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Climate action, environment, resource
Efficiency and raw materials

D1.3: SIM4NEXUS – REVIEW OF THEMATIC MODELS AND THEIR CAPACITY TO ADDRESS THE NEXUS AND POLICY DOMAINS

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Dissemination and uptake

Targeted audience of this report is the general public, stakeholders within and outside the project, the Commission, as this report provides the theoretical background to macro-economic modelling of nexus components, their interlinkages, and a discussion of different kinds of models and their use in policy assessment.
This report will be released on the project website. The deliverable has been written to support the development of the SIM4NEXUS project and is open to all stakeholders, including the case study leaders and researchers contributing to the case studies.

Short Summary of results (<250 words)

This report explores various features of the SIM4NEXUS models, and compares them to the requirements of the case studies and the serious game. There could be challenges in linking the modelling tools due to the different natures of their coverage, for example level of detail in geographical detail or length of forecast horizon. It should also be noted that the project includes both optimisation and simulation models, which have different underlying assumptions that require careful consideration when linking.

There is also some crossover in model capabilities between the different tools available, they allow a comparison between different tools – giving insights into the importance of different assumptions or approaches and allowing some assessment of risk/uncertainty in the model outcomes.

There is a toolbox at disposal from which models with the most appropriate coverage can be selected across the different dimensions assessed. The developers of the serious game, in conjunction with the systems dynamics modelling and the complexity analysis, also have a set of tools that they can draw upon.

Evidence of accomplishment

Report

Glossary / Acronyms

CAPRI	Common Agricultural Policy Regional Impact Analysis
E3ME	Energy-Environment-Economy Macro-Econometric model
ETS	Emissions Trading System
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization of the United Nations
FTT	Future Technology Transformations for the Power sector
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GLOBIO	Global biodiversity model
IMAGE	Integrated Model to Assess the Global Environment
INDCs	Intended Nationally Determined Contributions (UNFCCC)
IPCC	Intergovernmental Panel on Climate Change (WMO/UNEP)
JRC-IES	EC Joint Research Centre - Institute for Environmental Studies
JRC-IPTS	EC Joint Research Centre - Institute for Prospective and Technological Studies
LPJmL	Lund-Potsdam-Jena managed Land
MAGNET	Modular Applied General Equilibrium Tool
MAGPIE	Model of Agricultural Production and its Impact on the Environment
NUTS	Nomenclature of Units for Territorial Statistics
OECD	Organisation for Economic Co-operation and Development
OSeMOSYS	Open Source Energy Modelling System
RCP	Representative Concentration Pathway
SSP	Shared Socio-economic Pathway
SWIM	Soil and Water Integrated Model
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

1.1 Structure of this report

This report reviews the seven thematic models that will be used to address the nexus and its components in SIM4NEXUS. As we shall show, most of the models address at most only one or two of the Nexus components and their interlinkages, which means that the scope for carrying out policy analysis across the whole of the nexus with a single tool is quite limited. We therefore also discuss the potential to link the different models.

Section 2 discusses and compares modelling approaches used for understanding the impacts of sustainability policies, then reviews the SIM4NEXUS Thematic Models and records their strengths and weaknesses in describing the Nexus.

Section 3 identifies how each model can be used to analyse effects of sustainability policies that relate to the nexus. The chapter discusses which policy domains are covered by each of the models in SIM4NEXUS and provides a set of relevant references of previous work under the different policy domains.

Section 4 describes the coverage of the models in terms of geographical coverage, temporal coverage and level of policy detail. It then discusses the underlying model philosophies.

Section 5 summarises how the thematic models could be used in the case studies and the serious game, discusses potential model linkages and interactions, as well as possible areas of improvement by pinpointing to weaknesses that SIM4NEXUS needs to address to improve the existing situation and to go beyond the current state-of-the-art.

2 Nexus-related models and how they are applied

2.1 Overview of models that cover parts of the nexus

There are many different types of quantitative models available. Not all modelling approaches are relevant to the analysis of nexus-related policy (at least not unless they are coupled to another modelling framework) but it is still useful to be aware of the potential options available, for example to guide future development.

Of the types of modelling approaches that are typically used to assess the economic impacts of alternative climate policies and energy strategies, the most widely used models fall under the following categories:

- **Computable General Equilibrium (CGE) models**: Optimisation models founded on neoclassical micro-economic foundations, capturing the interactions of all markets and economic agents. These models are often criticised for their assumption of full employment of resources and a lack of representation of market failures (Dixon & Parmenter, 1996).
- **Partial equilibrium models:** Optimisation models founded on neoclassical micro-economic foundations, which takes into consideration only a part of the market, ceteris paribus, to attain equilibrium, based on restricted range of data.
- **Macro-econometric models**: Econometrically estimated models with a high degree of realism. These models typically do not assume full employment of resources. Their validity can be questioned when the scenario that is being modelled is far away from the experience of their estimation domain (the Lucas Critique).
- **Bottom-up engineering models**: Models that provide a detailed and realistic representation of an isolated sector/part of the system, for example energy or land use. On their own, they lack feedback loops with the rest of the system.
- **Climate models**: Models of the dynamics of the earth's climate system, using a simulation approach. Climate models vary considerably in their degree of complexity but focus exclusively on the planet's natural systems (Hasselmann, 1976).
- **Large-scale Integrated Assessment Models:** Tools that combine the model types described above, including a representation of the climate system. Often the large-scale IAMs combine other distinct tools and linking these tools is a key challenge (Ackerman et. al., 2009).
- **Small-scale Integrated Assessment Models**: Models that integrate different system processes into a unified framework with the aim of optimising outcomes across the whole system. These models have been heavily criticised for their 'reduced form' nature and simplified representation of complex economic structures (Ackerman et. al., 2009, Pindyck, 2013, & Stern, 2013)).
- **Agent-based models**: Models that focus on the interaction of autonomous entities according to rules specified by the modeller. Typically, a stochastic process is applied, and the set of simulation results is analysed to examine the properties that emerge with the greatest frequency. These

models may be used for theoretical analysis, where simulation is the only feasible way of obtaining results; typically, there are challenges in parameterising and validating models in relation to historical experience (Bruch & Atwell, 2013).

- **Bayesian network models**: These models use probabilistic relationships to describe the connections of agents. They are strong in treating uncertainty but poor in considering feedback loops and in providing precise causal relationships (Jensen & Nielsen, 2007).
- **Systems dynamics models:** Models which identify and map the structure of systems, and the feedback interlinkages between elements within them. Computer simulation enables the modelling of behaviour resulting from complex, non-linear feedback relationships within a system.

In most cases the models operate through a scenario-based approach. First a baseline case is defined, usually from an extrapolation of the present situation, and then inputs to the models are adjusted. By comparing the results of the scenarios to the baseline results it is possible to identify the impacts of changing the specific input.

Scenario analyses have been central to the assessments of the potential impacts of climate change on natural and human systems over the past decades – and modelling has been used in the IPCC since at least the second assessment report (IPCC, 1995). The socio-economic and energy system models that are used in the current IPCC literature[1], most of which can address at least some nexus components, predominantly use equilibrium and optimisation approaches, such as cost-benefit analysis, optimal growth, general equilibrium, partial equilibrium and cost-optimisation (see Table 2.1). In contrast, the climate models used in IPCC analysis are simulation models; the distinction between optimisation and simulation is discussed further in Section 4.6.

Table 2.1 Socio-economic models

Cost-benefit analysis (CBA)	Compares potential risks and gains of a decision
Optimal growth	Defines the stable path of a decentralized dynamic economy, where output is Pareto optimal
General equilibrium	Analyses the behavior of supply, demand, and prices in a whole economy to attain equilibrium
Partial equilibrium	Examines the effects of policy action in creating equilibrium only in that particular sector or market which is directly affected
Cost-optimisation	Finding either maximum revenue, or minimum costs, or maximum profits

Whichever modelling approach is used, it is acknowledged that the baseline case can be important in determining the final results from the model. Many recent studies have adopted the Shared Socioeconomic Pathways (SSPs, O'Neill et al, 2014) to use as baselines for specific regions, countries, cities, and sectors. The SSPs were developed by IPCC researchers and are intended to increase

[1] http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml

coherence among studies, particularly those with a strong bottom-up component (i.e. where socio-economic indicators are inputs to, rather than outcomes of, the modelling).

The analysis in SIM4NEXUS will also use the SSPs to provide baseline values for future projections where possible. Box 2.1 presents the SSPs in more detail. Table 2.2 describes data from the SSP library each Sim4Nexus thematic model uses. Further information about the SSPs is available from the database maintained by IIASA[2].

The SSPs should not be confused with the Representative Concentration Pathways (RCPs) that are used by many scientific research and publications. The SSPs present a set of socio-economic characteristics that are intended to be independent of both the impacts of climate change and the impacts of any policy designed to reduce climate change. The RCPs represent different states of the world based on future emissions trajectories and different climate outcomes. Table 2.3 describes the RCPs in more detail.

Although the focus of SIM4NEXUS is not climate change, it is clear (see e.g. Deliverable 1.1) that climate change could intensify pressures across the nexus, for example through reduced crop yields or less reliable rainfall patterns. Although there is considerable uncertainty about how climate change could affect each nexus component, it is anticipated that the RCPs will be used in the project to provide a consistent starting point for assessing potential impacts.

2.2 The models used in SIM4NEXUS

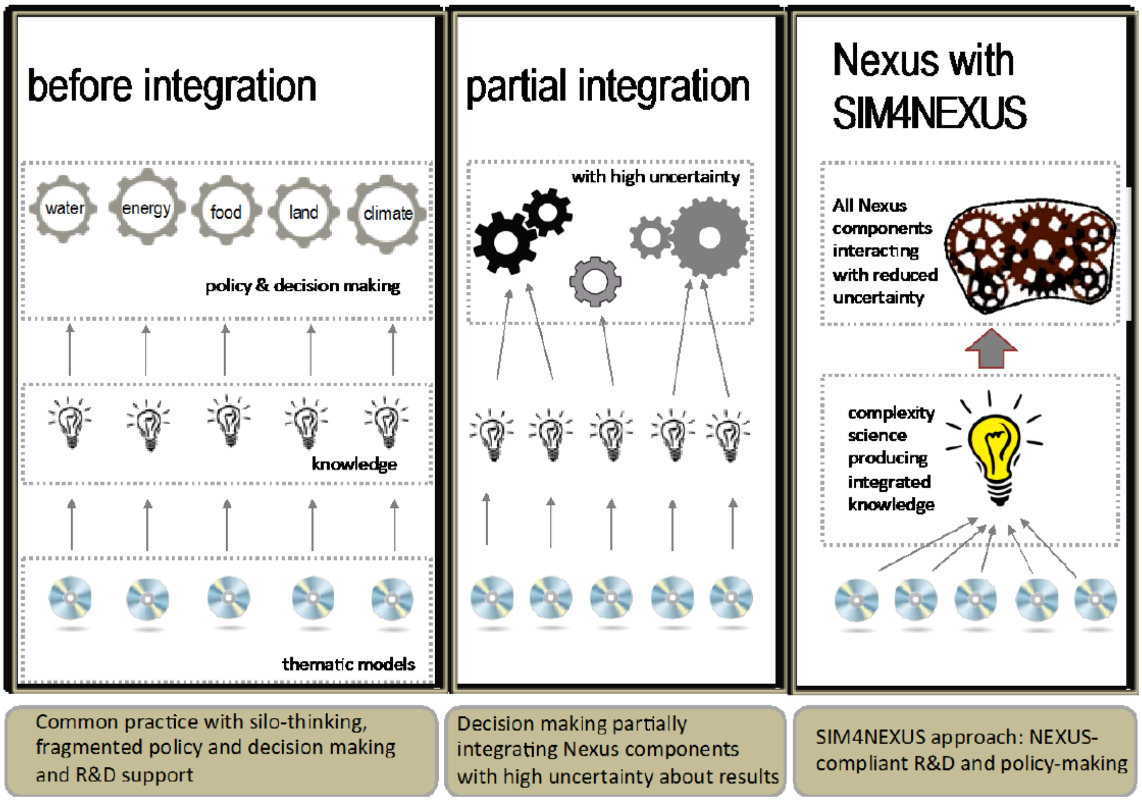
We describe each of the models used in SIM4NEXUS in the following sections. The models are:

- E3ME, linked to FTT
- Magnet
- CAPRI
- IMAGE and GLOBIO
- OSeMOSYS
- SWIM
- MAgPIE-LPJmL

As a means of introduction, Figure 1 presents the SIM4NEXUS framework concept, followed by Table 2.2 which links the SIM4NEXUS to the different elements of the SSPs. The table shows that there is quite a varied coverage of the different linkages across the various models.

[2] http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/SSP_Scenario_Database.html

Figure 1 Sim4Nexus framework concept



Box 1.1 Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs)

Members of the IPCC research community have formed an *International Committee On New Integrated Climate change assessment Scenarios* (ICONICS) to coordinate, amongst other activities, the development of Shared Socio-Economic Pathways (SSPs) that can be used in conjunction with the Representative Concentration Pathways (RCPs) to develop scenarios for use by the research community.

SSPs are intended to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. SSPs are defined as reference pathways describing plausible alternative trends in societies and ecosystems evolution over a century timescale. They assume no climate change or climate impacts, and no new climate policies so can be used to compare outcomes in a policy scenario with outcomes in a reference (no-policy) scenario. They consist of two elements: a narrative storyline and a set of quantified measures of development.

RCPs characterise varying levels of greenhouse gas and aerosol concentrations in the atmosphere as well as changes in land use that can affect the global climate. The four most used RCPs, presented below, are defined by their total radiative forcing (cumulative measure of human emissions of GHGs from all sources expressed in Watts per square metre) pathway and level by 2100. The RCPs were chosen to represent a broad range of climate outcomes, based on a literature review, and are neither forecasts nor policy recommendations.

The framework is built around a matrix that combines climate forcing on one axis (as represented by the Representative Concentration Pathways) and socio-economic conditions on the other. Together, these two axes describe situations in which mitigation, adaptation and residual climate damage can be evaluated. "The matrix architecture of combining SSPs with RCPs into scenarios allows researchers to ask questions such as: 'what could be the impacts of a given amount of climate change in worlds characterized by different development pathways?' (i.e. combining a single RCP with multiple SSPs), or 'what could be the impacts of different levels of climate change under one possible future world?' (i.e. combining a single SSP with multiple RCPs)' (O'Neill, et al 2014). The unpacking of the scenarios into climate, development pathway, and policy provides researchers with a tool kit for asking more policy relevant questions than were possible with earlier scenario sets.

However, SSPs should be seen as hypothetical development pathways that serve as a starting point for developing integrated scenarios of the future, rather than as plausible scenarios themselves

Quantification of several SSP elements uses Integrated Assessment Models (IAMs). Some of the key drivers of social, economic, and environmental change, such as population and gross domestic product (GDP) are globally specified on the country-level. For each SSP a single population and urbanisation scenario is provided. These were developed by the International Institute for Applied Systems Analysis (IIASA) and the National Center for Atmospheric Research (NCAR). For GDP, three alternative interpretations of the SSPs have been developed – by the teams from the Organization for Economic Co-operation and Development (OECD), the International Institute for Applied Systems Analysis (IIASA) and the Potsdam Institute for Climate Impact Research (PIK).

Table 2.2 Elements of SSPs relevant to defining challenges to mitigation and adaptation

Category	Scenario element	Elements present in thematic models as exogenous inputs	as model outputs
Demographics	• Population total and age structure	E3ME, CAPRI MAgPIE: Population total IMAGE	
Economic development	• Global and regional GDP, or trends in productivity	MAGNET CAPRI	E3ME MAGNET
	• Regional, national, and sub-national distribution of GDP, including economic catch-up by developing countries	MAgPIE (GDP, trade) IMAGE	E3ME (national) MAGNET
	• Sectoral structure of national economies, in particular the share of agriculture, and agricultural land productivity		E3ME (national) MAGNET
	• Nature of international trade		E3ME MAGNET
Welfare	• Human development	MAgPIE: Food availability	MAGNET (food)
Environmental and ecological factors	• Soil	SWIM IMAGE (static input)	
	• Fertilisation	SWIM	MAgPIE IMAGE
	• Biodiversity • Floods and droughts		IMAGE GLOBIO
	• Land use, Vegetation	SWIM	
	• Wetlands and irrigation areas	SWIM	MAgPIE (irrigation areas) IMAGE
Resources	• Fossil fuel resources and renewable energy production	E3ME MAGNET CAPRI OSeMOSYS	MAgPIE (bioenergy) OSeMOSYS
	• Livestock production		SWIM MAgPIE IMAGE GLOBIO
	• Other key resources, such as phosphates, fresh water etc.	CAPRI OSeMOSYS	MAGNET OSeMOSYS

Category	Scenario element	Elements present in thematic models as exogenous inputs	as model outputs
Technological development	• Type (e.g. slow, rapid, transformational) and direction (e.g. environmental, efficiency, productivity improving) of technological progress	MAGNET OSeMOSYS MAgPIE: technological development in farming and lifestock husbandry, nitrogen uptake efficiency CAPRI IMAGE	E3ME MAgPIE
	• Diffusion of innovation in particular sectors, e.g. energy supply, distribution and demand, industry, transport, agriculture	OSeMOSYS	E3ME
Broader societal factors	• Attitudes to environment/sustainability/equity and world views	MAGNET IMAGE	
	• Life styles (including diets)	MAGNET IMAGE MAgPIE: Diets & Household food waste	
Policies	• Non-climate policies including development policies, technology policies, urban planning and transportation policies, energy security policies, and environmental policies to protect air, soil and water quality. It is possible that SSPs could be specified partly in terms of policy objectives, such as strong welfare-improving goals, rather than specific policy targets or measures.	MAgPIE: Nature protection policies, land-based climate mitigation policies MAGNET IMAGE -GLOBIO (energy policies, protected areas) E3ME CAPRI OSeMOSYS	MAgPIE: GHG tax rates to reach climate targets

Table 2.3 Most used Representative Concentration Pathways (RCPs)

	Description	IA Model	Publication – IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m2 in 2100	MESSAGE	Riahi et al. (2007) Rao & Riahi (2006)
RCP6	Stabilization without overshoot pathway to 6 W/m2 at stabilization after 2100	AIM	Fujino et al. (2006) Hijioka et al. (2008)
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m2 at stabilization after 2100	GCAM (MiniCAM)	Smith and Wigley (2006) Clarke et al. (2007) Wise et al. (2009)
RCP2.6	Peak in radiative forcing at ~ 3 W/m2 before 2100 and decline	IMAGE	van Vuuren et al. (2006; 2007)

Source: IPCC (http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html)

The models used in the IPCC analysis are designed to map out the feasible possible outcomes based on a set of input assumptions about available technologies over a certain timescale. The tools are designed to show optimal (usually meaning least-cost) outcomes within the range of potential outcomes. While there is a role for this type of analysis in SIM4NEXUS, there is also a requirement for simulation-based analysis, partly to look at the impacts of certain policies but also to feed into the serious game. This issue is discussed further in Section **Error! Reference source not found.**.

The remainder of this chapter introduces the individual models in the project.

2.2.1 E3ME, coupled to FTT

E3ME is a macroeconomic simulation model that is based on post-Keynesian economic principles[3]. It is based on a set of macro-econometric behavioural equations (estimated over time series covering 1970-2015) that are fitted into the standard national accounting framework. The model thus has a strong empirical basis and solves annually out to 2050.

FTT (Future Technology Transformations) is an evolutionary model of technology diffusion, with sufficiently realistic features of consumers that enable the user to simulate the impact of detailed climate policies. It focuses on anticipating the effects of sustainability policies, by integrating behavioural and non-equilibrium complexity science and environmental feedbacks into the analysis (J-F Mercure et al, 2016). E3ME is coupled to FTT models of the power and transport sectors, with additional models covering land, industry and households under development. Policies in the combined framework are assessed on the basis of their ability to effectively achieve certain objectives through the simultaneous use of several policy instruments that interact with one another. This approach is consistent with the one recommended by the European Commission in its Better Regulation guidelines (European Commission, 2015).

Recent applications of E3ME include: inputs to the assessment of the EU's 'Winter Energy Package', the joint IEA/IRENA G20 report on expanding renewable energy[4] and an assessment of the economic and labour market effects of the EU's Energy Roadmap 2050[5]. The full model manual (Cambridge Econometrics, 2014) is available at the model website www.e3me.com

2.2.2 MAGNET

MAGNET is a global computable general equilibrium model with an additional focus on agriculture, it is a tool for analysis of trade, agricultural, climate and bioenergy policies. The MAGNET model has been used in the Agricultural Model Inter comparison Project (AgMIP) (van Lampe et al., 2014),

[3] Post-Keynesian models are demand driven models which are characterised by non-optimisation (full employment of resources is not a necessary result in Post-Keynesian models). Microeconomic theory in the Post-Keynesian tradition is based strongly in behavioural economics.

[4] http://www.irena.org/DocumentDownloads/Publications/Perspectives_for_the_Energy_Transition_2017.pdf

[5] https://ec.europa.eu/energy/sites/ener/files/documents/2013_report_employment_effects_roadmap_2050.pdf

looking at long-term effects of projected climate change on agriculture (Wiebe et al. 2015) as well as the effect on food prices and land use of a significant increase in bio-energy as a climate mitigation option (Banse et al., 2008). The macro-economic contributions of the emerging bio-economy are studied for the EU and The Netherlands by including detailed biofuels, bioenergy, biochemicals sectors and related policies within the model (Bartelings et al., 2016). MAGNET has been used to examine the interplay between the U.N. program to Reduce Emissions from Deforestation and Forest Degradation (REDD) and increased biofuel production from the Renewable Energy Directive (RED) (Dixon et al., 2015). MAGNET is coupled to the integrated assessment model IMAGE (see section 2.2.4), as its agro-economic component.

2.2.3 CAPRI

CAPRI is a global agro-economic model specifically designed for policy impact assessment of EU agricultural, trade and environmental policies. It is a global spatial partial equilibrium model, solved by sequential iteration between supply and market modules. CAPRI has been extensively used to assess agricultural policy measures, GHG emissions from the agricultural sector, food-water-energy linkages and climate change impacts.

Recent applications of CAPRI include: evaluation of the impacts of climate change on EU agriculture; evaluation of the livestock sector's contribution to the EU greenhouse gas emissions; assessment of the effects of EU biofuel policies; analysis of the effects of recent agricultural policy reforms (direct payments harmonisation, greening); assessment of agriculture-water relationships; Evaluation of the impact of recent Agricultural and Trade Policy Reform on Land Use.

2.2.4 IMAGE and GLOBIO

IMAGE is a comprehensive integrated modelling framework of global environmental change, suited to large-scale and long-term assessments of the interactions in the society-biosphere-climate system. (Stehfest et al. 2014). Core themes of the model are the effects of climate change, land-use changes, food and energy production in relation to human population growth and economic development. The agro-economic modelling in IMAGE is done via a coupling to MAGNET (section 2.2.2). For representing vegetation dynamics, crop and grass production, Carbon and Water Cycles, IMAGE has incorporated the LPJmL model (hard link, annual time step of data exchange). For assessing the impacts of global environmental change, IMAGE uses a range of additional models. The GLOBIO model is used to assess the consequences of global environmental change on biodiversity (terrestrial and aquatic), and ecosystem services, and can use input from IMAGE, but also from other models, at a lower resolution. Next to GLOBIO, other impact modules of the IMAGE framework are used in SIM4NEXUS: GLOFRIS, a global model to calculate the risks and effects of river flooding, which makes use of the hydrological model PCR-GLOBWB, the global nutrient model GNM, calculating nutrient flows to groundwater, surface water and coastal zones water quality, and PCLake for lake water quality. IMAGE output is also used in GISMO: global health model focussing on changing health risks under global environmental change. The model has been widely used for global environmental studies such as the Global Environmental Outlooks, Global Biodiversity Outlooks, OECD Environmental Outlooks, and in several other global and European projects (UNEP 2012 & 2007, Secretariat of the Convention on Biological Diversity, 2014 & 2007, OECD 2012).

In principle, most of the nexus components are addressed. A close link has been defined with the agro-economical model MAGNET and the energy demand model TIMER.

2.2.5 OSeMOSYS

OSeMOSYS is a systems cost-optimization model idealised for long-run energy planning. Yet, this modelling tool can flexibly accommodate constraints imposed by other systems, e.g. land use, water availability and climate change. For example, from a land use perspective, the integration can be achieved using different approaches, either by acting over biomass availability or by diversifying its sources.

At global level, the GLUCOSE (UN, 2014; Taliotis et al., 2013) toolkit aimed at exploring climate change and mitigation strategies by exploring the interactions between three modules: the energy sector, land and food production, and material production.

More recently it was used to model the electricity systems of African countries, for the World Bank's study "Enhancing the Climate Resilience of Africa's Infrastructure", in which the water-energy nexus was explored through the analysis of climate change impacts in selected river basins, which were then reflected on the performance of African countries energy generation mix and in cross border electricity trade. Competing uses of shared water resources were studied using Sava River, Syr Darya, and Drina River basins. The competition was represented with an integrated analysis that considered agriculture, energy and ecosystem needs. In these studies, which contributed the UNECE nexus assessment process under the water convention, a generic methodology was developed. That methodology helped reconcile a variety of approaches and tools for the assessment of resources. For example, for the Sava River Basin, included the nexus between climate change, hydropower expansion and water demand for agriculture. Two other nexus projects are currently under development for Nicaragua and Uganda, based on the Climate, Land Use, Energy and Water strategies (CLEWs) framework, under the supervision of UNDESA.

2.2.6 SWIM

SWIM is an eco-hydrological semi-distributed model integrating hydrological processes, crop/ vegetation growth, nutrients and erosion at the river basin and regional scales. The model can be applied for climate and land-use change impact assessment.

SWIM has contributed to many regional and national impact and vulnerability assessments and adaptation frameworks, e.g. within Germany and for the river basins of the Elbe, Danube, Niger, Blue Nile, Rio San Francisco (Brazil), or for the Guanting basin (China).

During the last decade, SWIM was extensively tested in mesoscale and large catchments for hydrological processes (discharge, groundwater), nutrients, extreme events (floods and low flows), crop yield and erosion. Several modules were developed further (wetlands and snow dynamics) or introduced (glaciers, reservoirs, water allocation). The applications are typically regional, for assessing climate and land use change scenario impacts and the development of adaptation strategies within the water nexus. All these applications integrate water resources and biomass production.

2.2.7 MAgPIE-LPJmL

MAgPIE is a global land use allocation model, which is coupled to the grid-based dynamic vegetation model LPJmL. Based on economic conditions, demand for agricultural commodities and food, technological development, land and water constraints, MAgPIE derives specific land use patterns, crop yields and total costs of agricultural production. The objective function of the land use model is to minimize total cost of production for a given amount of regional food and bioenergy demand.

It has contributed to the development of the SSP Scenarios: SSP Database (Shared Socioeconomic Pathways); and to the AgMIP model intercomparison project and to several World Bank reports.

3 Modelling nexus policy domains

3.1 Which models can assess which policy domains?

Chapter 3 identifies how each model can be used to analyse effects of sustainability policies that relate to the nexus. The chapter discusses which policy domains are covered by each of the models in SIM4NEXUS and provides a set of relevant references of previous work under the different policy domains.

3.1.1 Water

The treatment of water in models is very different depending upon whether the model is demand or supply focused. Supply focused hydrological models cover level of rainfall and volume of river discharges, etc. Demand focused models cover volume of water demanded and the price of water.

Which models can assess water policy?

- E3ME does not have a detailed module of water demand or supply. However, an interface exists with which E3ME could be linked to another model that can handle these aspects, and also includes econometric equations for water demand. Economic feedbacks occur through adjustments to input-output coefficients relating to the water supply sector.
- Until now water markets were not included in MAGNET. In 2017, virtual water flows will be integrated within the MAGNET model (including biophysical water flows).
- The water module in CAPRI accounts for agricultural water use all over the EU. Both irrigation and livestock water use are included. The water module enables the CAPRI model to simulate the potential impact of climate change and water availability on agricultural production at the regional level, as well as assessing the sustainable use of water, the implementation of the Water Framework Directive or other water related policies (e.g. water pricing).
- Water is addressed in IMAGE and GLOBIO. IMAGE contains a fully-coupled hydrology model in LPJmL, covering for example irrigation water demand, irrigation water use, run-off and water stress indicators. The water demand from non-agricultural sectors (energy, households, industry) is also calculated and accounted for. Information from the hydrological model is also used to inform the potential for hydropower in the energy system. Aquatic biodiversity (GLOBIO) and water quality (Global Nutrient Model, GNM and PCLake) and flood risks (PCR-GLOBWB, GLOFRIS) are also covered.
- OSeMOSYS allows for the representation of water use by the energy sector, or other sectors included in the model. Although no specific module exists to model hydrological processes, it can be fed with water availability information modelled as storage or technologies for water production.
- SWIM's major modelling outputs are river discharges at the regional and water basin scale. With additional crop yield simulations, it covers large parts of the water and food sectors. Climate is, however, only included on the input side (no feedbacks), and there are a few links into the energy sector through hydropower potential and accidental throttling of thermal power plants. The ability to simulate riverine ecology is still in the research stage and seems rather unreliable due to the high number of involved processes and respective auxiliary data

needs.

- The MAgPIE model includes the interactions between food, water and (bio)energy in the agricultural sector. It covers climate-induced changes in physical blue water availability and water-use, economic water-scarcity indicators, full endogenous interaction between food, water and bioenergy as well as optimisation of resource use.

3.1.2 Energy and Climate

For modelling energy and climate, models differ with regards to whether they are primarily models of the economy, or the environment. The former group is suitable for modelling emission and waste outputs from economic activity. The latter group is suitable for modelling the impact of these outputs on the environment/climate.

Which models can assess energy (and climate) policy?

- E3ME has been designed to handle interactions between the economy and the energy system. Its two-way linkages make it well placed to provide detailed analysis of the macroeconomic impacts of energy policy. The link to FTT allows detailed 'bottom-up' representation of key energy-using sectors. Emissions from energy consumption are also included in the model.
- MAGNET allows for a quantitative analysis of the interaction between climate policies, energy sectors and the economy. MAGNET includes fossil fuels and various renewables (including among others bioelectricity, 2nd generation biofuels) as distinct economic sectors. Greenhouse gas emissions are also included and can be taxed to implement climate policy or used to evaluate the impact of energy policy on the climate.
- The IMAGE model includes a detailed energy and climate model, and is used to explore future mitigation pathways taking into account all relevant emissions and sources. Land-based mitigation via bio-energy, REDD and afforestation are linked to the grid-level vegetation and crop modules of LPJmL. Implications of climate change, land use and land-based mitigation and hydropower on biodiversity and water quality can be analysed via the GLOBIO model and related impact models.
- The OSeMOSYS model primarily uses the energy sector as its entry point, but it is flexible in terms of inputs from other sectors, modelling other sectors, and at providing outputs to other modelling tools. In the case of climate, for example, it can be used for emission accounting, investigate the impact of carbon emission prices, and of emissions' constraints.
- SWIM was specifically developed to investigate climate change impacts at the regional scale, where the impacts are manifested and adaptation measures take place. Regarding climate impacts, SWIM can help assess impacts on hydropower and other water-related energy production (water-dependent cooling of thermal power plants).
- The MAgPIE model includes the interactions between food, water and (bio)energy, as well as several other co-benefits (nutrient pollution, greenhouse gas emissions, climate impacts, etc.) in the agricultural sector. It includes bioenergy production and competition for biophysical resources, full endogenous interaction between food, water and bioenergy as well as optimisation of resource use.

3.1.3 Food and Agriculture

Models capture many aspects of food and agriculture: food demand, policies, supply constraints, security of supply, and linkages to the environment. Aspects covered are diverse across models.

Which models can assess food and agriculture policy?

- E3ME includes macro-econometric equations for food demand at national level. These are currently being expanded to cover a wider range of food types and will be linked to the model of land allocation described below.
- Agricultural policies are treated explicitly in the MAGNET model (e.g. production quotas, intervention prices, (de)coupled payments, second pillar policies). Food and nutrition security indicators are included at the national level.
- Food and agriculture issues are addressed in IMAGE via the link with the agro-economic model MAGNET. The dynamically coupled gridded crop, vegetation, water and land-use modules allow a consistent assessment of the link between crop productivity, irrigation water use, and food, feed, and bio-energy. Links to nutrient loss, water quality and biodiversity are covered by the modules Global Nutrient Model (GNM),PCLake and GLOBIO.
- OSeMOSYS can accommodate the representation of the agriculture sector and its interactions with the energy sector and water, in terms of input requirements, needed to meet a specific crop production demand.
- The SWIM model simulates interlinked processes such as runoff generation, plant and crop growth, nutrient and carbon cycling, and erosion from a natural systems perspective. It provides respective model outputs such as river discharge, crop yield, and nutrient concentrations and loads. The primary driver are weather data, so there are only limited possibilities to assess policy effects. Land use changes or alterations in the agricultural regime (e.g. fertiliser input) have to be explicitly provided as model inputs.
- The MAgPIE model includes the interactions between food, water and (bio)energy in the agricultural sector. It includes processes like: socio-economic dynamics of the food value chain from crop production through processing and animal husbandry up to the consumer, international food availability as food security indicator, food trade, impact of biophysical resources (land, water, nutrients) on the agro-economic system, yield patterns of irrigated and non-irrigated agricultural production, and full endogenous interaction between food, water and bioenergy as well as optimization of resource use.

3.1.4 Land Use and Soil

Technical specifications of land use and soil differ across models, but linkages to sectors in the economy are broadly similar.

Which models can assess land use and soil?

- A land use module is currently under development in E3ME. This is principally being developed to allow for a better assessment of biofuels, with feedbacks to food prices. Land use interactions with energy/climate policy and economic effects have been modelled previously.
- Information from the OECD’s Policy Evaluation Model (PEM) is used to improve the substitution between different land uses in the MAGNET model. A new land supply curve has been introduced to model the expansion of agricultural land. Land use is key in the

assessment of renewable energy, environmental and climate change policies (including indirect land use effects, iLUC).

- The IMAGE model has been used in numerous studies and assessments to explore future land-use dynamics and the implications for climate change and climate change mitigation, biodiversity (via GLOBIO), and ecosystem services.
- In a similar manner as for the water and food systems, land classes can be represented in the OSeMOSYS model as technologies with capacity and activity information, to which costs can be associated. The interaction of the land classes, inputs and outputs, level of disaggregation are case-specific and defined by the analyst.
- SWIM needs detailed land use and soil profile information as model input. The effects of land use changes can be assessed through respective scenarios, but SWIM cannot simulate land use changes on its own. There are pre-processing tools allowing the translation of regional crop frequencies (from agricultural statistics) into a number of spatially explicit crop rotations. Long-term effects on soil fertility through C-content alterations have been studied, but are rather uncertain due to the high number of influential factors.
- The MAgPIE model includes updated quantitative long-term scenarios for global and European land-use and land-use change dynamics and its impact on the agricultural food-water-energy nexus.

3.2 Examples of previous work

Policy priorities to be addressed by the models considering the nexus and components include food security, resource efficiency, low-carbon energy and climate change mitigation, water availability and vulnerability to water stress and floods, water quality, biodiversity and ecosystem services and their interlinkages. Below, references of examples of previous work done with the models are listed.

3.2.1 Water

Burek, P., Mubareka, S., De Roo, A., Bianchi, A., Baranzelli, C., et al. (2012). A multi-criteria optimisation of scenarios for the protection of water resources in Europe support to the EU blueprint to safeguard Europe's waters. http://dx.doi.org/10.2788/55540

SWIM

Conradt, T. (2017) Simulation of natural water availability with the eco-hydrological model SWIM. In: Wechsung, F., S. Kaden, M. Venohr, J. Hofmann, J. Meisel, Z. Xu (eds) Sustainable Water and Agricultural Land Use in the Guanting Basin under Limited Water Resources. Schweizerbart, Stuttgart, pp. 85–105. ISBN: 978-3-510-65325-6

Huang, S., V. Krysanova, F.F. Hattermann (2013) Projection of low flow conditions in Germany under climate change by combining three RCMs and a regional hydrological model. Acta Geophysica 61 (1) 151–193. doi:10.2478/s11600-012-0065-1

Krysanova, V., F. Hattermann, S. Huang, C. Hesse, T. Vetter, S. Liersch, H. Koch, Z.W. Kundzewicz (2015) Modelling climate and land-use change impacts with SWIM: lessons learnt from multiple applications. Hydrological Sciences Journal 60 (4) 606–635. doi:10.1080/02626667.2014.925560

3.2.2 Energy and climate policies

E3ME-FTT

European Commission (2016). Clean Energy For All Europeans. Brussels: European Commission.

European Commission (2014). Impact Assessment Accompanying the Communication "A policy framework for climate and energy in the period from 2020 up to 2030". European Commission, Brussels, SWD(2014) 15 final.

European Commission (2011). Directive of the European Parliament and of the Council on Energy Efficiency and Amending and Subsequently Repealing Directives 2004/8/EC and 2006/32/EC. Brussels: European Commission.

European Commission (2011). Smarter Energy Taxation for the EU: Proposal for a Revision of the Energy Taxation Directive. Brussels: European Commission.

CAPRI

EC (2013). Impact Assessment Accompanying the Communication "An EU Strategy on adaptation to climate change". European Commission, Brussels, SEC(2011) 1153 final/2. http://ec.europa.eu/clima/policies/adaptation/what/docs/swd_2013_132_2_en.pdf

OSeMOSYS

EC funded (ongoing) – H2020 project "Role of technologies in an energy efficient economy – model based analysis policy measures and transformation pathways to a sustainable energy system (REEEM)".

REEEM aims to gain a clear and comprehensive understanding of the system-wide implications of energy strategies in support of transitions to a competitive low-carbon EU energy society, given the objectives and framework outlined in the Strategic Energy Technology Plan. The provisions of the energy services in this society will be defined by their sustainability, affordability, efficiency, energy security and reliability.

MAGNET

BE-BASIC (2010-2014) The Biotechnology based Ecologically Balanced Sustainable Industrial Consortium (BE-BASIC) aims to develop industrial bio-based solutions to build a sustainable society. The MAGNET model is used to assess the macro-economic and food security impacts of a shift towards a bio-based society to 2050.

3.2.3 Food and agriculture

MAGNET

Within the EU FP7 project FoodSecure (grant agreement no. 290693. Project duration: March 2012 - February 2017) an approach is developed to integrate the impact of agricultural, trade, bio-economy and climate policies on various dimensions of food security (food availability, food access, utilisation) by including various households for selected countries within MAGNET. The addition of multiple household types adds a range of food and nutrition security indicators which can be used in combination with all other MAGNET modules including those covering biofuels and nutrition, to identify impacts varying by household type and inform policy interventions.

SUSFANS is an H2020 project (grant no. 633692) which examines EU-wide food policies with respect to their impact on consumer diet and their implications for nutrition and public health in the EU, the environment, the competitiveness of the EU agri-food sectors, and global food and nutrition security.

CAPRI

EC (2013). Medium-term prospects for EU agricultural markets and income 2013-2023. European Commission, Brussels, D.G. Agriculture and Rural Development.

EC (2011). Impact Assessment Accompanying the Communication "Common Agricultural Policy towards 2020". European Commission, Brussels, SEC(2011) 1153 final/2.

SWIM

Conradt, T. (2017) Simulation of natural water availability with the eco-hydrological model SWIM. In: Wechsung, F., S. Kaden, M. Venohr, J. Hofmann, J. Meisel, Z. Xu (eds) Sustainable Water and Agricultural Land Use in the Guanting Basin under Limited Water Resources. Schweizerbart, Stuttgart, pp. 85–105. ISBN: 978-3-510-65325-6

Kollas, C., K.C. Kersebaum, C. Nendel, K. Manevski, C. Müller, T. Palosuo, C.M. Armas-Herrera, N. Beaudoin, M. Bindi, M. Charfeddine, T. Conradt, J. Constantin, J. Eitzinger, F. Ewert, R. Ferrise, T. Gaiser, I. Garcia de Cortazar-Atauri, L. Giglio, P. Hlavinka, H. Hoffmann, M.P. Hoffmann, M. Launay, R. Manderscheid, B. Mary, W. Mirschel, M. Moriondo, J.E. Olesen, I. Öztürk, A. Pacholski, D. Ripocche-Walter, P.P. Roggero, S. Roncossek, R.P. Röttiger, F. Ruget, B. Sharif, M. Trnka, D. Ventrella, K. Waha, M. Wegehenkel, H.-J. Weigel, L. Wu (2015) Crop rotation modelling – a European model intercomparison. European Journal of Agronomy 70 98–111. doi:10.1016/j.eja.2015.06.007

Wechsung, F., F.-W. Gerstengarbe, P. Lasch, A. Lüttger (eds) (2008) Die Ertragsfähigkeit ostdeutscher Ackerflächen unter Klimawandel (The yield potential of East German agricultural plots under climate change). PIK-Report no. 112, Potsdam Institute for Climate Impact Research, Potsdam, 114 pp. URL: https://www.pik-potsdam.de/glowa/pdf/bvvg/pr112.pdf – Last accessed in May 2017

3.2.4 Land use

MAGNET

'Visions of Land Use Transitions in Europe'. VOLANTE aims to develop a new European land management paradigm, providing an integrated conceptual and operational platform which allows policy makers to develop pro-active and context-sensitive solutions to the challenges for the future.

3.2.5 Resource Efficiency

E3ME-FTT

Ex'Tax (2016) New Era, New plan.

European Commission (2014) "Study on modelling of the economic and environmental impacts of raw material consumption ", final report by Cambridge Econometrics and BIO Intelligence Service. Full text.

BIO Intelligence Service, Cambridge Econometrics, LEI and the Institute of Social Ecology (2013). Modelling of Milestones for Achieving Resource Efficiency. *Study Report for the European Commission*, Brussels: DG Environment.

CE, GWS, SERI and WI (2011). Macroeconomic Modelling of Sustainable Development and the Links between the Economy and the Environment. Brussels: DG Environment.

OSeMOSYS

UNECE, 2017. Reconciling resource uses in transboundary basins: assessment of the water-food-energy-ecosystems nexus in the Sava River Basin. Geneva: United Nations.

Nexus assessment of the Sava River basin is located in South Eastern Europe and shared between Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro, carried out under the framework of the UNECE Water Convention's Programme of Work. The study describes the different nexus systems and their governance, and informs on how resources systems are interlinked in the basin. The assessment concludes that the countries in the basin will benefit from the transboundary cooperation in the integrated management of resources. OSeMOSYS was used to provide quantitative insights on the water-energy nexus through the development of a multi-country water-energy model of the countries sharing the Sava River basin.

4 Other key model features

4.1 Introduction

So far, the focus of this report has been the coverage of the models across the nexus and the linkages between nexus components. However, to address the requirements of the project (namely application for the case studies and input to the serious game) we must also consider coverage across several other dimensions. In this section, we describe the coverage of the models in terms of geographical coverage, temporal coverage and level of policy detail. The final section in this chapter discusses the underlying model philosophies to summarise whether the models focus on exploring the available policy space (optimisation models) or look at the impacts of specific policies (simulation models).

4.2 Geographical coverage

The case studies in SIM4NEXUS cover a range of geographical areas including:

- The whole world (global case study)
- Europe (European case study)
- Individual countries (e.g. Latvia case study)
- Subnational areas (e.g. Sardinia case study)

The modelling tools in SIM4NEXUS must thus also be able to provide a range of geographical representations.

The geographical requirements of models also vary across the different parts of the nexus. Table 4.5 illustrates this point and we find that, unsurprisingly, the coverage of the modelling tools is quite consistent with these requirements. The requirements in the tables should not be taken as prescriptive, for example there may be benefits to looking at energy or economy issues at sub-national level, but aggregating beyond these levels could produce misleading results.

Table 4.4 Geographical requirements of the models

Nexus component	Suggested geographical requirements	Reasoning
Energy	National	Statistics are collected at national level. Electricity grids are national.
Water	River basin	Water supply is determined by physical factors.
Food	National	Usually food production and consumption is considered at national level in the data.
Land use	Local area	Land use characteristics vary across local areas.
Economy	National	Statistics and many policies are coordinated nationally.
Climate	Local area	Although it is the global concentrations of GHGs that determine the scale of climate change, impacts are localised.

Different geographical scales can be a major complicating factor in covering the nexus as a whole – whether within a single modelling tool or when linking models. Aggregation of areas may be relatively straight forward in many cases (but not all, e.g. if river basins cross national borders) but disaggregation requires some kind of extrapolation or estimation procedure.

It is not only the geographical scales that is important but the overall coverage of models as well. For example, to carry out a climate assessment requires total global emissions, so a model that only covers part of one country would not be able to contribute very much. However, there are strong trade-offs required and a 'trilemma' of scope of coverage, detail of coverage and the size/complexity of the model. In summary, if a model is global and also has very detailed geographical coverage, it is likely to be large and take a long time to run.

Table 4.6 shows the geographical coverage of the models in SIM4NEXUS.

Table 4.5 Geographical coverage of Thematic Models

SIM4NEXUS Model	Geographical scope	Level of geographical detail
E3ME-FTT	Global	National
MAGNET	Global	National
CAPRI	Global	EU: Sub-national (NUTS2 or grid-based) RoW: National
IMAGE/GLOBIO	Global	Sub-national (grid-based)
OseMOSYS	Selected areas	National (in SIM4NEXUS)
SWIM	Selected areas	River basin, or disaggregation of
MAgPIE-LPJmL	Global	Sub-national (grid-based)

4.3 Temporal coverage

When considering temporal coverage, we must ask the equivalent questions: how far do the models need to go into the future and what level of timestep is required? However, we find that there is a higher degree of consistency between the modelling approaches than was found above for geographical coverage.

The longest timeframe is required in the climate modelling. Climate models typically look ahead at least 50 years into the future and usually longer than that. At the other end of the scale, economic models rarely look beyond 2050; for many economic policies, it is not of interest to look more than a few years ahead. In most cases, annual timesteps would be sufficient to cover the sorts of policy questions that the models are intended to answer but it is noted that events within years may also be of interest, for example floods in water modelling, or short recessions in economic modelling.

We also see the same trade-offs as for geographical coverage. Models that report a long time into the future may not need to generate results for every single year on the way there – and if they do, will probably be generating very large sets of data and increasing their run time.

The key question for SIM4NEXUS is whether these different temporal scales may create issues for assessing the nexus as a whole. For example, if we want to assess the effects of climate on the nexus, this will require all the modelling tools to consider impacts a long way into the future. Questions about different degrees of uncertainty in baselines in the model are likely to arise; for example, by 2050 physical systems may remain relatively stable, but there could be substantial changes in land allocation and a very different looking global economy.

There may be practical issues about linkages between models with e.g. annual and 5-year timesteps but these seem more manageable in comparison.

4.4 Degree of detail

The level of detail in the models refers specifically to the trade-off between breadth and depth that has been discussed in previous sections – but here relates more to the components of the nexus. The trade-off is the reason that models that cover a range of different aspects of the nexus, for example the Integrated Assessment Models used by the IPCC, are formed by linking separate tools, allowing for a more flexible use of the individual models to look at certain aspects in more detail.

This approach can be contrasted with the smaller-scale Integrated Assessment Models that consist of a small number of equations at aggregate level and are used to estimate 'optimal' carbon prices. These tools cover a broad range of issues but in a level of detail that leaves them open to criticism (e.g. Pindyck, 2013).

The issue is also relevant to models that assess a single linkage or area of the nexus. For the types of questions being asked in SIM4NEXUS we require a level of detail that is high enough to provide reassurance that the policy questions are being assessed within a reasonable degree of accuracy but not too much that the tools are unwieldy or overly complex to use. Key issues could be, for example, the number of crop types in a land allocation model, the number of energy technologies in an energy model, or the number of sectors in an economic model.

This type of question can be difficult to judge for a policy maker or modeller that comes from a different subject area, unless we can compare each tool against similar models in the field. In SIM4NEXUS the tools have the advantage of being largely validated already, for example in the references provided in Section **Error! Reference source not found.**. On this basis, we conclude that the level of detail in the models is sufficient for the case studies and activities related to the serious game.

4.5 Model units

It may seem surprising that the model units are described as a key feature, but different units may present major challenges when linking model tools together. Across the nexus, units may include:

- Tonnes (e.g. food consumption, emissions)
- Square kilometres (land use)
- Cubic metres (water consumption)
- GJ, GWh, tonnes of oil equivalent (energy consumption)
- Degrees (temperature change)
- Dollars or euros (anything with economic value)

Within each category there may be many different definitions are well. For example, measures of emissions may be just for CO_2 or all greenhouse gases, they may be energy-only emissions, energy plus process and waste emissions, or may include emissions from land-use change as well.

While these distinctions may be clear to the model operators and researchers in the particular field, they may be alien to researchers in other nexus components. However, misunderstanding the definitions could easily lead to bias in the results from linked models.

The systems dynamics modelling in SIM4NEXUS will play a key role in understanding the linkages. An important feature of systems dynamics models is the relationships between indicators that are expressed in different units. With relation to the serious game in particular, the role of this task is one of ensuring consistency between the different modelling tools that are used.

Finally, there is often a choice of whether to present model results in either physical or monetary units. In some cases this may be a question of presentation only, but the attachment of economic values to physical indicators may be controversial (for example in valuing human health or the natural environment). Using monetary values may imply that false trade-offs are possible, for example that a damaged ecosystem can be restored for a given price, when in the natural world such processes are often irreversible.

4.6 Approach: Optimisation and Simulation

In Chapter **Error! Reference source not found.** we mentioned the current IPCC socio-economic and climate models that contribute to WG3 of the assessment reports. In general, the results from these models must be interpreted as normative (i.e. they seek to identify optimal strategies) rather than something that is likely to happen in reality. The optimisation methodology used in Integrated Assessment Models (IAMs) is very useful from a normative perspective as it helps map out feasibility and identifies desirable future outcomes and configurations of the economy-nexus components-technology solutions. However, such models support only certain steps in the policy cycle. In order to effectively inform policy-making, it is crucial to differentiate normative (i.e. “tell me what are the components are and I will tell you the best way to organise the system”) from positive (i.e. “tell me the context and I will predict what people will choose”) modelling methods.

The normative models typically rely on a society minimising total costs or maximising aggregate utility and implicitly assuming a unique stable economic equilibrium. These long-term outcomes help to understand the available policy space, but for policy makers can disregard critical aspects of reality such as unemployment and market disequilibria. For example, an economy in constant equilibrium, in permanent optimal state would not plan for or incentivise technological change – which may be the focus of sustainability policies.

It should be noted that the distinction of optimisation and simulation applies only to models that have a behavioural component – for purely natural systems models (e.g. climate or hydrological models), only a simulation approach makes sense. However, the situation can become somewhat confused by mainstream neoclassical economics, which relies on assumptions about optimising behaviour in order to link micro level decisions to the broader macro picture. However, the models that rely on equilibrium and optimisation principles miss the insights of behavioural science (now widely acknowledged from the work of Kahneman, 2012). More generally, it is acknowledged that the two different approaches are designed to answer different questions and using the wrong type of model could lead to misleading outcomes; a simulation model could never find the optimal outcome unless it assessed every single policy/technology combination, which is not possible in anything but the simplest model. Likewise, if an optimisation model is used in a simulation exercise then the behavioural assumptions it is based on become a feature of the results, suggesting unrealistic responses.

The issues are discussed more broadly in Mercure et al (2016), with a strong focus on technology development (see also European Commission, 2017). The links between micro and macro levels can also come under close scrutiny (e.g. Kirman, 1992; King, 2014) as the assumptions required to solve the optimisation routines in neoclassical models impose homogeneity on agents while the post-Keyensian macro-econometric models focus on the macro level only. New approaches (including the FTT model in SIM4NEXUS) attempt to bridge this gap and it is also where the complexity modelling, that will assess emergent properties from the interactions of individual agents, will play a role in the project.

For the formal modelling exercises with the tools we have available in SIM4NEXUS we must consider which approach is the most suitable. Requirements are likely to be different for the case studies and the serious game:

- The case studies will likely require a combination of both approaches. It is certainly useful to assess the available policy space and the range of possible outcomes that could affect the nexus in each of the case study regions. It will also likely be of use to be able to assess individual policies that could address the issues that have been highlighted.
- The serious game will likely draw heavily on simulation models, as its own simulation-based nature hints at. The aim of the game will be to determine the responses across the nexus to various inputs, playing to the strengths of the simulation tools. This is not to discount that there may be some role for optimisation approaches, for example in determining how close outcomes are to the best possible options.

The models in SIM4NEXUS cover a range of approaches, encompassing both optimisation and simulation methods. In some cases there may be combinations of methods. Table XX summarises the models in the project.

Table 4.6 Typology of the Thematic Models

SIM4NEXUS Model	Approach	Micro-macro links
E3ME-FTT	Simulation	FTT provides a micro component to E3ME
MAGNET	System level simulation with optimising agents	Macro-economic changes provide signals for micro-level agents which are represented in aggregate
CAPRI	System level simulation with optimising agents	Exogenous macro-economic drivers
IMAGE/GLOBIO	Mixed approach[6]	
OseMOSYS	Optimisation	Least cost investment and power plant

[6] see IMAGE documentation Stehfest et al. 2014

		dispatch decisions
SWIM	Simulation	No direct economic links
MAgPIE-LPJmL	mixed approach MAgPIE optimisation, LPJmL simulation	Partial equilibrium model with linkage to the energy-macroeconomy-climate model REMIND

5 Conclusions

The table below summarises the thematic models used in the Sim4Nexus project, discusses their typology, which nexus components they cover.

Table 5.1 Nexus components covered by the models

Model feature	E3ME-FTT	MAGNET	CAPRI	IMAGE and GLOBIO	OSeMOSYS	SWIM	MAgPIE-LPJmL
Model type	Global macro-econometric energy, environment and economy model	CGE model with a focus on bio-economy and food security	Global agro-economic model with regionalized EU detail	Global integrated assessment model	Global energy modelling system	Eco-hydrological model	Global socio-economic model of the agro-food system and the environment
Main topics	Economy, Energy and climate policies	Trade, agricultural and bioenergy policies, climate impacts	Agricultural, trade, bioenergy and water policies, climate impacts	Sustainability, climate change, land use, hydrology, biodiversity, ecosystem services	Energy efficiency, climate change, mitigation strategies; technology transition	Sustainable water and land use management, climate change impacts	Land-use change
Nexus components	Energy, land, economy, climate	Food, land, economy, energy, climate	Food, water, bioenergy, environment, climate	Environment, biodiversity, land, water quantity and quality, energy	Energy, land, climate, water, materials	Water, food, land, climate, (energy)	Food, land, water, bioenergy, environment, climate
Geographic coverage	Global	Global	Global	Global	Flexible: regional, national, continental, global	Several river basins around the world	Global
Application to case studies	national regional European transboundary global	national regional European global	national regional European transboundary global	national regional European global	national global	transboundary	European global
Connection between models	-	CAPRI, IMAGE	MAGNET, SWIM	MAGNET	-	CAPRI, MAgPIE-LPJmL	SWIM

Model feature	E3ME-FTT	MAGNET	CAPRI	IMAGE and GLOBIO	OSeMOSYS	SWIM	MAgPIE-LPJmL
Key gaps in addressing the nexus	Food, water	Water	Water, land	Food (via link with MAGNET)	-	Land, energy	-

Table 5.2 Nexus components interlinkages covered by the models

Model linkages	E3ME-FTT	MAGNET	CAPRI	IMAGE	GLOBIO	OSeMOSYS	SWIM	MAgPIE-LPJmL
Climate to Water	-	-	Covered but only agricultural water use	Climate effect on crops, and on irrigation water demand, and on run-off, water availability	Covered. Climate effects on water temperature, water quality, algal blooms, water flow deviation and biodiversity.	-	Direct runoff effects of weather time series (also climate scenario realisation) are calculated on a daily basis.	Climate effect on rainfed crop yields as well as irrigation water availability and irrigation requirements
Land-use to Water	-	-	-	Land-use effect on evapotranspiration and run-off, area of irrigated cropland affects water use and run-off.	Covered. Land-use effects on wetland area, water quality, algal blooms, water flow deviation and aquatic biodiversity/ ecosystem state.	Covered but with no simulation of the hydrological cycle, resource flow impacts	Discharge effects of different land use map inputs can be assessed	Expansion of irrigated areas and crop types on water usage
Energy to Water	Coefficients to estimate water consumption by the power sector, split by generating technology.	-	-	Water demand (withdrawal and consumption) for cooling, also water demand from household and industry is covered. Water is extracted from the hydrological model LPJmL which is internally coupled to IMAGE.	Covered. Effect of hydropower on aquatic biodiversity.	Covered but with no simulation of the hydrological cycle, resource flow impacts	-	-
Food to Water	-	-	Covered	Irrigation water demand for food production, and also livestock water demand accounted for.	Covered. Effects of food production on wetland area, water quality, algal blooms and aquatic biodiversity	Covered but with no simulation of the hydrological cycle, resource flow impacts	-	covered via land-use to water
Climate	-	Climate affects	-	Heating and cooling energy	-	Covered	Only regarding	Climate change

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Model linkages	E3ME-FTT	MAGNET	CAPRI	IMAGE	GLOBIO	OSeMOSYS	SWIM	MAgPIE-LPJmL
to Energy		land productivity for bio-energy		demand is affected by climate change			hydropower and throttling of thermal PP	mitigation increases bioenergy production; climate impacts change bioenergy yields
Land-use to Energy	-	Bio-energy crops compete with other agricultural activities for land	-	Covered in a very simple way, energy demand of agricultural operations, and energy demand for pumping irrigation water is included.	-	Covered	Only regarding hydropower and throttling of thermal PP	Bioenergy potential for energetic use
Water to Energy	-	-	-	Covered in a new version (not yet in current baseline). Runoff, elevation and other parameters are used to determine the potential for hydropower	-	Covered	-	Via crop yields and water availability on bioenergy potential
Food to Energy	Covered in a fairly basic way, in terms of the food sector demanding energy.	Bio-energy crops compete with other agricultural activities for land	Covered	Not covered. Energy demand of food processing not covered. Energy demand of agriculture (ploughing etc.) is covered, see above " land-use to energy".	-	Covered	-	Competition between food and bioenergy
Water to Climate	-	-	-	-	C uptake and emissions by water systems planned, but not in current version.	-	-	
Land-use to Climate	The land use model in E3ME is under development. It will be linked to a climate model (see below)	Land can be allocated to agriculture or forests to be used as a carbon sink	-	Land-use change CO2 emissions, and CH4 and N2O emissions from agriculture affect climate	-	Covered	-	Greenhouse gas emissions from land uses and landuse change (CO2, N2O, CH4)
Energy to Climate	E3ME can be linked to a climate model to give a full range of physical impacts.	GHG emissions from energy production and consumption	-	GHG emissions from energy system affect climate	-	Covered	-	bioenergy<
Food to Climate	-	Via energy and land demand for food production.	Covered	-	-	-	-	covered via land-use to climate
Climate	-	Climate change	Covered	Covers the effect of climate	-	-	Crop yields are	food price impacts

Model linkages	E3ME-FTT	MAGNET	CAPRI	IMAGE	GLOBIO	OSeMOSYS	SWIM	MAgPIE-LPJmL
to Food		affects land productivity		change on agricultural production, and thus on food production			calculated annually and this allows respective climate scenario simulations	of climate change
Land-use to Food	FTT:Agriculture will provide this link in E3ME in the future.	Land is an input in food production	-	Land use affects food production directly. Process of land degradation on agricultural productivity and food not covered.	Effects of and degradation planned, but not in current version.	Covered	Crop yields are calculated annually and this allows respective climate scenario simulations through altered maps	various, e.g. forest protection or crop rotations on food prices
Energy to Food	-	Energy is an input in food production and bio-energy crops compete with food crops for land	-	Demand for bio-energy competes with agricultural production of food crops and livestock, and thus affects the food system.	-	Covered	-	Competition between food and bioenergy
Water to Food	-		Covered	water availability affect irrigated crop production, and thus also food.	Effects of floods and droughts on food production.	Covered	-	water availability influence food prices
Climate to Land-use	FTT:Agriculture will provide this link in E3ME in the future, although only fully endogenously if connected to a climate model.	Climate change affects land productivity which may changes land allocation among agricultural activities		Climate change affects crop yields, and crop yields affect the pattern of land use change, and also total agricultural production.	Climate effect on land-use allocation and biodiversity.	Covered, not the impacts on land use change, desertification etc. but rather how emission limits can affect land allocation	-	changed yields will influence optimal land use patterns
Water to Land-use	-	-	-	Water availability is taken into account in the expansion and allocation of irrigated areas.	Effects of floods and droughts on land-use.	-	-	changed water availability will change optimal landuse patterns
Energy to Land-use	Will be provided in future through FTT:Agriculture.	Bio-energy crops compete with other agricultural activities for land	-	Demand for energy, namely in the form of bio-energy, affects land use. Higher energy prices also lead to higher prices of fertilizer, and thus lead to	-	Covered, not the impacts on land use change, desertification etc. but rather how	-	deforestation and intensification due to bioenergy plantations

Model linkages	E3ME-FTT	MAGNET	CAPRI	IMAGE	GLOBIO	OSeMOSYS	SWIM	MAgPIE-LPJmL
				slightly lower fertilizer input.		energy production can affect land allocation		
Food to Land-use	The food equations that are currently under development in E3ME will provide a detailed coverage of this link.	Agricultural activities compete for land.	-	Demand for food products affects land use.	Land-use allocation and biodiversity.	Covered, not the impacts on land use change, desertification etc. but rather how food production can affect land allocation	-	deforestation and intensification due to rising food demand (population and income growth)

5.1 The thematic models and their application in the case studies

This issue is discussed in much more detail in Deliverable 3.1 in the project and so we only touch on it briefly here. From our analysis, it appears that all the models in SIM4NEXUS will play a role in one or more of the case studies. The case study leaders will need to make appropriate choices based on their geographical requirements and components of the nexus on which they wish to focus.

More generally there are questions to the leaders of the case studies about whether they wish to explore the policy space in their area more generally (likely drawing on the optimisation models in the group) or wish to assess individual policies – and if so which ones. As an early step in Work Package 3 in the project, this should allow more concrete recommendations for which tools are the most suitable to use in the case studies.

5.2 The thematic models and their application in the serious game

This section summarises how the thematic models could be used in the serious game, discussing potential model linkages and interactions, as well as possible areas of improvement. Some of the findings are also relevant to the case studies and will be picked up on in Work Package 3.

The section is split into two parts, the fist looking in particular, at the model coverage of the nexus components, data-related issues with respect to the models' baseline, input and outputs and the level of harmonisation between these. It will also briefly discuss how the different model structures affect scenario design and how this might impact on the serious game. The second part of this section will focus in more detail on the policy-making dimension of the serious game and how this is reflected in the structure of the different thematic models.

5.2.1 Nexus components and the thematic models

As we have seen from the chapters above, different thematic model cover different nexus components, and while there is some overlap between the areas covered by different models, there is no thematic model that covers all nexus components. This means that for the serious games, inputs from different models need to be used in order to get a full picture of nexus policy domain interactions and impacts. However, this approach raises several issues, from data harmonisation to interpreting and implementing a specific policy in the modelling framework, to potential contradictory model results.

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The type and structure of a thematic model determines what the model inputs and outputs are and how the baseline and scenarios are modelled. While for the cases studies it was agreed to use the SSP pathways to align model baselines and scenarios, because each model is different in structure this means that the SSP information may be interpreted differently by the thematic model, and this may lead for to discrepancies in scenario design and model results. For example, the SSP pathways provide assumptions on GDP and economic structure (among other variables) and IAM-based data on energy use and supply, land-use, emissions and climate change. While some thematic models would take the GDP and economic structure assumptions as inputs in their modelling framework (e.g. CAPRI, OSeMOSYS), for other such assumptions are model outputs (e.g. for E3ME GDP is a model output and changes based on policies implemented). This may lead to inconsistencies between model results within a specific case study. To follow up on the GDP example above, if the purpose of a policy scenarios is to achieve a certain emission reduction, some models would only need to revise their assumption an GDP growth and economic structure until the emission reduction is met. Other model would need to introduce a mix of polices to achieve a similar emission reduction result, but this may also result in a different GDP pathway (and economic structure), that may not be consistent with the assumption used by the other models. In the context of the serious game, a decision would have to be made with regards to which GDP numbers are given to the policy-maker.

The situation outlined above also highlights an area for potential improvement: model linking. The linking of models used within the case studies would partly resolve the problem of inconsistency between different model outputs and would offer a more cohesive story to the policy maker, even if it is only done at a very aggregate level. Results from one thematic model (e.g. GDP) can be fed through other thematic models that use them as inputs, creating a more consistent story. As noted in various places in this report, there will be challenges in the linking as well. It is the tasks of the systems dynamics modelling and complexity analysis to ensure that this is carried out successfully.

5.2.2 The serious game, policy-making and the thematic model application

The main purpose of the serious game is to provide detailed information of different policies to the relevant actor. As such, the main focus of the modelling going behind the serious game is on relevant policies and policy interactions. This implies that the focus of the modelling is based more on a simulation approach., e.g. estimate what the impact could be given the existing context. This means that the outcome of such an analysis may not reflect the most cost-efficient or optimal way to achieve a target, as it would be the case with an optimisation approach.

To be more specific, optimisation models are constructed with an objective function in mind (e.g. to, minimize cost, maximize welfare) and a set of constraints that reflect the physical environment (e.g. resource availability) and other requirements. Their results are driven by their cost assumptions (e.g. How much does it cost to build this plant? What is the cost of fuel?) and give us the cheapest option available. Optimisation models offer us information on the optimal solution but not on the path to achieve it. For the purpose of the serious game it is the ‘How?’ that needs to be answered, i.e. the policy choices are the most relevant. For this reason, simulation models are more suited to provide the relevant information for the serious game. Nevertheless, a role for optimisation models should not be ruled out, e.g. in judging the outcomes from the game in relation to the best possible approach. There is a combination of optimisation / simulation models used in this project, so for its purposes all linkages are covered.

5.3 Summary of findings

This report has explored various features of the models that are available in SIM4NEXUS, and compared them to the requirements of the case studies and the serious game (see above sections). Overall, we have found a diverse range of tools that, between them, cover the different nexus components but, in many cases, may need to be linked in order to adequately cover the linkages.

It is acknowledged that there could be challenges in linking the tools due to the different natures of their coverage, for example level of detail in geographical detail or length of forecast horizon, and this will be a key challenge moving ahead in the project. It should also be noted that the project includes both optimisation and simulation models that have very different underlying assumptions that require careful consideration when linking.

There is also some crossover in model capabilities between the different tools available. These overlaps are not necessarily bad things, as they allow a comparison between different tools – giving insights into the importance of different assumptions or approaches and allowing some assessment of risk/uncertainty in the model outcomes. This approach of comparing model results is now standard in many policy applications in Europe (e.g. European Commission, 2015).

Overall, however, the message for moving ahead in the project is a positive one. The leaders of the case studies have a toolbox at their disposal from which they can select models with the most appropriate coverage across the different dimensions we have assessed. The developers of the serious game, in conjunction with the systems dynamics modelling and the complexity analysis, also have a set of tools that they can draw upon.

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