourist by affecting the climatic comfort. Climate influences the amount and timing of energy use for heating and cooling of buildings. Climate change will reduce energy requirements in winter and increase them in summer. Climate will also influence the productivity of solar and wind power plants.
	Energy	Key sector for the economic growth of the region since the costs for energy are higher than national averages. This difference in price is mainly due to the absence of methane in the region. However, projects to bring methane on the island are in progress, as well as projects to increase the share of renewables.

		(From the E3ME baseline run reported in D5.2) the baseline scenario of E3ME does not project any major change except for an increase in energy production from wind (256%) and a reduction from coal (-45%) for 2030, compared to 2013. Under this scenario, and in agreement with the simulations performed for the development of the Regional Energy Plan, reduction of CO_2 emissions will not meet regional targets. The region has approved to continue to use coal as fuel for energy production: while this allows to satisfy energy demands and contribute to control energy costs, it has a negative impact on the objective of reducing CO_2 emissions.
	Land	Agriculture is of high importance for the region in terms of its contribution to GDP, food security, employment and cultural heritage. It is also the most water demanding sector and holds a great potential for the reduction of CO_2 emissions as well as contributing to important ecosystem services. Irrigated area in Sardinia show a relevant increase between 2010 and 2030, according to CAPRI model outcome. The largest expansion of irrigated land by crop types is expected for vegetables, identifying several cash crops that can be promoted by high prices in the market. Furthermore, both rice and maize could encounter an expansion of their irrigated distribution, while the largest decreases in irrigated areas are foreseen for fruit trees and grapes. Irrigated areas show a constant and positive trend in the past 50 years and model projections suggest a further increase.
	Food	See description in the “Land” nexus domain. The case study uses “agriculture” to represent agricultural activities, which may not be exclusively correspond to food production.

Table 36. Compilation of narrative elements for the case study of South West Water - UK.

Major Elements for the narrative		Qualitative Description
Structural elements	Objective	Continuing current trends – BAU up to 2050.
	Boundaries	The UK Case Study covers the region of South West England, and includes the counties of Cornwall, Devon, and parts of Somerset and Dorset.
	Motivating forces / drivers	Tourism and agriculture are the main sectors in the economy. Drivers for drinking water and waste water services: temperature rise, increase in urbanisation rates, feedback effect of water services becoming more energy intensive.
	Nexus-induced challenges	Tourism and agriculture are greatly dependent on water for their activities. The seasonality of their water creates challenges for water management. Climate to water: vulnerability of the water industry to climate change due to temperature change, more intense rainfall, and drought coupled with increased demand during hot weather, and sea-level rise. Vulnerability is exacerbated by (DEFRA, 2012): increased demand due to population rise; resource depletion/rising energy cost; increased urbanisation, and higher taxation.
	Key nexus interactions	(W -> L) Sludge disposal (W -> E) Energy demand for water transport and treatment (W -> C) Process and fugitive emissions (L -> W) Raw water quality and surface drainage (L -> E) Waste transport fuel demand (L -> F) Land utilisation for agricultural production (L -> C) Greenhouse gas emissions and sequestration from land-use (F -> E & W) Irrigation, livestock and food processing demand (L <-> L) Land to societal demand (within land use): land utilisation of the housing and housing demand
	Critical Trade-offs from baseline runs	Not available. To be added if available. Thematic models used: E3ME-FTT (CE), CAPRI (UPM)
Key SSP scenario elements	Policies, institutions and social conditions	The water sector is privatised and water services are provided by South West Water. However, the water sector is regulated by three separate and independent bodies, which work on behalf of the government. Government, and is further advised that by several NGOs. The OFWAT (water Services Regulation Authority, non-ministerial government department acts as economic regulator; the Environment Agency (EA) is an executive non-departmental public body acts as environmental regulator (EA regulations are typically implementations of the EU directives); Drinking Water Inspectorate (DWI) oversees Quality in the water sector, to monitor and direct water quality. And then Lobbyist and Research (independent, non-government): Water UK, industry representative; and UK Water Research Institute, acts as a research platform to the water industry.
	Human development	Not available or specified. To be added if information is available.
	Economy and lifestyles	Tourism and agriculture are the main sectors in the economy. GDP per person employed is 78% of the national average in the metropolitan region of Exeter (EUROSTAT).

		Regional GVA (Devon and Cornwall) has increased, on average, at a 3.1% rate in the period of 2010 - 2016. (Office of National Statistics, UK).
	Population and urbanization	The region, with a population of less than 2 million, receives around 11 million tourists during the peak summer season. Largest share of the population lives in rural areas, whereas 45% are distributed over 13 urban centres. (Assuming similar growth to all SW region) Population is expected to grow at 0.6% rate up to 2030 and 0.4% until 2041* (last year of projections). (ONS, population projections based on 2016. 2012-based projections project a higher growth in 0.03% and 0.05% in respect to 2016-based, for the period up to 2037).
	Environment and resources	See descriptions in sections dedicated to the nexus domains.
	Technology	No specific information provided on technology trends. To be added if available.
Nexus Domains Elements	Water	The low perceived value of water by users delays a behavioural change towards water conservation. Water prices continue increasing due to water services' provider tight financial margins and increasing costs, related to maintenance (leakages), development of new infrastructure, and energy consumption. The water industry market structure follows the traditional approach and the wholesale water market model is not implemented (in the baseline case). Bio-solids are generated at several stages in the urban water cycle which can be used to generate valuable products including energy, fertiliser's and aggregates. Currently the majority of bio solids are disposed to land incurring both environmental impact and financial burden.
	Climate	Increase in temperatures and longer periods of hot weather increase the demand for water from different users. Water supply and treatment becomes continuously challenging towards mid-century, due to increased degree of urbanisation, and seasonally in peak tourism periods.
	Energy	Energy consumption for the operation of water systems in the UK is responsible for 1.1% of the UK's total CO2 emissions. Fluctuation in energy costs affect the unit cost of water, subsequently affecting water tariffs. A flat rate tariff for energy is considered in the water sector (or, whatever is considered now continues in place, or no flexible tariffs' models are available in the baseline).
	Land	Increased demand for water services requires the use of land for the development of infrastructure. Although this is done in line with the regulatory framework, the environment may be negatively affected, as more environmentally sensitive practices are not opted for as they are less economically efficient.
	Food	Land is the main receptor of rainwater, and the use under which the land is placed influences the quality and availability of run-off to surface water, therefore integrated management is key. The south-west region is predominantly agricultural producing arable crops, meat and dairy products, which are historically major contributors to poor groundwater quality. The application of ecosystem services is seen as one of the major routes for management in this area. Ecosystems: Currently in the UK paid ecosystem services exist within a voluntary framework supported by government endorsed guidance notes, with no obligatory or regulatory foundation. South West Water has engaged in a number of projects incorporating paid ecosystem services as a cost-effective means of flood mitigation and minimising raw water pollution.

Appendix H: Inventory of assumptions (technological, social and policy-related) in the thematic models in the baseline and 2-degree scenarios

Scenarios	Models
B - Baseline	E3ME
2DS - 2-degree scenario	MAGNET
P - Policy scenario	CAPRI
	IMAGE-GLOBIO (**IMGB**)
	OSeMOSYS (**OSE**)
	SWIM
	MAgPIE (**MPIE**)
	G-RDEM

Table 37. Inventory of policy, technological, social and other assumptions in the thematic models in the baseline and 2-degree scenarios (based on MS17).

Nexus dimension	A) Policy assumptions	B) Technological assumptions	C) Social assumptions	D) Other type
CLIMATE	2DS-OSE- Emission cap introduced for the entire model consistent with the 2DS narrative	B-CAPRI- Impact on crop yields are simulated for the respective climate		
	2DS-MAGNET-Emissions quotas + carbon market considerations for emission permits for in sectors within EU.			
	2DS-CAPRI-The overall mitigation target is distributed among Member States, according to the EU effort sharing agreement, based upon a cost-effective allocation of mitigation efforts.			

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LAND USE	**2DS-MAGNET**-Limitations on (the increase of) agricultural area to simulate land based carbon sequestration			
	2DS-IMGB-Reforestation of degraded forest areas, protection of all forests with carbon storage of >10 tC/ha			
	B-MPIE-Areas for forest plantations for wood production and built-up areas are fixed over time			
	B-MAGNET-extension of protected areas to achieve Aichi target			
ENERGY	**B-E3ME-**Energy demand standards in the US. Renewable energy portfolios in the US. Cafe standards (for transport energy demand). All assumptions are in line with WEO-CPS		**B-MAGNET-**Consumer preference shifts for household energy savings	
	B-E3ME-China (Restriction on fossil fuel share in TPEC)			
	B-E3ME-China (Subsidies for hybrid and electric vehicles)			
	B-E3ME-India-fossil fuel mandate and energy efficiency policy (as per the WEO CSP) implemented as energy demand trends)			
	B-E3ME-Implementing EU-ETS prices as per PRIMES model (also projections until 2050)			
	B-E3ME-Biofuel blending mandate in each EU member state			
	B-E3ME-CO2 emission cap on transport sector is introduced as per PRIMES results.	**B-E3ME-** Introducing alternate fuel vehicles in the model (e.g. EVs)		
	B-E3ME- Fixing electricity generation capacity in countries as per the RES-2020 policy			
	B-E3ME- Effort sharing legislations-emission trajectories for GHG not included in the EU-ETS			

	B-E3ME-Implementing Energy Efficiency Directive (EED) and the Energy Performance of Buildings Directive (EPBD) through, country, sector and fuel specific demand projection in the model			
	2DS-E3ME-Constant carbon pricing from 2012-2050			
	2DS-E3ME-Feed in tariffs and renewable subsidies for RES support			
	2DS-E3ME.High fuel taxes, vehicle taxes based on gCO_2/km rating, phasing out of polluting vehicles			
	2DS-E3ME- Phase out of coal in China, Russia, Ukraine, ASEAM and parts of Latin America			
	2DS-E3ME-South Africa- No new coal after 2020			
	B-MAGNET-Fuel consumption tax to pay for biofuel subsidy.			
FOOD	**B-CAPRI-**different payment schemes, production quotas and market subsidies are implemented to represent the different levels of CAP	**B-IMGB-** Exogenous tech inputs to increase yield (FAO agricultural outlook 2013)		
	B-CAPRI- Commodity balances and price assumptions are made for agri-food markets in the EU or other parts of the world.	**B-IMGB-** Exogenous tech inputs for livestock intensification(FAO ag outlook 2013)		
	B-MAGNET- Removal of production limits to simulate the end of milk and sugar quotas			
WATER		**B-IMGB-** Increase in Irrigation to increase yield (FAO ag outlook 2013)		

Horizon 2020 Societal challenge 5
Climate action, environment, resource
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