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

D3.1: REPORT ON THE "FIRST RUN" SIMULATION RESULTS OF THE THEMATIC MODELS: IDENTIFYING THE GAPS

LEAD AUTHOR: Maria Blanco

OTHER AUTHORS: Pilar Martínez, Hector Pollitt, Eva Alexandri, Hans Van Meijl, Jason Levin-Koopman, Elke Stehfest, Jan Janse, Georgios Avgerinopoulos, Tobias Conradt, Benjamin Bodirsky

DATE: 31 May 2017

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

PROJECT	Sustainable Integrated Management FOR the NEXUS of water-land-food-energy-climate for a resource-efficient Europe (SIM4NEXUS)
PROJECT NUMBER	689150
TYPE OF FUNDING	RIA
DELIVERABLE	D 3.1 Report on the "first run" simulation results of the thematic models: Identifying the gaps
WP NAME/WP NUMBER	Thematic Models and Integration / WP3
TASK	Task 3.1
VERSION	2
DISSEMINATION LEVEL	Public
DATE	20/11/2017 (Date of revised version) – 31/05/2017 (Due date)
LEAD BENEFICIARY	UPM
RESPONSIBLE AUTHOR	Maria Blanco
ESTIMATED WORK EFFORT	9 person-months
AUTHOR(S)	Maria Blanco (UPM), Pilar Martínez (UPM), Hector Pollitt, Eva Alexandri (CE), Hans Van Meijl (WUR-LEI), Jason Levin-Koopman (WUR-LEI), Elke Stehfest (PBL), Jan Janse (PBL), Georgios Avgerinopoulos (KTH), Tobias Conradt (PIK), Benjamin Bodirsky (PIK)
ESTIMATED WORK EFFORT FOR EACH CONTRIBUTOR	UPM: 4 person-months; all others: 1 person-month
INTERNAL REVIEWER	Claudia Teutschbein (UU), Daina Indriksone (BEF), Ingrīda Brēmere (BEF)

DOCUMENT HISTORY

VERSION	INITIALS/NAME	DATE	COMMENTS-DESCRIPTION OF ACTIONS
1	MARIA BLANCO	12/05/2017	DRAFT VERSION FOR REVIEW
2	MARIA BLANCO	28/05/2017	SECOND DRAFT, REVISED ACCORDING TO COMMENTS BY REVIEWERS
3	MARIA BLANCO	15/06/2017	FINAL REPORT TO SIM4NEXUS PROJECT LEAD
4	MARIA BLANCO	20/11/2017	FINAL REPORT UPDATED ACCORDING TO 1ST YEAR REVIEW RECOMMENDATIONS

Version 4 of the report follows from the comments of the project reviewers, received on 12 October 2017. The table below illustrates how the comments have been addressed.

Review comments 12/10/2017	Adjustments in report
The translation of SSPs into each model would deserve some clarification. This is key to the modelling exercises and credibility of the analyses.	New Section 3.3.2 provides additional explanation on the way the SSPs are translated into each thematic model. Some further details for each model are provided.
The Core Report mentions the use of RCP8.5 in the case of Sardinia. It would be useful to explain the reasons behind this choice (quite extreme scenario), and if RCP8.5 will be used for all case studies.	The scenario RCP8.5 has been used in the case of Sardinia only for illustration purposes. Using scenario results for RCP8.5 (available from previous research) facilitated the development of the SDM in the fast track case study. Nevertheless, since it is not planned to use this scenario in all case studies, it is not mentioned in D3.1.
It would be useful to explain how the data gathered in WP1 and 2 were used in this analysis, and if not, how they will be used in future work.	In Section 2.2, we clarify that data gathered in WP1 has helped to select the thematic models for each case study. Data gathered in WP2 will be used in the following reporting period to identify policy scenarios.
Were some models coupled? Are such couplings expected in future work?	Section 3.3.1 explains that the thematic models are run independently and the integration of outputs from different thematic models is done through the SDM.
Any issues with scaling? For example, the application of E3ME to Andalusia and Southwest UK would deserve clarification since E3ME is available at national level.	As explained in Section 4.3.2, downscaling is used to apply the E2ME model to regional case studies. Regional data is used to downscale national results.
It would also be interesting to better understand how the selection of the models used in each case study was done (how did the stakeholders select a model? what did they understand/know about the models? etc.). Certainly good lessons learned here. It seems that not all model teams have contributed 1st run results.	Further details on the way the models were selected are provided in Section 2.2.

Some minor editing changes are also made throughout the report.

Table of Contents

Figures

Tables

Executive summary

The primary objective of the Deliverable is to report on the first application of the thematic models to selected case studies. The thematic models are applied both to support nexus-compliant decision making in the case studies and as an input for the development of complexity methodologies. This Deliverable summarises the work undertaken during the first year of the project. First, we describe the process undergone to select the suitable thematic models to be applied in each case study. Next, we define the setup of the simulation exercise, particularly the baseline scenario chosen for the preliminary run of the models. Finally, we report on the simulations done with each thematic model.

Changes with respect to the DoA

Not applicable.

Dissemination and uptake

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 presents the first application of the thematic models to the case studies. The thematic models are applied both to support nexus-compliant decision making in the case studies and as an input for the development of complexity methodologies. During the first year of the project, the suitable thematic models to be applied in each case study have been selected, the baseline scenario has been agreed and preliminary results have been provided. This report provides valuable information to guide the modelling work in each case study.

Evidence of accomplishment

Submission of report.

Glossary / Acronyms

TERM	EXPLANATION/MEANING
AGMIP	The Agricultural Model Intercomparison and Improvement Project
CAPRI	Common Agricultural Policy Regional Impact Analysis
CORINE	Coordination of Information on the Environment
E3ME	Energy-Environment-Economy macro-econometric model
ETS	Emissions Trading System
FADN	Farm Accounting 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
GTAP	Global Trade Analysis Project
IAM	Integrated Assessment Modelling
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change (WMO/UNEP)
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
SDM	System Dynamics Modelling
SRES	Special Report on Emissions Scenarios
SSP	Shared Socio-economic Pathway
SWIM	Soil and Water Integrated Model

1 Introduction

The objective of this Deliverable is to report on the first application of the thematic models to the 12 case studies in SIM4NEXUS. The thematic models are applied both to support nexus-compliant decision making and to serve as an input for the development of complexity methodologies. The application of the thematic models is carried out in close interaction with Task 5.2. During the first year of the project, the following activities have been carried out:

a) Selection and adaptation of the suitable thematic models for each simulation scenario and case study.

b) Preliminary use of the thematic models in order to identify the gaps in assessing the Nexus for the case studies. This activity involves running the thematic models for the case studies, separately, based on general requests and guidelines implied by WP5. It will act as a means for identifying existing gaps in the Nexus representation, using existing and established thematic models and the expertise of the partners involved with these models. The outputs from this task are being used for the development of the complexity models in Task 3.4, especially regarding their structure and components.

The report is organised as follows. First, we present an overview of the available thematic models as well as the process to select the suitable thematic models to be applied to each case study. Next, we describe the setup of the first run of the models, with an emphasis on the selection of the baseline scenario. The following sections present the main features of each thematic model as well as the first application to selected case studies. Finally, the last section discusses some of the challenges to model the Nexus with the thematic models.

2 Mapping of models to case studies

2.1 Pool of thematic models in SIM4NEXUS

Seven thematic models are available in SIM4NEXUS. They are well-known, existing thematic models that will provide detailed outputs for specific aspects of the Nexus. The set includes operational climate-energy-economic-water and land-use models, with most of them considering the interdependencies of only a few sectors and no single one taking into account all five components of the Nexus. The main features of the thematic models are presented in Table 1.

The application of these models to the case studies supports nexus-compliant decision making and provides information for the development of complexity methodologies. The advantage of complexity science methodologies is that they can integrate the results of other models and data sources to develop a Nexus simulation capable of addressing the complex interactions between the components in the Nexus in each case study.

Table 1. Pool of thematic models in SIM4NEXUS

Model feature	E3ME-FTT	MAGNET	CAPRI	IMAGE-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	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	Long-term scenarios of agriculture and the environment (land, water, climate, nitrogen)
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, land, climate	Food, land, water, bioenergy, environment climate
Geographic coverage	Global	Global	Global	Global	Global	Several river basins in Europe	Global
Spatial resolution within EU	National	National	National and regional (NUTS2)	Detailed grids	River basin, national, international	River sub-basins (100–1000 km²)	Detailed grids
Application to case studies	Global, European and national	Global, European and national	Global, European, national and regional	Global and European	Global and European	Regional and transboundary	Global and European
Time step	Annual	2030, 2050 (flexible)	Flexible, until 2030/ 2050	Annual	Annual (and sub-annual)	Daily with arbitrary aggregations	5-year steps
Time frame	Until 2050	Flexible, until 2050	Until 2050	Until 2100	Until 2050	Until 2050	Until 2100
Partner	CE, RU	WUR-LEI	UPM	PBL	KTH	PIK	PIK

2.2 Selection of the suitable thematic models for each case study

To achieve a detailed understanding of the scientific interrelationships between the Nexus components, 12 case studies will be analysed, representing different spatial scales (regional, national, continental and global). SIM4NEXUS comprises three regional case studies (Andalusia, Sardinia and Southwest of the UK), five national (The Netherlands, Sweden, Greece, Latvia and Azerbaijan), two transboundary (France-Germany and Germany-Czech Republic-Slovakia), one continental (European) and one global case study.

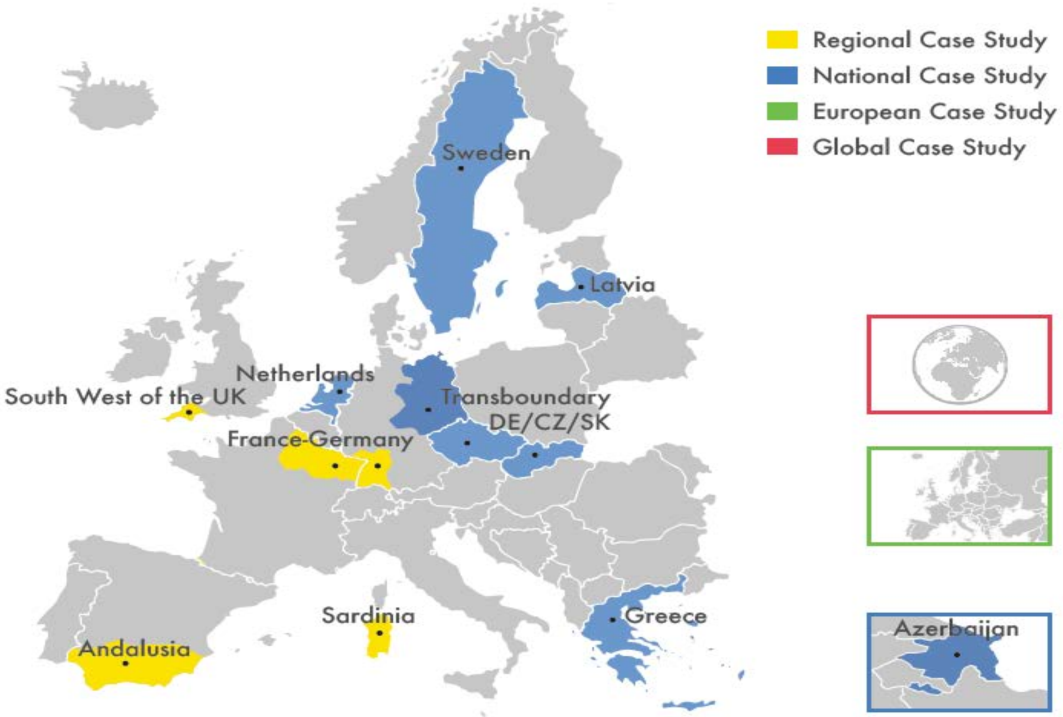


Figure 1: Case studies in SIM4NEXUS

Two or more thematic models will be applied to each case study, depending on suitability as well as the main Nexus components to be analysed. The selection of the thematic models to be applied to each case study followed a participatory and iterative process:

- The case studies as well as the thematic models were presented during the kick-off meeting (July 2016). Each case study prepared a poster to outline the Nexus challenges and the policy goals they had drafted during the first weeks of the project. This was the start of interaction between the case studies and the thematic models. The partners who are responsible for the thematic models discussed the capabilities of the models to partly cover the ambitions of each case study.

- A review of the thematic models was developed, giving an overview of each model as well as its coverage of Nexus components. The review report was made available in ProjectPlace in October 2016: -> documents -> WP3 -> Task 3.3 Thematic Models.
- The thematic models were presented and discussed during a tailored workshop in Barcelona (16-17 November 2016). The coverage of each of the thematic models was presented and first conclusions were made in how far the thematic models are able to cover the requirements of each case study. The presentations of the thematic models were made available at ProjectPlace -> documents -> WP5 -> 201611 Workshop in Barcelona -> Presentations.
- Factsheets of the seven thematic models were developed. The factsheets present the model, its spatial and temporal coverage, Nexus coverage, as well as key input and output variables. The contacts of those responsible for each model are included as well. The factsheets are also available in ProjectPlace since December 2016: -> documents -> WP3 -> Task 3.3 Thematic Models -> Model factsheets.
- Case study leaders use the review report, the model factsheets, and the presentations from the Barcelona workshop, to identify suitable outputs and corresponding models.
- Case study leaders contact directly the model developers to explore the applicability of each thematic model to address Nexus components in their case study. Bilateral or group meetings are organized when needed to discuss model outputs.

As a result, each case study selected the suitable thematic models for the first scenario run (Milestone MS31, February 2017). Meanwhile, WP5 together with WP3 developed a note to guide the use of thematic models in the case studies (February 2017). Also, the leads of WP5 had regular Skype sessions with the case study leads and the selection of thematic models was on the agenda in several rounds. Table 2 shows the selection of the thematic models that will be applied to each case study as agreed during the third project meeting (Trebon, June 2017).

Progress in other work-packages has been beneficial to reach agreement. More specifically, D1.1 (Scientific inventory on the NEXUS) was important to address the Nexus challenges in each case study, while D1.3 (A review of thematic models and their capacity to address the Nexus and policy domains – Key Gaps) was important in reaching agreement for the selection of thematic models.

Moreover, the case study leaders are presenting the thematic models that will be used to the stakeholders (during bilateral discussions or workshops). The stakeholders are, thus, informed of the Nexus dimensions addressed by the models, the spatial coverage and time resolution, the necessary inputs and potential outputs. Interaction with the stakeholders does not aim at selecting the thematic models but rather identifying relevant model outputs for the case study as well as gaps in addressing the Nexus issues.

Table 2. Use of thematic models in the 12 case studies

Case study	Thematic model applied						
	E3ME	MAGNET	CAPRI	IMAGE-GLOBIO	OSeMOSYS	SWIM	MAgPIE-LPJmL
Andalusia	XX[1]	XX[1]	XX				
Sardinia	XX		XX				
Southwest UK	XX		XX				
The Netherlands	XX	XX	XX				
Sweden		XX	XX	XX[2]			
Greece	XX	XX	XX	XX[2]	XX		
Latvia	XX	XX	XX				
Azerbaijan	XX	XX	XX[3]		XX		
France-Germany	XX		XX			XX[4]	
Germany-Czech Republic-Slovakia			XX			XX	
Europe	XX	XX	XX	XX			XX
Global	XX	XX	XX	XX	XX		XX

(1) Results available at the national level; (2) Application of GLOBIO; (3) Results available for a group of countries including Azerbaijan; (4) Results available for the Rhine basin.

The data gathered so far in WP2 has not been used in the selection of the models. The policy solutions or pathways will be connected to modelling activities at a later stage.

3 First application of the thematic models

3.1 Setting up the modelling exercise

The thematic models are diverse and so are their outcomes. Applying two or more thematic models to each case study raises questions about the practicability of combining results from different models. To the extent possible, efforts have been made to harmonize the application of the models by defining a common simulation setting.

To define a common simulation setting, we have selected a base period (2010) and a simulation horizon (2050, with an intermediate time horizon in 2030). Next, we have agreed on a common baseline scenario that will be explained below. Finally, we have decided that the first application of the thematic models will consist of running the baseline scenario, with results for 2010, 2030 and 2050 time horizons.

Case study leaders have been involved from the beginning in modelling activities. Case studies identify the main Nexus challenges and the corresponding output variables to assess them. Modellers provide information about the outcomes available from each model (input variables, output variables). Modellers and case study leaders work together to develop a common reporting format.

In parallel, the Sardinia regional case study was selected as a fast track case study to test the whole process, from the selection of the thematic models to the development of complexity models and the integration of modelling outputs.

3.2 Identification of the baseline scenario

SIM4NEXUS will cover pathways to achieving (i) the 2050 vision ‘living well within the borders of our planet’, (ii) climate and sustainability goals, and (iii) opportunities and limitations of low-carbon options in view of near-term policy initiatives (i.e. IPCC goals from the Paris Agreement, circular economy package).

To define a suitable baseline scenario, we take into account that the scenario analysis will use the set of climate scenarios selected by the IPCC for the Fifth Assessment Report (IPCC 2014). This scenario framework has been developed by the international climate change research community to increase consistency and comparability across climate impact studies (Kriegler et al. 2012, Van Vuuren et al. 2012). It consists of a two-dimensional matrix representing key environmental and socioeconomic drivers of uncertainty in future climate outcomes. Each scenario results from the plausible combination of a Representative Concentration Pathway (RCP) with a Shared Socio-economic Pathway (SSP). The RCPs comprise four trajectories according to different levels of anthropogenic radiative forcing in the year 2100 (2.6, 4.5, 6 and 8.5 W/m2) (van Vuuren et al., 2011). The SSPs consist of five narratives describing alternative socio-economic developments that built on socio-economic drivers consistent with different challenges to adaptation and mitigation: SSP1 (sustainability), SSP2 (middle of the road), SSP3 (fragmentation), SSP4 (inequality) and SSP5 (conventional development) (O'Neill et al. 2017).

For the baseline scenario, we assume no impacts of climate change; this means that we assume the climate situation in 2010 will stay the same in 2030 and 2050.

Regarding the socio-economic drivers, the baseline scenario corresponds to the middle-of-the-road socio-economic pathway (SSP2) assuming a moderate capacity to adjust to future mitigation and adaptation challenges in the medium term (O'Neill et al. 2017). The narrative for the SSP2 scenario is explained below. Data for the SSP2 scenario are publicly available through the interactive SSP web-database at https://secure.iiasa.ac.at/web-apps/ene/SspDb, which comprises quantitative estimates for economic growth, demographics, energy, land-use, and emissions projections (Riahi et al. 2017).

> Narrative for the SSP2 scenario (O'Neill et al. 2017)
>
> *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 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.*

3.3 First run of the thematic models

3.3.1 Modelling work schedule

The thematic models are run for each case study on demand. Some of the models do not need additional data from the case studies to deliver the baseline (E3ME, MAGNET, CAPRI, IMAGE/GLOBIO and MAgPIE-LPJmL). In contrast, OSeMOSYS and SWIM are case-study specific and input data from the case studies may be required to apply them.

For each case study, the modelling process starts with the case study leader contacting the leaders of the selected models for the case study. For the fast track case study (Sardinia) selected to test the process, the work is well advanced. The thematic models selected for this case study were E3ME and CAPRI. Baseline results have already been provided for 2010 and 2030.

The rest of the case studies progresses at different speeds, depending on previous modelling experience of the researchers, involvement of stakeholders, etc. Where feasible, case study leaders will be involved in modelling activities so they better understand what are the capabilities and limitations from the models applied and how to interpret model results.

Table 3. Tentative timeline for the Case Study work (Coordination WP3/WP4)

Case Study	Conceptual model	Thematic models	System Dynamics Model development	Policies	Serious Game
Sardinia	✓	✓	✓	June 2017	June-July 2017
Greece	✓	✓	June 2017	Sep 2017	Oct 2017
Andalusia	June 2017	July 2017	Sep 2017	Nov 2018	
Netherlands	Sept 2017	Oct 2017	Nov 2017	Jan 2018	
Latvia	Oct 2017	Nov 2017	Dec 2017	Feb 2018	
Southwest UK	Nov 2017	Dec 2017	Jan 2018	Mar 2018	
Sweden	Dec 2017	Jan 2018	Feb 2018	Apr 2018	
Azerbaijan	Jan 2018	Feb 2018	March 2018	May 2018	
France-Germany	Feb 2018	March 2018	May 2018	July 2018	
Germany-Czech-Slovakia	Mar 2018	Apr 2018	July 2018	Oct 2018	
European	Apr 2018	May 2018	Sep 2018	Nov 2018	
Global	Apr 2018	May 2018	Nov 2018	Jan 2019	

The application of the thematic models to the case studies is coordinated with the development of the complexity models, which, in turn, will provide input to the Serious Game. Table 4 shows the tentative timeline for the development of the Serious Game in each case study, which follows the following steps:

- The case study team develops the conceptual model and investigates what numerical data are needed from thematic models and other sources;
- The selected thematic models are run to provide baseline results;
- The SDM team develops the system dynamics model and transfers it for feeding the Serious Game;
- Both the SDM and the case study teams use the Game to produce and assess alternative policies/scenarios (additional runs of the thematic models will provide scenario results);
- An interactive process takes place between the conceptual and the simulation models, so that the Game is improved by iterations.

The thematic models are not linked together but run independently. The integration of outputs from different thematic models is done through the SDM.

3.3.2 Harmonisation of baseline assumptions

As seen in the previous section, the baseline scenario assumes no additional impacts of climate change and up to 2050 as well as socio-economic drivers in line with the middle-of-the-road socio-economic pathway (SSP2).

All the thematic models have defined a baseline scenario consistent with SSP2. Baseline assumptions are harmonised by using the same projections for population and GDP growth for all thematic models.

Moreover, four of the thematic models used at the global level (MAGNET, CAPRI, IMAGE and MAgPIE) have been applied together in a recent climate impact study where an important effort of harmonisation of model assumptions was undertaken (for further details see Van Meijl et al. 2017).

3.3.3 Common reporting format

To exchange information and provide input to the complexity models, it has been decided to use a common reporting format that is similar to the one used by Integrated Assessment Modelling (IAM) teams to exchange SSP results. As shown in Table 3, this reporting template includes five dimensions (model, scenario, region, variable and time) and information about the units used.

Table 4. Common reporting template for model outcome

Model	Scenario	Region	Variable			Year					
			Category	Variable	UNIT	2005	2010	2020	2030	2040	2050

The use of a common reporting template will ease the interaction between case study leaders and modellers. It will also help to identify common and specific model outputs and will allow for a cross-comparison of model results.

The common reporting template has the advantage that through the different variables all the Nexus components are represented. However, for some variables, some thematic models can provide a higher level of detail than specified in this template. For instance, MAGNET and CAPRI provide information for specific crops or crop groups that goes beyond the other models. In this case, a good option will be to use the Agricultural Model Inter comparison Project (AGMIP) reporting template, as this template identifies a lot of key variables (variable definition, units). Moreover, a common definition of dimensions (commodities, regions) allows for model comparison.

Beyond the general reporting structure, model comparison requires agreement on which variables to include, their definition and unit. A long list of standard variables, covering the themes energy, emissions, climate, carbon capture and storage, economy, SDGs, land, water, investment and capital cost is provided (available in Project place: -> documents -> WP3 -> Task 3.3 Thematic Models -> D3.1). If required, additional variables, especially for new themes like biodiversity or water quality, can be introduced.

4 E3ME-FTT model

4.1 Description of the model E3ME-FTT

Model name:	E3ME-FTT: E3 (Energy-Environment-Economy) macro-econometric model
Model type:	Global macro-econometric energy-environment/economy model
Purpose:	Assessment of long-term impacts of climate and energy policy on economic activity and employment
Spatial coverage:	Global
Spatial resolution:	National (covering all EU-28 Member States)
Temporal scale:	Until 2050 in annual time steps
Website:	http://www.e3me.com

E3ME-FTT is a global macro-econometric energy, environment & economy-modelling tool, integrating global economies, energy systems, emissions and material demands. E3ME is designed to consider the impacts of climate and energy policy on economic activity and employment. The FTT modules add technological detail to the assessments, i.e. 22 different power sector technologies. The model assesses both short- and long-term impacts up to 2050 impacts. E3ME covers all EU28 Member States explicitly. The current version of E3ME has expanded the model's geographical coverage from 33 European countries to 61 global regions.

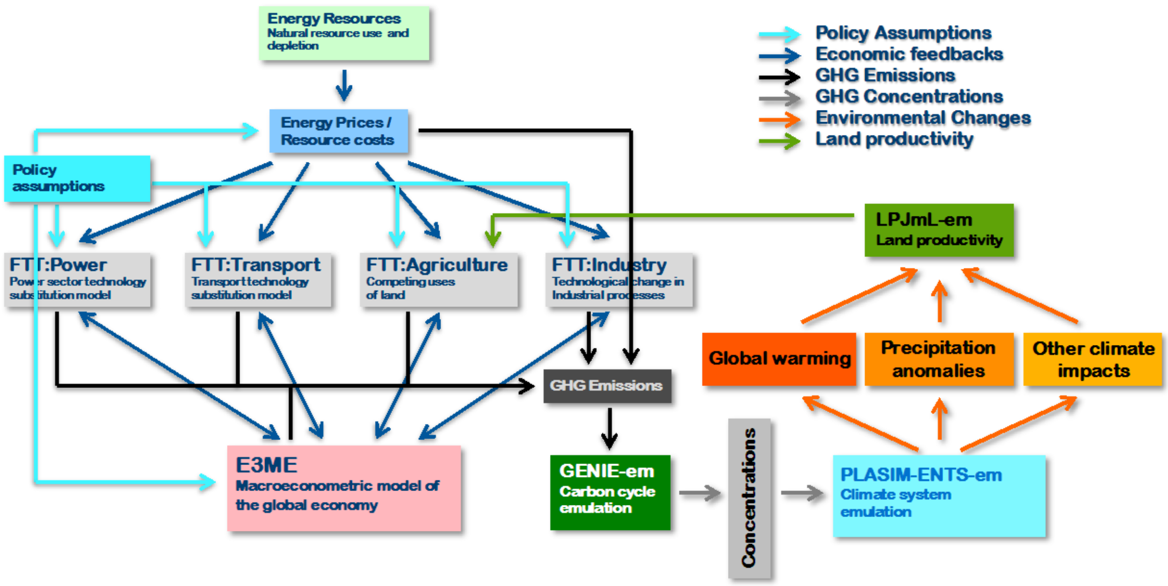


Figure 2: E3ME-FTT Integrated assessment model

The E3ME model embodies three core strengths:

- **Integrated treatment of the world's economies, energy systems, emissions and material demands**, enabling the model to capture two-way linkages and feedbacks between these components. Key environmental factors, such as greenhouse gas emissions and resource use are represented explicitly in the model using physical units where appropriate.
- **A high level of disaggregation**, enabling detailed analysis of sectoral and country-level effects from a wide range of scenarios. Social impacts (including unemployment levels and distributional effects) are important model outcomes.
- **Its econometric specification**, addressing growing concerns over conventional macroeconomic models and providing a strong empirical basis for analysis. E3ME's specification enables the model to fully assess both short and long-term impacts. It is not limited by many of the restrictive assumptions common to Computable General Equilibrium (CGE) models.

E3ME is widely used in Europe and beyond for policy assessment. Recent applications include:

- Input to the EU Impact Assessment of the Clean Energy package and previous energy efficiency targets (European Commission 2014b, 2014c).

- Input to EU Impact Assessment of 2030 climate and energy targets (European Commission 2014a, Mercure et al. 2014, Pollitt et al. 2015).
- Assessment of the economic and labour market effects of the EU Energy Roadmap 2050 (Barker et al. 2015, Pollitt et al. 2014).
- Evaluations of the economic impact of removing fossil fuel subsidies (European Commission 2011).
- Assessment of the potential for green jobs in Europe.

4.2 Capacity to address the Nexus

E3ME has been designed to handle interactions between the economy and the energy system. Its two-way linkages make it well placed to provide a detailed analysis of the macroeconomic impacts of energy policy. A land use module is currently under development to allow for a better assessment of biofuels, with feedbacks to food prices. 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. E3ME can also be linked to a climate model.

Potential contribution to the Nexus analysis:

- Macroeconomic analysis of energy/climate policy.
- Land use interactions with energy/climate policy and economic effects.

Strengths and weaknesses of the model:

- Water would need to be dealt with externally unless a new module is developed.
- Principally linkages to other models would be through water. Main strengths are interactions between economy, energy, material consumption and (once developed) land requirements.
- Global coverage, with detailed sectoral disaggregation (42 economic sectors).
- Empirical specification, which sets it apart from the more theoretical CGE modelling approach.

Energy consumption in E3ME

Final energy consumption is modelled in E3ME in physical units using a set of econometric equations that link consumption to prices and rates of economic activity. Feedbacks to the economy are implemented by making changes to input-output coefficients.
The power sector is modelled using a bottom-up approach that is based on a series of differential equations and theories of evolutionary economics. The approach uses bottom-up technical data to define 22 different electricity generation technologies.

Water consumption in E3ME

The E3ME model also includes econometric equations for material and water demand. In the case of water, these have not been applied previously due to a lack of data at European level but the framework is in place. The model allows for various possible specifications for modelling water demands, including econometric equations but also linking to other model variables. Economic feedbacks occur through adjustments of the input-output coefficients relating to the water supply sector.

Water supply in E3ME

As a macroeconomic model, E3ME does not include measures of water supply. We suggest that these are estimated based on historical patterns or, preferably, using the results from a hydrological model.

Modelling the energy-water nexus

E3ME has the potential to cover water demand. For each of the 22 power sector technologies E3ME includes a coefficient (based on literature review) of units of water consumed per GWh of generation. Consumption of water by other sectors can be assessed by using econometric equations or other model-based relationships. Agriculture, as a key consumer of water, will be considered in additional detail through linkages with a land-use model.

Linking the water-energy direction, there is the potential to consider scenarios based on different technologies and implementation of desalination. We will derive a coefficient approach for units of energy per cubic metre of water produced and use E3ME to determine system level impacts.

The focus of E3ME on economic interactions means it is unlikely to ever integrate a model of water supply. For this aspect of the Nexus, E3ME would need to be linked to an external tool (it may be possible, for example, to link to SWIM).

4.3 First application to case studies

4.3.1 Selected case studies

E3ME can be used to assess the global and national case studies. It is a simulation model, meaning that it is used to assess changes in policies based on real-world behavioural characteristics.

E3ME can also provide background results for the regional case studies. To be applied to regional case studies, additional data from the regions is needed in order to downscale model outputs from the national to the regional level.

Currently, E3ME is being applied to Sardinia, Greece and the Global case study. Baseline results have already been provided for Sardinia and Greece. The Azerbaijan case study is using a tool similar to E3ME but based on a smaller number of sectors, reflecting local data availability. The simulation of the baseline scenario for the Azerbaijan and Global case studies is in progress.

4.3.2 Simulation scenarios

Spatial and temporal scales

E3ME provides results at the national level (for large economies) up to 2050, in yearly time steps. Results can be provided for 2010, 2030 and 2050.

Alignment with the scenario framework for climate change research

Many of the features of the SSPs are indicators that are regarded as outputs from E3ME. This in part reflects the aim of the SSPs, which is typically to feed into IAMs that require assumptions about the economy, rather than estimating economic impacts.

It is, however, possible to calibrate the E3ME baseline solution to be consistent with any of the SSPs. Policy scenarios, which could be informed by the RCPs (i.e. sets of policies that meet the targets specified in the RCPs) can then be compared to these different baselines. The outputs from the model are the impacts of these policies, i.e. how meeting the RCP targets affects employment and GDP, under different sets of starting conditions.

Baseline scenario: Main assumptions

The baseline scenario is designed to be consistent with SSP2 (see section 3.2).

Additional data from the case studies

For the Sardinia case study, E3ME uses additional data from the case study in order to downscale E3ME results to the region. In Azerbaijan, local data are collected as part of the case study.

In the other case studies, the additional data are likely to inform the scenarios (see below).

4.3.3 Input data

Energy policy (i.e. energy technology-specific transport and electricity sector regulations, feed-in tariffs, subsidies, registration taxes, etc.), energy/carbon price/taxes, Emissions Trading System (ETS) coverage, other taxes, additional exogenous investment assumptions, optional exogenous energy technology scenarios.

4.3.4 Model outputs

The following Table gives an overview of the main output variables in E3ME. The extensive list of variables that the model can provide is reported in Appendix A, Table 16.

Table 5. Summary of output variables in E3ME

Output variable	Units
GDP	Billion EUR 2005 per year
Output	Billion EUR 2005 per year
GVA	Billion EUR 2005 per year
Employment	Million
Energy demand by fuel and fuel user	Thousand TOE
CO2 emissions	Million tonnes of CO2 emissions per year
Electricity generation by technology	GWh/y
Electricity capacity	Gigawatts

4.3.5 Technical implementation

E3ME is programmed in FORTRAN. A full model run takes approximately 20 minutes.

Results are provided in excel format. The SSP reporting template can be used.

4.3.6 Baseline results: global level

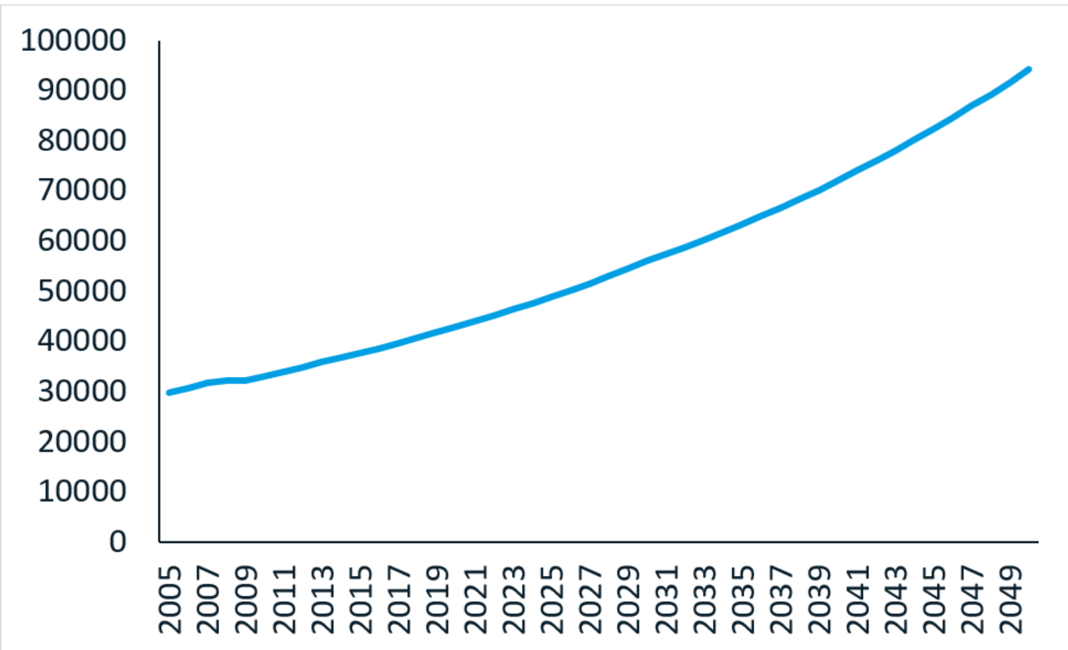
Table 6 shows the main baseline results. More detailed results as well as the description of output variables can be accessed in Project place: -> documents -> WP3 -> Task 3.3 Thematic Models -> D3.1.

Table 6. Summary of baseline results at the global level (E3ME)

Variable	Unit	2010	2030	2050
Consumption	billion US$2005/yr	33083.0	56106.7	94232.5
Emissions|CH4	Mt CH4/yr	370.9	361.8	370.4
Emissions|CO	Mt CO/yr	914.2	974.1	1004.6
Emissions|CO2	Mt CO2/yr	37209.7	47469.8	55989.3
Emissions|F-Gases	Mt CO2-equiv/yr	774.1	1242.1	2011.1
Emissions|Kyoto Gases	Mt CO2-equiv/yr	49114.4	59931.0	70365.6
Emissions|N2O	kt N2O/yr	10782.4	11680.8	14794.9
Emissions|NOx	Mt NOx/yr	108.7	125.4	149.8
Emissions|Sulfur	Mt SO2/yr	119.1	140.3	180.8
Emissions|VOC	Mt VOC/yr	3.0	3.2	3.8

Final Energy	EJ/yr	396.5	520.5	609.8
Final Energy|Electricity	EJ/yr	65.0	109.2	165.0
Final Energy|Gases	EJ/yr	66.6	90.6	137.9
Final Energy|Heat	EJ/yr	12.2	13.4	14.1
Final Energy|Industry	EJ/yr	192.1	263.9	333.0
Final Energy|Liquids	EJ/yr	151.4	179.8	154.4
Final Energy|Residential and Commercial	EJ/yr	114.8	135.4	153.9
Final Energy|Solids	EJ/yr	94.1	113.4	123.6
Final Energy|Transportation	EJ/yr	82.4	111.7	108.7
GDP|MER	billion US$2005/yr	54728.0	94089.5	161858.3
Population	million	6840.7	8270.9	9283.6
Price|Carbon	US$2005/t CO2	2.4	3.2	5.3
Price|Primary Energy|Coal	US$2005/GJ	4.7	7.2	9.2
Price|Primary Energy|Gas	US$2005/GJ	26.6	49.3	73.5
Price|Primary Energy|Oil	US$2005/GJ	23.0	38.0	75.0
Price|Secondary Energy|Electricity	US$2005/GJ	48.6	75.5	110.7
Primary Energy	EJ/yr	541.5	727.8	897.8
Primary Energy|Biomass	EJ/yr	47.8	61.7	67.1
Primary Energy|Coal	EJ/yr	140.3	201.9	274.7
Primary Energy|Fossil	EJ/yr	414.7	544.1	653.5
Primary Energy|Gas	EJ/yr	106.7	134.5	192.1
Primary Energy|Hydro	EJ/yr	0.0	0.0	0.0

Global Consumption, E3ME Baseline (billion US$2005)



Source: E3ME, Cambridge Econometrics.

Figure 3: Global Consumption, E3ME Baseline (billion US$2005)

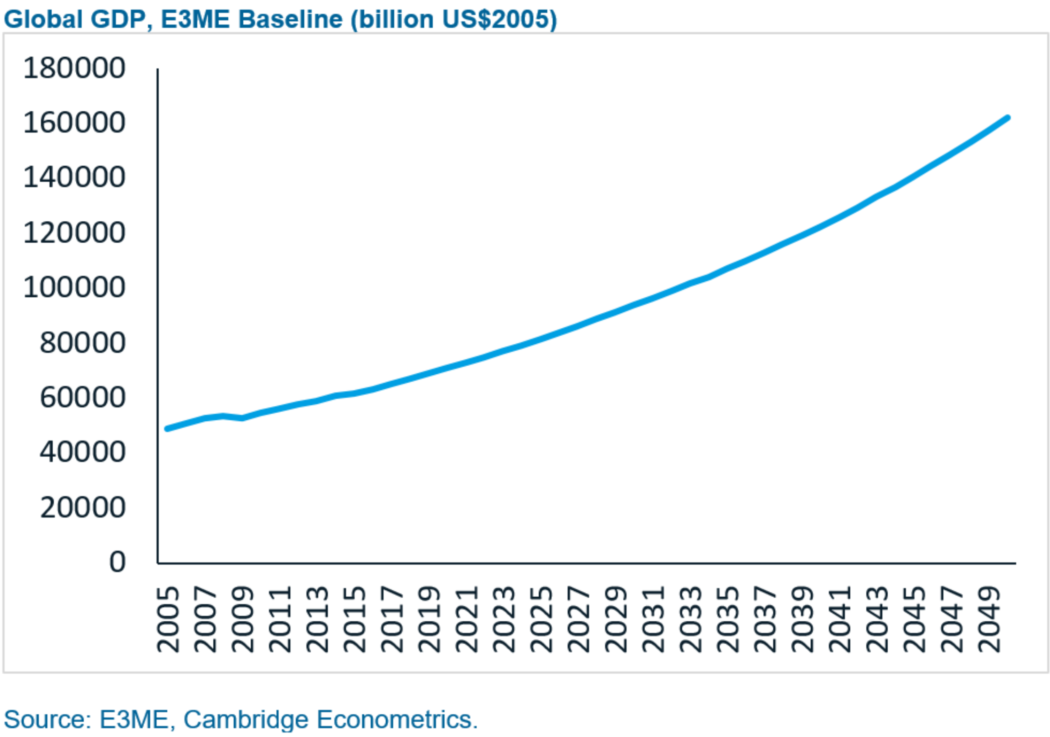


Figure 4: Global GDP, E3ME Baseline (billion US$2005)

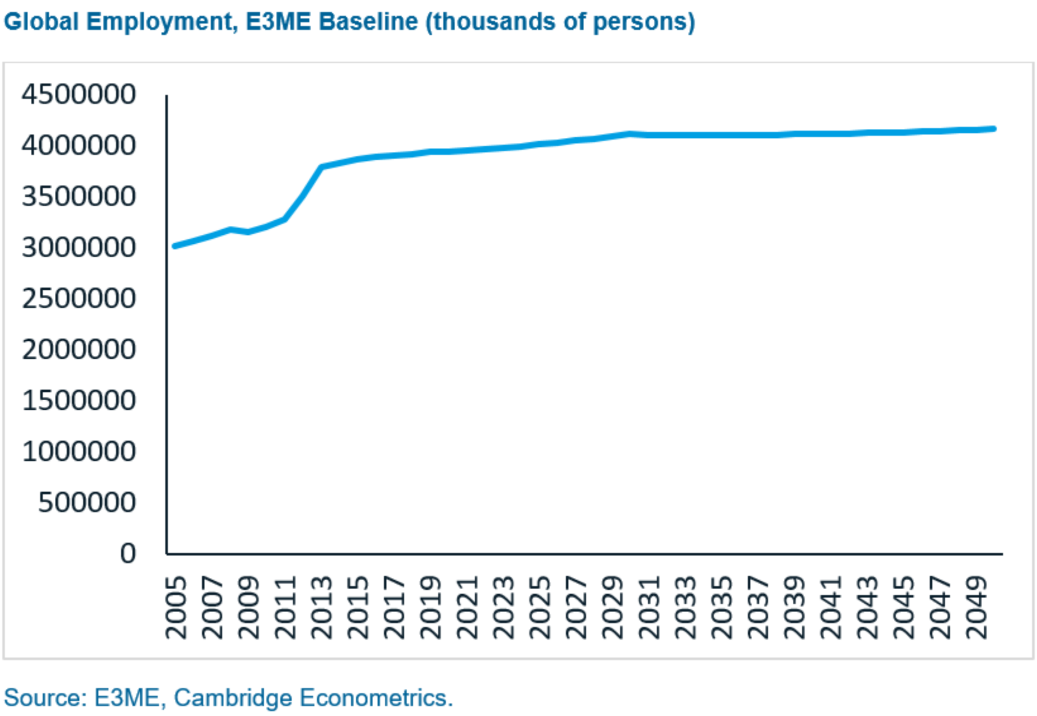


Figure 5: Global Employment, E3ME Baseline (thousands of persons)

5 MAGNET

5.1 Overview of the MAGNET model

Model name:	MAGNET: Modular Agricultural GeNeral Equilibrium Tool
Model Type:	Global computable general equilibrium model
Purpose:	Economic Impact Assessment
Spatial coverage:	Global
Spatial resolution:	National
Temporal scale:	Until 2050 in flexible time steps (2100 is possible)
Website:	http://www.magnet-model.org/

MAGNET is a recursive dynamic computable general equilibrium model that covers the whole economy, with an additional focus on agriculture, food processing and the rest of the bioeconomy. It is a tool for analysis of trade, agricultural, climate and bioenergy policies and builds on the database of the Global Trade Analysis Project (GTAP) model. A detailed description of the model is found in Woltjer et al. (2014).

MAGNET has global coverage and national level resolution. Most nations, including all EU 28 member states, are represented individually while some small nations are represented as aggregates. In a few countries the representative household has been disaggregated into rural and urban households and various income groups based on specific specialized data.

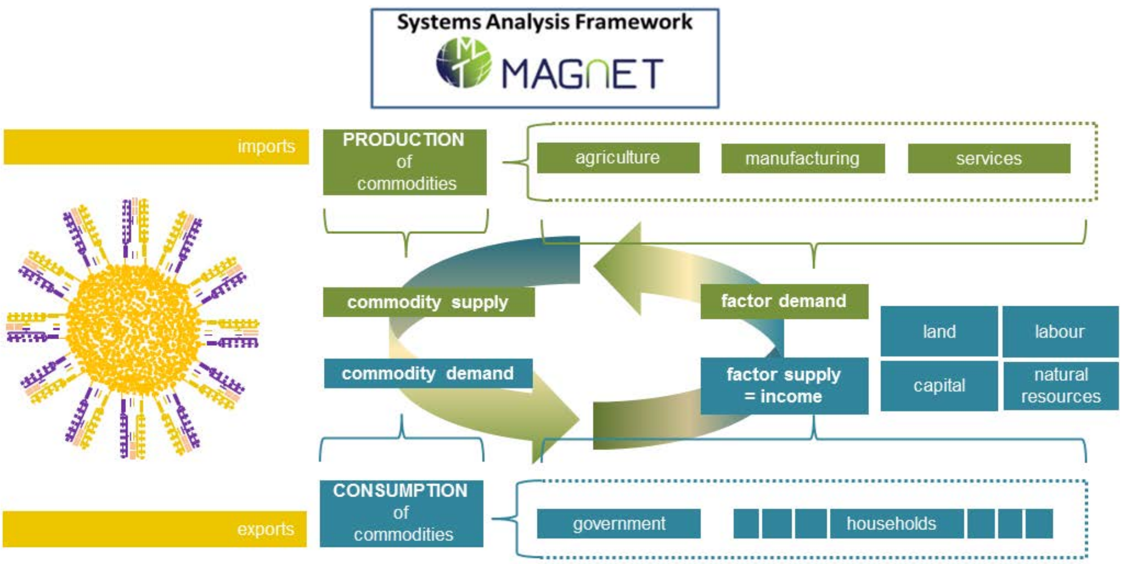


Figure 6: MAGNET (Modular Applied General Equilibrium Tool)

MAGNET covers 63 products of which more than 20 primary agricultural activities (including horticulture) and agricultural processing activities (see Figure 6). A feeding sector links the crop sectors in MAGNET to the livestock sectors. In MAGNET the fertilizer sector, further split into nitrogen (N), phosphorus (P2O5) and potassium (K2O), has been disaggregated from the chemical sector. Fertilizer is used in the crops and livestock sectors as a substitute of land. This allows for intensification taking place based on land rent and agricultural prices. It has a detailed treatment of the bioeconomy including agriculture, food processing, forestry, fishing, paper, textile, wood industries, bioelectricity and various biobased chemicals. It includes also the rest of the economy, including energy (coal, gas, oil, petro, wind\sun,...), electricity (biomass, gas, coal, wind\sun, hydrological), manufacturing and services (i.e. transport, tourism).

The MAGNET model has been used in the Agricultural Model Inter comparison Project (AgMIP). The studies included the long run effects of SRES scenarios including projected climate change on agriculture and the effect on food prices of a significant increase in bioenergy as a climate mitigation option (Nelson et al. 2013, Schmitz et al. 2014, Von Lampe et al. 2014, Wiebe et al. 2015, Van Vuuren et al. 2016). The macro-economic contributions of the emerging bioeconomy are studied for the EU and The Netherlands by including detailed biofuels, bioenergy, biochemicals sectors and related policies within the model (Smeets et al. 2014a). In the FoodSecure project[1], the impact of agricultural, trade, bioeconomy and climate policies on various dimensions of food security (food availability, food access, food utilisation) are integrated within the model by including various households for selected countries.

MAGNET has been used to examine the interplay between the U.N. program to Reduce Emissions from Deforestation and forest Degradation (REDD) (Dixon et al. 2013, Overmars et al. 2014) and increased biofuel production from the Renewable Energy Directive (RED) (Lotze-Campen et al. 2014, Smeets et al. 2014b).

5.2 Capacity to address the Nexus

Food-land-energy-climate links

MAGNET is a tool for quantitative analysis in the area of agricultural policies, international trade policies and bio-economy policies (including bioelectricity, 2nd generation biofuels and biochemicals policies). Farmers use energy as an input in food production and farmers also choose to cultivate food and/or bioenergy crops on limited land resources based on the market price of these products.

[1] EU FP7 project FoodSecure (grant agreement no. 290693. Project duration: March 2012 - February 2017) http://www.foodsecure.eu/.

Emissions from all economic activities including agriculture are accounted for in the model and can be taxed and traded depending on the climate policy. The energy system includes coal, gas, oil, petro, electricity (biomass, gas, coal, wind\sun, hydrological) and transport fuels.

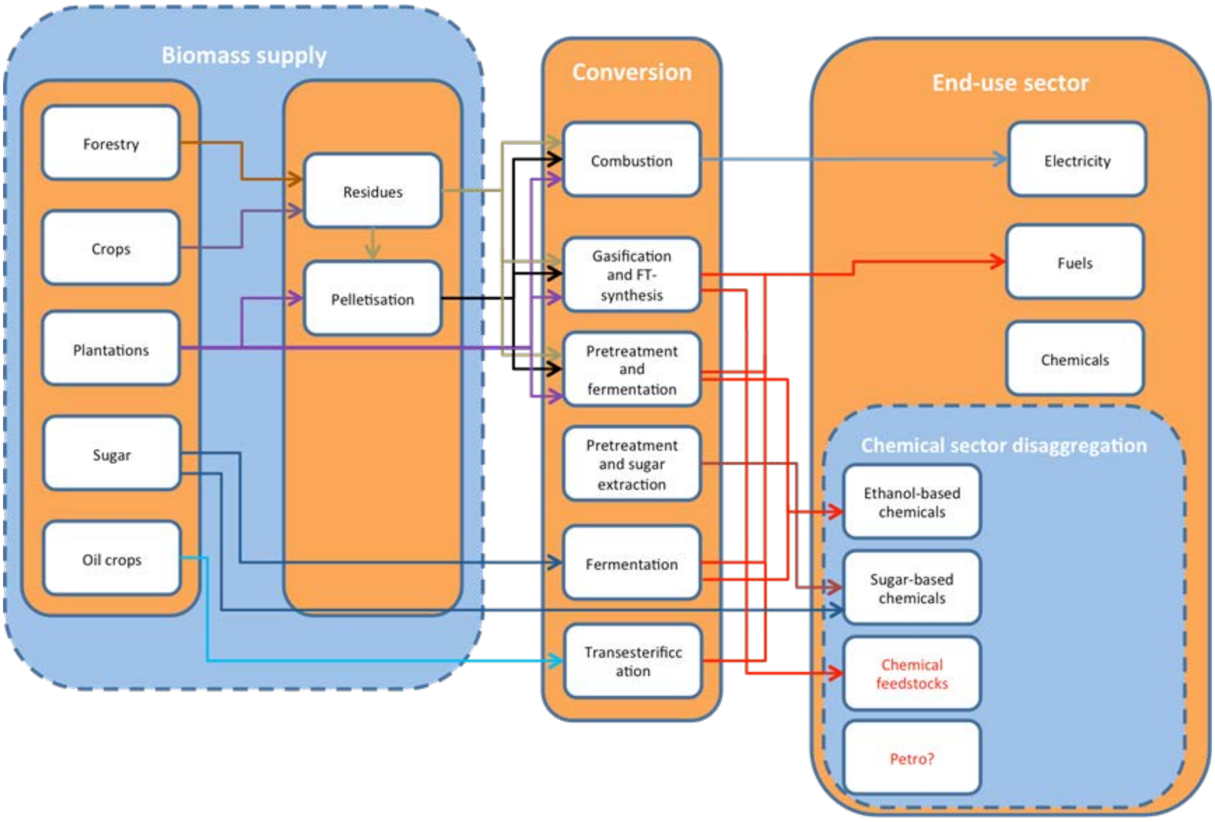


Figure 7: Overview of bio-based sectors and linkages within MAGNET

To the various agricultural sectors, two additional biomass producing sectors are added, namely a residue producing sector and an energy crop sector (see Figure 7). Biomass from the residue sector and energy crop sector are partially delivered to a pre-treatment sector, which uses the raw, untreated biomass compacts the biomass for long distance transport for intra- and interregional trade. The residue sector, the energy crop sector and the pre-treatment sector deliver biomass to the sectors that convert biomass into bioelectricity, 2nd generation biofuels and biochemicals.

Agricultural policies are treated explicitly in the model (i.e. production quotas, intervention prices, (de)coupled payments, second pillar policies). Information from the OECD's Policy Evaluation Model (PEM) is used to improve the substitution between different land uses.

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).

To address climate change issues, MAGNET includes emissions coefficients per sector per region including emissions from agriculture. MAGNET includes CO_2 and non-CO_2 GHG emissions (CH4, N2O, and the group of fluorinated gases (F-gases), including CF4, HFCs, and SF6). Emission coefficients are taken from GTAP databases (Ahmed et al. 2014).

Within the EU FP7 project FoodSecure, an approach is developed to include different household types to 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 to inform policy interventions.

Food-water links

Until now water markets are not included in MAGNET. In 2017, virtual water flows will be integrated within the magnet model (including biophysical water flows). The way forward would be to follow the approach as developed by GTAP-W (Calzadilla et al. 2011).

5.3 First application to case studies

5.3.1 Selected case studies

MAGNET can be used to assess the global, European and national case studies. So far, contacts have been established with the Global, European, Greek and Dutch case studies.

The model is being updated to the latest GTAP dataset and the requested case study countries are being introduced. SSP2 results will be provided to the case studies in summer 2017.

5.3.2 Simulation scenarios

Spatial and temporal scales

MAGNET can provide results through 2050 (and beyond if necessary).

Results are provided at the national level for the periods 2010, 2020, 2030 and 2050.

Alignment with the scenario framework for climate change research

The model can already produce results within the new scenario framework for climate change research. The SSP and RCP pathways have already been implemented and are currently being updated.

Baseline scenario: Main assumptions

The baseline scenario is consistent with SSP2. We simulate the SSP scenarios with the drivers being population, GDP, lifestyle assumptions, bioenergy needs, trade policies, land-use policies, assumptions on land-based mitigation, and assumptions on technological progress.

Key assumptions in SSP2 are the given GDP and population data. In addition, we have some agricultural and trade policy assumptions (i.e. abolition of the EU milk quota in 2015). Yield projections are from FAO\PBL.

5.3.3 Input data

Input data comprises:

- GDP and population developments
- Policy changes such as percent changes in taxes, subsidies, tariffs, biofuel mandates, production quotas, etc.
- Changes in productivity of land, labour and capital as well as efficiency changes in the economic sectors themselves (in percent change).
- Changes in patterns of consumption preferences such as a shift to a more meat based diet.

5.3.4 Model outputs

Appendix A, Table 17 presents the detailed list of variables that MAGNET can provide. The main output variables are shown in Table 7.

Table 7. Summary of output variables in MAGNET

Output variables
GDP, value added, employment, wages, bilateral trade flows, trade balances, self-sufficiency rates
Changes in prices and quantities of units produced and consumed as well as quantities of production inputs, i.e. land, types of labour and capital
Changes in C02 emissions and the market price for emission permits (if non zero)
The amount of new land brought into production (hectares)
The amount of energy produced and consumed (in tons of oil equivalent) from various fossil fuel and clean energy sources

5.3.5 Technical implementation

Results can be stored in an interactive interface.

Results are provided in excel format, using the AgMIP reporting template., as shown in this example:

Model	Scenario	Region	Item	Variable	Year	Unit	Value
MAGNET	SSP1a_FLC	USA	wht	FEED	2010	mn	287
MAGNET	SSP1a_FLC	USA	sug	FEED	2010	mn	23
MAGNET	SSP1a_FLC	USA	wht	FEED	2020	mn	327
MAGNET	SSP1a_FLC	USA	sug	FEED	2020	mn	25

5.3.6 Baseline results: global level

Table 8 and Figure 8 show the examples of main baseline results. More detailed results can be accessed in Project place: -> documents -> WP3 -> Task 3.3 Thematic Models -> D3.1.

Table 8. Summary of baseline results at the global level (MAGNET)

item	variable	unit	2010	2030	2050
TOT	AREA	1000 ha	4853231.2	5045117.6	5169472.0
TOT	CONSUMPTION	mn USD	113205271.7	172471380.0	228398328.0
TOT	EXPORTS	mn USD	15174140.1	22960209.5	31519956.6
TOT	FEED DAIRY	mn USD	67950.3	96955.2	117585.6
TOT	FEED	mn USD	220219.6	317019.1	380813.5
TOT	FEED NON RUMANENTS	mn USD	94637.0	129690.0	148827.7
TOT	FOOD	mn USD	2087553.4	2571798.4	2878385.0
TOT	FEED RUMANENTS	mn USD	57632.3	90373.9	114400.2
TOT	GDP TOTAL	bn USD 2007 MER	57846.8	107840.0	163830.1
TOT	IMPORTS	mn USD	16283381.5	24933491.6	34439385.4
TOT	POPULATION TOTAL	mn pers	6851.3	8237.4	9133.1
TOT	PRODUCTION	mn USD	112096030.3	170498097.9	225478899.2
WHT	AREA	1000 ha	276725.0	279024.8	286661.3
WHT	CONSUMPTION	mn USD	156309.5	213602.3	248830.4
WHT	EXPORTS	mn USD	31077.2	39216.1	45318.4
WHT	FEED DAIRY	mn USD	6610.6	12020.6	16200.4
WHT	FEED	mn USD	31693.0	50329.5	60835.6
WHT	FEED NON RUMANENTS	mn USD	20100.6	28555.7	31660.5
WHT	FOOD	mn USD	98146.2	124047.3	139089.0
WHT	FEED RUMANENTS	mn USD	4981.8	9753.1	12974.6
WHT	IMPORTS	mn USD	36837.0	46772.0	54382.5
WHT	PRODUCTION	mn USD	150549.7	206046.4	239766.2

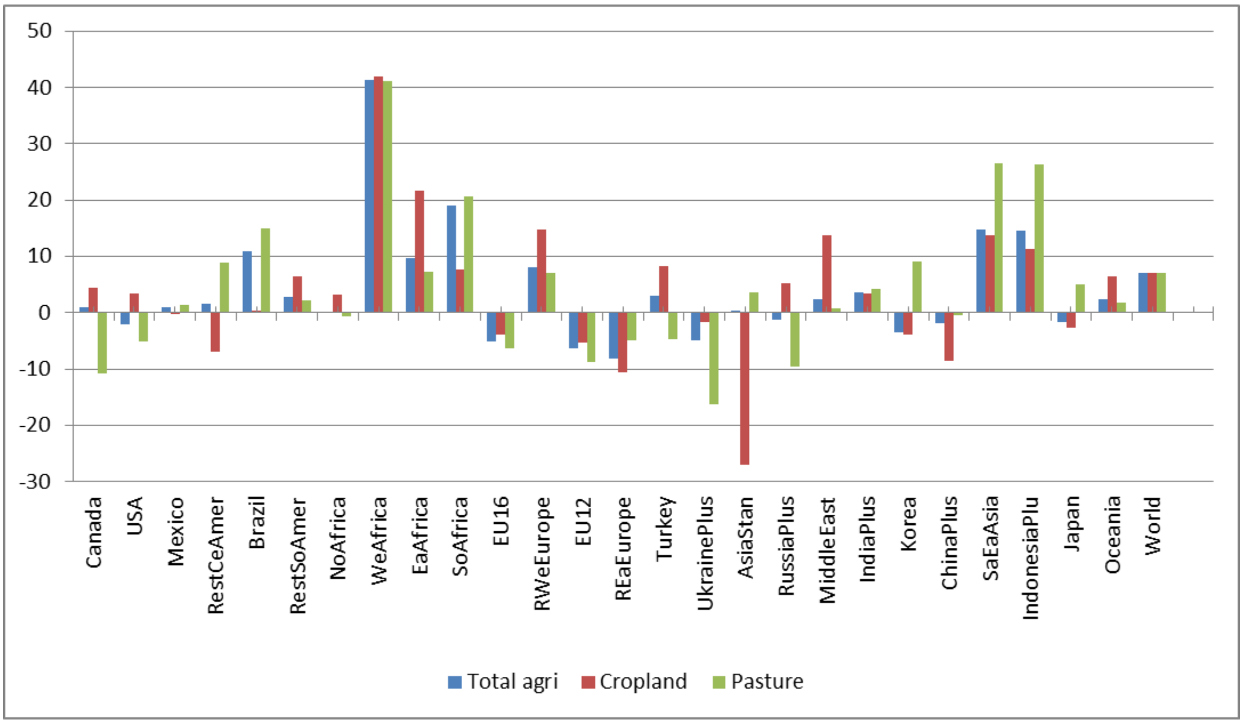


Figure 8: Total agricultural land, cropland and pasture change percentage change for each MAGNET region in 2010 – 2050.

6 CAPRI

6.1 Overview of the CAPRI model

Model name:	CAPRI (Common Agricultural Policy Regional Impact Model)
Model type:	Global agro-economic model
Purpose:	Policy impact assessment of EU policies
Spatial coverage:	Global
Spatial resolution:	National and regional within the EU
Temporal scale:	Until 2050 in flexible time steps
Website:	http://www.capri-model.org

CAPRI is a tool for the ex-ante impact assessment of agricultural, environmental and trade policies with a focus on the European Union. It covers global to regional scales. It is a global spatial partial equilibrium model, solved by sequential iteration between supply and market modules (for a detailed description see Britz and Witzke 2014).

- The supply module consists of independent regional agricultural nonlinear programming models for EU-28 and candidate countries. Supply models depict farming decisions in detail at subnational level (NUTS 2 level or farm type level) by means of a mathematical programming approach, which captures a wide range of important interactions between production activities, the environment and the institutional context.

- The market module is a static, deterministic, partial, spatial model with global coverage, depicting about 60 commodities (primary and secondary agricultural products) and 40 trade blocks. It is capable of simulating bilateral trade flows, as well as bilateral and multilateral border protection instruments.

The unique combination of regional supply-side models with a global market model for agricultural products provides simulated results for the EU at subnational level, whilst, at the same time, simulating global agricultural markets. The main strength of the CAPRI modelling system is the fact that it is based on a unified, complete and consistent data base, and integrates economic, physical and environmental information in a consistent way. CAPRI assesses food-water linkages at a regionalized level and incorporates a wide range of environmental indicators and food-energy linkages of global biofuel markets.

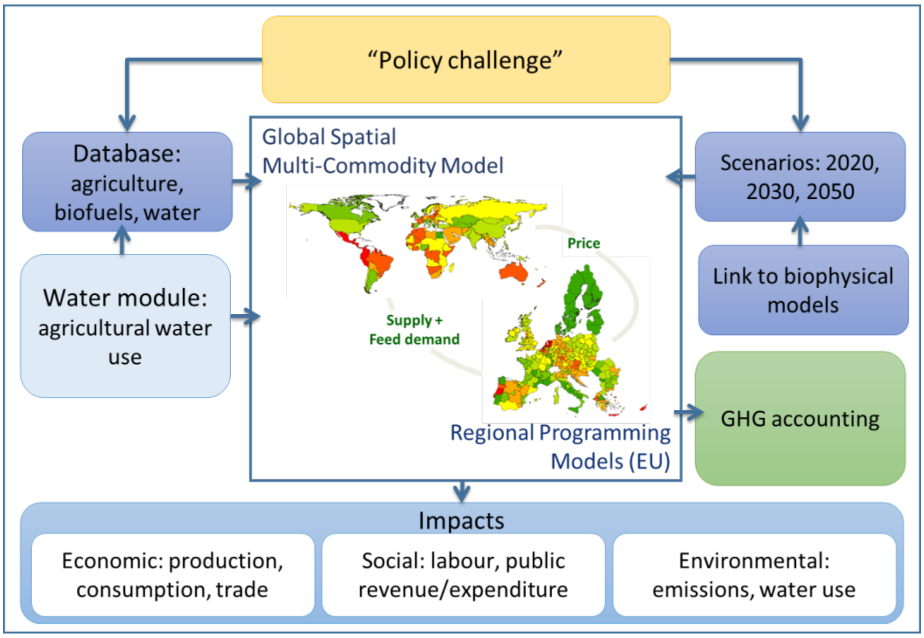


Figure 9: CAPRI Global Agri-Food Modelling System

CAPRI has been extensively used to assess agricultural policies, food-water-energy linkages and climate change impacts. Recent applications and impact studies include:

- Impact assessment of new agricultural policy measures (EC 2011, EC 2013, Gocht et al. 2013).
- Projections for EU agrifood markets (EC 2015).
- Evaluation of the impacts of climate change on EU agriculture (Shrestha et al. 2013, Delincé et al. 2015, Blanco et al. 2017).

- GHG emissions from the agricultural sector (Weiss and Leip 2012, Leip et al. 2015, Gocht et al. 2016).
- Assessment of the effects of EU biofuel policies (Blanco et al. 2010, Blanco et al. 2013).
- Analysis of agriculture-water relationships (Burek et al. 2012) and the role of irrigation as an adaptation strategy to climate change (Blanco et al. 2015).

6.2 Capacity to address the Nexus

Food-water linkages

The water module in CAPRI accounts for agricultural water use all over the EU (Blanco et al. 2015). 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 (i.e. water pricing).

Food-energy linkages

CAPRI includes a global representation of biofuel markets (ethanol and biodiesel), with endogenous supply, demand and trade flows for biofuels and biofuel feedstocks (Blanco et al 2013). The model is capable to simulate the impacts of EU biofuel policies on food production and prices, the potential use of by-products in the feed chain, the increasing pressure on marginal and idle land and the share of imported biofuels (self-sufficiency indicators). The CAPRI biofuel module allows for a detailed analysis of most relevant biofuel support instruments like consumer tax exemptions, quota obligations, import tariffs and other trade measures. While only first-generation biofuels are represented endogenously in the model, CAPRI allows for analysing scenarios regarding technical progress in second-generation technologies for biofuels.

6.3 First application to case studies

6.3.1 Selected case studies

CAPRI can provide results for all case studies. So far, baseline results have been provided at the global level and also at the regional level for the fast-track case study (Sardinia) and the Greece case study.

6.3.2 Simulation scenarios

Spatial and temporal scales

The model runs up to 2050. Results can be provided for 2010, 2030 and 2050 (also for intermediate years in between).

Worldwide, CAPRI provides results for about 40 countries/trade blocks. Within the EU, results can be provided at the national or regional (NUTS 2) level.

Alignment with the scenario framework for climate change research

The CAPRI baseline for 2030/2050 is aligned with the new scenario framework for climate change. 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).

Baseline scenario: Main assumptions

The CAPRI baseline used in this study builds upon 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.

6.3.3 Input data

CAPRI exploits wherever possible well-documented, official data sources from EUROSTAT, FAOSTAT, OECD and extractions from de Farm Accounting Data Network (FADN). Specific modules of the model ensure that the data used are compatible and complete in time and space.

6.3.4 Model outputs

Simulation results cover areas cropped, herd sizes and income indicators for each agricultural activity and each region; prices, supply and demand positions at country level; environmental indicators (balances for N,P,K, emissions of ammonia, methane and N_2O, greenhouse gas inventories and life-cycle assessment of energy use in agriculture) at regional level; producer and consumer prices, supply and demand positions as well as bilateral trade flows with attached prices, transport costs and tariffs globally for each trade block. The modelling system allows for spatial downscaling part to 1x1 km, which covers crop shares, yield, stocking densities, fertilizer application rates and the environmental indicators.

The main outputs from the model are presented in Table 9. The extensive list of variables that the model can provide is reported in Appendix A, Table 18.

Table 9. Summary of output variables in CAPRI

At the regional level (EU NUTS 2 regions)	At the global level (trade blocks)
Activity levels (crops, livestock activities, feeding activities, processing activities)	Supply indicators (production)
Supply indicators (production, yields)	Demand indicators (food, feed, processing and biofuel demand)
Demand indicators (food, feed, processing and biofuel demand)	Trade indicators (bilateral trade flows)
Input indicators (input use, feed use)	Market prices
Income indicators (variable costs, revenues, farm income)	Welfare indicators (agricultural profit, tariff revenue, consumers well-being)
Environmental indicators (nitrogen and phosphate balances, ammonia emissions, GHG emissions, agricultural water use)	

6.3.5 Technical implementation

The economic model and the data base generation are coded in GAMS[2]. A graphical user interface (written in JAVA) is available to visualize results.

Results can be provided in excel format. Moreover, the user friendly interface allows for generating tables, graphs and maps.

6.3.6 Baseline results: global level

The following Figures illustrate the main baseline results. More detailed results as well as the description of output variables can be accessed in Project place: -> documents -> WP3 -> Task 3.3 Thematic Models -> D3.1.

Figure 10 shows the change in harvested area until 2050 while Figure 11 shows the change in crop production.

[2] General Algebraic Modeling System (GAMS), https://www.gams.com.

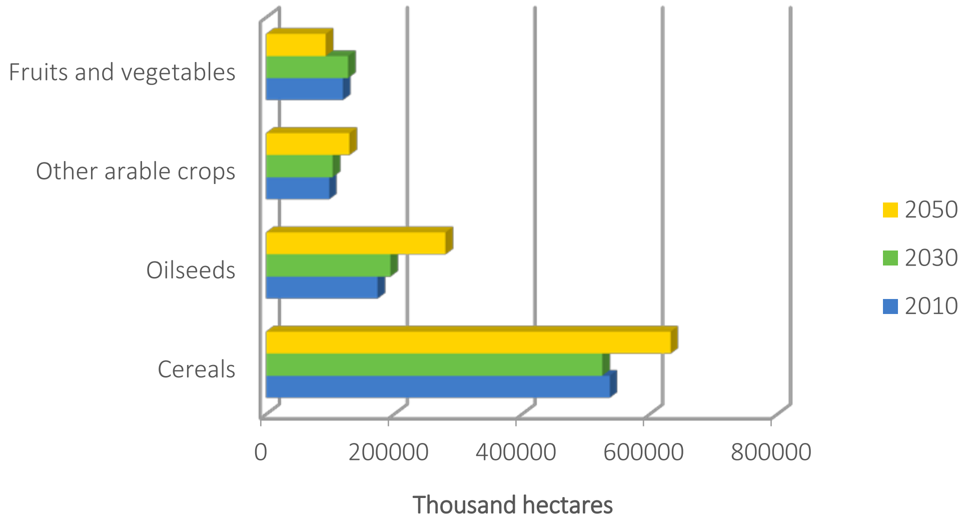


Figure 10: Global harvested area (CAPRI baseline)

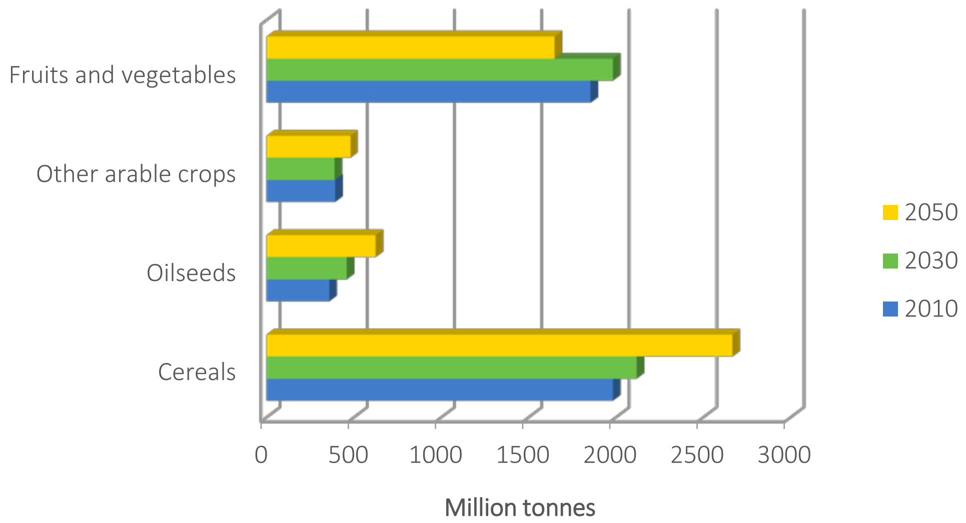


Figure 11: Global crop production (CAPRI baseline)

7 IMAGE-GLOBIO

7.1 Overview of the IMAGE-GLOBIO model

Model Type:	IMAGE-GLOBIO
Model Type: Purpose:	Integrated modelling framework of global environmental change
Spatial coverage:	Global
Spatial resolution:	30 or 5 arcminutes grids
Temporal scale:	Until 2100 in annual time steps
Website:	http://themasites.pbl.nl/models/image/index.php/Main_Page

IMAGE (www.pbl.nl/image) is a comprehensive integrated modelling framework of global environmental change, suited to large-scale and long-term assessments of the impacts of human activities on natural systems and resources.

GLOBIO (http://www.globio.info) is a global modelling framework to calculate the impacts over time of environmental drivers on terrestrial and aquatic biodiversity, and has recently been extended to also cover impacts on ecosystem services (GLOBIO-ES). Drivers include land use, infrastructure, phosphorus and nitrogen emissions, hydrological changes and climate change. Coupled to IMAGE, the GLOBIO model is used to assess the consequences of global environmental change on biodiversity (terrestrial and aquatic), and ecosystem services.

Next to GLOBIO, other impact modules of the IMAGE framework are used in SIM4NEXUS:

- GLOFRIS: global model to calculate the effects of climate change, land-use change, human population growth and economic development. It makes use of the hydrological model PCR-GLOBWB.
- GNM: global nutrient model, calculating nutrient flows to groundwater, surface water and coastal zones (GNM), water quality (GNM, PCLake). Its output is used in GLOBIO.
- GISMO: global health model focussing on changing health risks under global environmental change.

The IMAGE-GLOBIO 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. It has contributed to international scenario development activities like the SRES scenarios, and recently to the SSP scenarios. Most applications were run on a 30 arc minutes resolution, while 5 arc minutes is now available for most modules. Some modules have also been applied ‘stand-alone’ on a finer scale, such as the flood risk, water quality and biodiversity models. Recent applications include:

- OECD Environmental Outlook (OECD 2012)
- Global Sustainable Development goals (Van Vuuren et al. 2015)
- Resource efficiency in the EU (Van den Berg et al. 2011)
- Global Environmental Outlooks (Ward et al. 2013, Stehfest et al. 2014)
- Global Biodiversity Outlooks (PBL 2014, Janse et al. 2015)

A complete list of publications is available at http://www.globio.info/publications.

7.2 Nexus coverage

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.

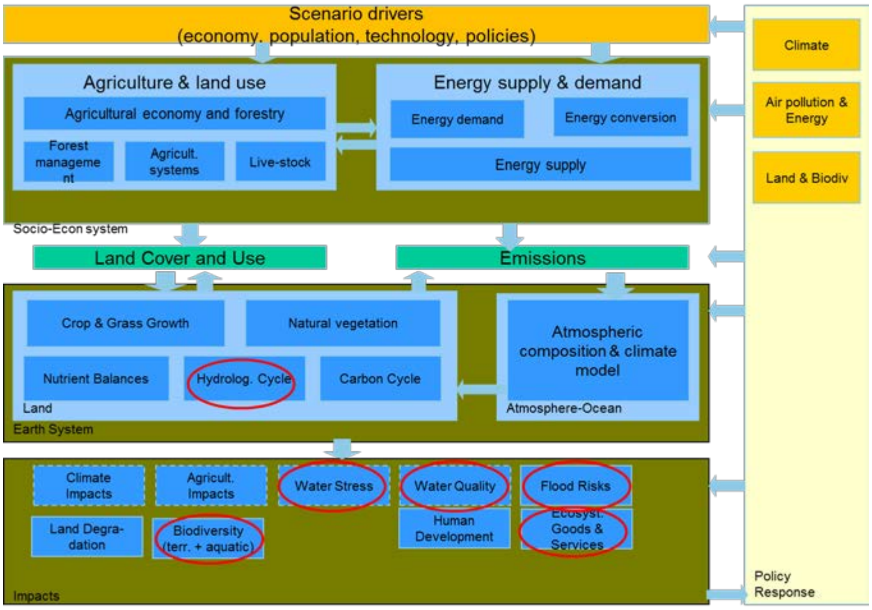


Figure 12: IMAGE-GLOBIO model framework

A strength of the model is its integrated nature, securing globally balanced flows of material. A weakness is its technically complex model structure which hampers easy links with other thematic models. However, several components can also be run 'stand-alone' and use input from or deliver output to external models. Some feedback between water and crop growth is incorporated via LPJmL simulations. Other feedbacks and trade-offs will be dealt with via the water quality, biodiversity and ecosystem services modules.

7.3 First application to case studies

7.3.1 Selected case studies

The IMAGE model as a whole can be used for the global and the European case studies, using the available scenario studies covering the effects of food and energy demand, land-use and consumption patterns on discharge patterns, water availability, water quality, biodiversity, algal blooms, temperature change and flood risk. The module for aquatic ecosystem services, allowing analysis of synergies and trade-offs between them, has not yet been incorporated in the scenario studies. The global scenarios and output may be used as 'background' for the national and regional case studies, but the model is not meant for detailed hydrological or land-use analyses at those scales. However, some empirical or meta-relations from the GLOBIO/GLOBIO-ES, PCLake and GLOFRIS models can be transferred to other scales.

GLOBIO (including GLOBIO_Terra, GLOBIO_Aqua, PCLake, GNM, GLOFRIS) is the biodiversity model of the IMAGE framework. It uses IMAGE output but parts may also be applied on smaller scales. Apart from the global and European case studies, it will be applied in two national case studies (Greece and Sweden).

7.3.2 Simulation scenarios

Spatial and temporal scales

The model can currently run up to 2100. Scenario results are provided for 2010, 2020, 2030, 2040 and 2050. Results are available at the scale of 26 large world regions (for socio-economic parameters), and most parameters of the physical system are available at a 5 minutes or 30 minutes grid resolution.

GLOBIO can also be run at regional scale if regional input data are provided. Most parameters in GLOBIO are at a 5 minutes or 30 minutes grid resolution. Aggregation can be done per IMAGE region (26), biomes, river catchments, etc.

Alignment with the scenario framework for climate change research

The SSP and RCP pathways have already been implemented.

Baseline scenario: Main assumptions

Both IMAGE and GLOBIO use SSP2 as the baseline scenario, and thus use the available projections for population (KC and Lutz, 2017) and economic development (Dellink et al., 2017). The 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).

Other specific assumptions in the GLOBIO baseline are described in Alkemade et al (2009), Janse et al (2015), Beusen et al (2016), and in technical papers on the website www.globio.info. A paper on the SSP scenario assumptions and results for biodiversity and water is in preparation.

7.3.3 Input data

IMAGE:

A detailed list of drivers is available at the website, for the entire model (http://themasites.pbl.nl/models/image/index.php/Variable_overview), and per model component (i.e. water, http://themasites.pbl.nl/models/image/index.php/Water). Here we present some key input variables:

- Population
- Economic growth
- Dietary preferences
- Technological change (agriculture and energy system)
- Policy assumptions

GLOBIO and GLOFRIS:

- P and N emissions (g m-2 y-1)
- Precipitation, evaporation (L m-2 d-1)
- Global mean temperature
- Land use and water maps
- River dams (location, capacity)

Further details on input data used can be found in the IMAGE 3.0 description (Stehfest et al. 2014).

7.3.4 Model outputs

A detailed list of model outputs, per model component, is available at the IMAGE website (i.e. for water (http://themasites.pbl.nl/models/image/index.php/Water). The model components can be viewed at http://themasites.pbl.nl/models/image/index.php/Framework_overview). In the following tables, we show some key output variables.

Table 10. Summary of output variables in IMAGE

Output variable	Units
Mean global temperature	Degree Celsius
CO2 and other GHG emissions	Gt CO2-equ.
CO2 concentration	ppm
Food production and allocation	Mtonne
Land use	grid scale
Carbon and water dynamics	grid scale stocks and fluxes

Table 11. Summary of output variables in GLOBIO and GLOFRIS

Output variable	Units
Biodiversity intactness (MSA) per pixel, terrestrial and aquatic per water type (-)	
Fish species richness	
Water discharge	m3 y-1
Total P	mg L-1
Total N	mg L-1
Algal blooms, Chlorophyll-a	mg m-3
Secchi depth	m
Aquatic vegetation	% coverage
Wetland area per pixel	km2
Water temperature (C), daily or monthly	C
Nutrient retention	%
C sequestration	
Flood risk per km2	

7.3.5 Technical implementation

The IMAGE model is programmed in FORTRAN, several other modules in different programming languages coupled via soft and hard links. GLOBIO is a coupled model in ArisFlow, some modules can also be run independently.

Results are provided in excel or csv, and maps in ArcGIS.

Scenario results will be provided as specified in the SSP reporting template. Additional variables will be added to cover topics such as biodiversity, ecosystem services, and water quality.

There is a User Support System (USS) to view scenario results. The USS and scenario results can be downloaded and installed from the IMAGE website, the SSP2 scenario will be available there in summer 2017 (http://themasites.pbl.nl/models/image/index.php/Download).

7.3.6 Baseline results: global level

Simulation results are already available for the global case study. Here, we show land use (Figure 13) and water demand (Figure 14) in the SSP2 baseline scenario, and also the range of results under SSP1 and SSP3. Land use covers cropland and pasture for food production, and also areas used for bioenergy plantations. More detailed results can be accessed in Project place: -> documents -> WP3 -> Task 3.3 Thematic Models -> D3.1. The full output dataset of IMAGE for SSP2 is shared with the other models in the global case study.

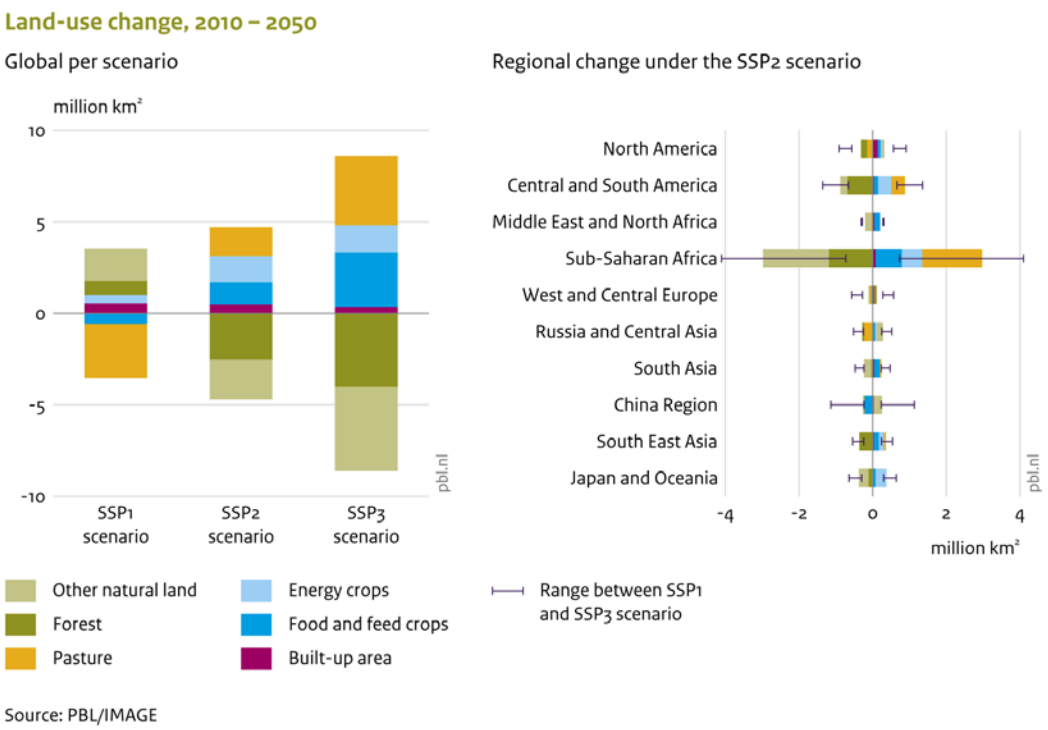


Figure 13: Land-use change between 2010 and 2050 at the global level (left) and per region (right). The coloured bars give the SSP2 projection of how in each region some types of land-use increase, while other types decrease. The black lines on each bar also represent those changes, but with ranges of increases and decreases as delimited by the values given by SSP1 and SSP3.

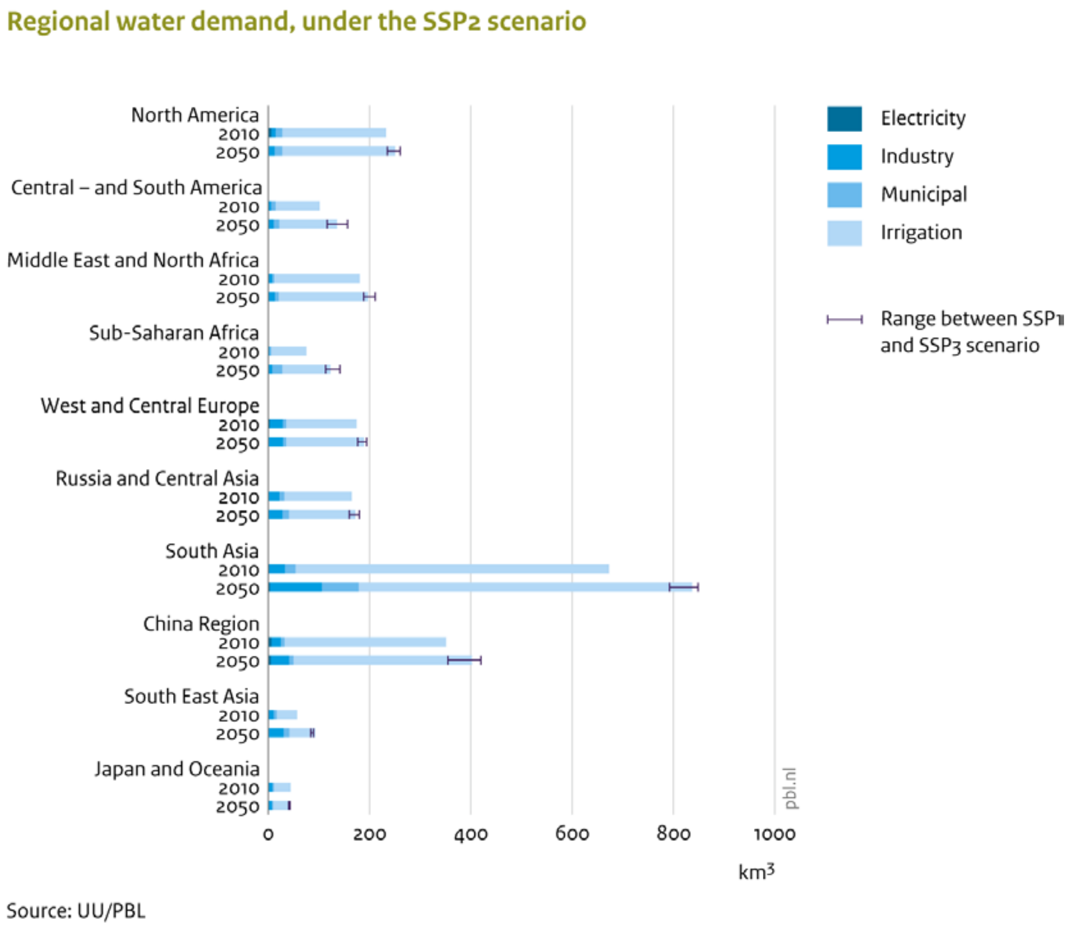


Figure 14: Regional water demand by the sectors electricity, industry, domestic use, and irrigation agriculture, for 2010 and the SSP2 projection for 2050. The black lines on the bars for 2050 represent the ranges of water demand delimited by the values projected for SSP1 and SSP3. Adopted from PBL 2017 (report in preparation).

8 OSeMOSYS

8.1 Overview of the OSeMOSYS model

Model name:	OSeMOSYS
Model type:	Global energy modelling system
Purpose:	New approaches to energy system analysis. Modelling developing country's energy systems
Spatial coverage:	Global
Spatial resolution:	Flexible (river basin, national, international)
Temporal scale:	Until 2050 in 5-year time steps
Website:	http://osemosys.weebly.com

OSeMOSYS is an open-source energy system optimisation model with a medium- to long-term time horizon and is designed to inform about the development of national and multi-regional energy strategies.

OSeMOSYS is a systems cost-optimization model idealised for long-run energy planning (Howells et al., 2011). It can flexibly accommodate constraints imposed by other systems, i.e. land use, water availability and climate change. For example, from a land use perspective, the integration can be achieved either by acting over biomass availability or by diversifying its sources.

This energy modelling system is designed to fill a gap in the analytical toolbox available to the energy research community and energy planners in developing countries. At present there exists a useful, but limited set of accessible energy system models. These tools often require significant investment in terms of human resources, training and software purchases in order to apply or further develop them. In addition, their structure is often such that integration with other tools, when possible, can be difficult.

OSeMOSYS has been applied in different studies of different spatial spans, from global, regional to country-level, and featuring all five Nexus components. **At global level**, the GLUCOSE (United Nations, 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 (Cervigni et al. 2015). Competing uses of shared water resources were studied using Sava River, Syr Darya, Alazani basins. The competition was represented with an integrated analysis that considered agriculture, energy and ecosystem needs. In these studies, which contributed to 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 example, for the Sava River Basin, it included the Nexus among climate change, hydropower expansion and water demand for agriculture (ISRBC-UNECE, 2015). 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 supervision of UNDESA. OSeMOSYS can be applied to investigate energy systems in a multi-sectoral approach.

At national and regional level:

- Additional application of OSeMOSYS is planned for selected Western Balkan and Central Asian countries. Specific follow up activities have been requested in member states, and follow up studies have been requested. Capacity building and consultative workshop were held for riparian countries of the Sava, Alazani, Syr Daria and Isonzo river basins and their authorities (KTH & UNECE 2014, KTH & UNECE 2015a, KTH & UNECE 2015b).
- OSeMOSYS provides guidance on the development of integrated strategies for the sustainable management of resources in the case of the UNECE Transboundary Nexus Assessment Process. This is a program under the water convention that has been well received, in particular as an extension to IWRM (Integrated Water Resource Management).
- Capacity building with deep modelling development and transfer is occurring in Nicaragua and Uganda for UNDESA as part of an ongoing project.

8.2 Capacity to address the Nexus

The 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.

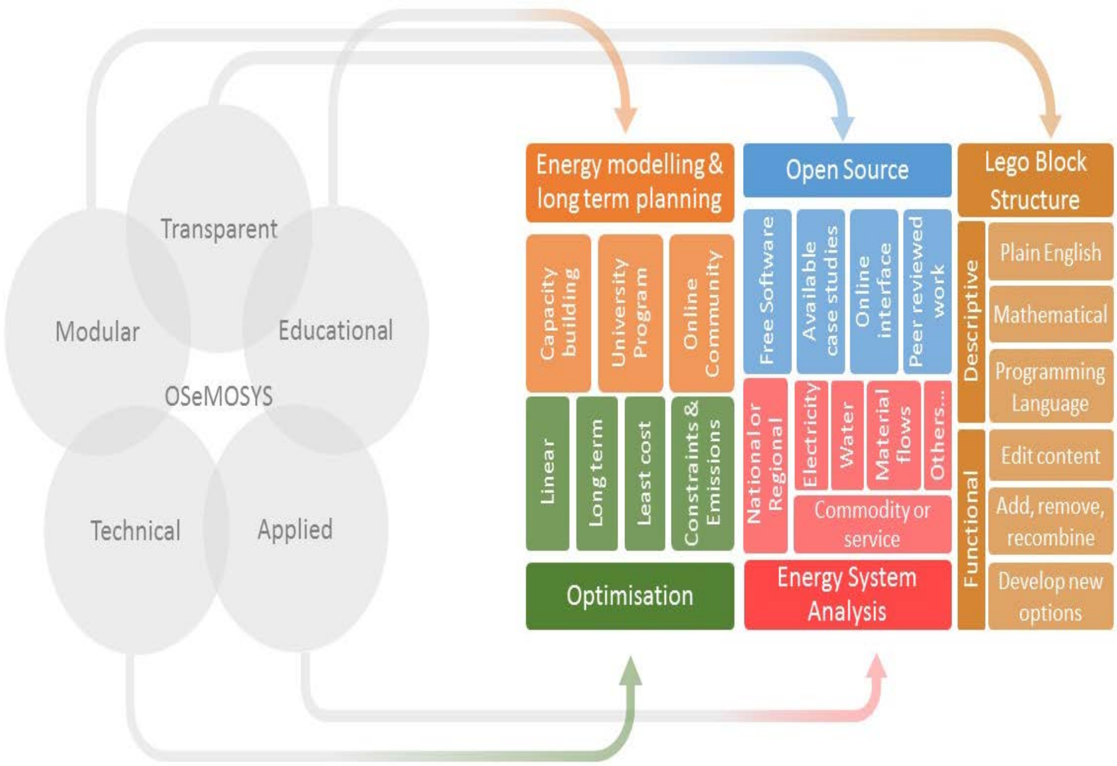


Figure 15: OSeMOSYS (Open Source Energy Modelling System)

One of the model strengths is its flexibility in terms of incorporating or delivering inputs/outputs than can be used in different stages of integrative-model development.

8.3 First application to case studies

8.3.1 Selected case studies

OSeMOSYS can be applied to any case study with an energy modelling component. In principle, it will be applied to Greece, Azerbaijan and the Global case studies. The OSeMOSYS team works in close contact with the leaders of these case studies. First simulation results are already available.

8.3.2 Simulation scenarios

Spatial and temporal scales

OSeMOSYS has no spatial analysis capabilities (i.e. grid resolution). The results are provided on a national scale for Azerbaijan and Greece and at global scale for the global case study.

The temporal scale is:

- Azerbaijan: 2015-2050
- Greece: 2010-2040
- Global: 2010-2070

Results can be provided for every year within the simulation period.

Alignment with the scenario framework for climate change research

OSeMOSYS cannot run scenarios aligned with the SSP-RCP scenario framework in a systematic way. However, RCPs have been taken into account when investigating the impacts of different climate scenarios in specific studies (Cervigni et al. 2015; UNECE-KTH 2014, ISRBC-UNECE 2015a, UNECE-KTH 2015b).

Baseline scenario: Main assumptions

For the global baseline, OSeMOSYS incorporates indicators aligned with SSP2 for final energy demand and land area. The baseline represents the business as usual with no further environmental regulations.

Azerbaijan: business as usual with modest growth and oil-based economy, no carbon price or renewable targets.

Greece: baseline scenario. For 2020, it has been set a target of 40% in the electricity generation to come from renewable energy resources and a carbon price has been set. From 2030 onwards, an annual emission cap on carbon dioxide emissions has been set.

Additional data from the case study

No additional data from the case studies has been used so far.

8.3.3 Input data

- All costs for all technologies and fuels
- Input and output fuels and efficiencies for all technologies
- Emissions for all fuels
- Disaggregated demand values
- Capacity and availability factors for all technologies
- Existing capacities and installation absolute and rate limits
- Renewable energy targets, emissions targets, other scenario factors

8.3.4 Model outputs

Cost minimised solution with capacity installations and energy outputs for all technologies, with associated costs

Table 12 presents the main output variables from OSeMOSYS. The extensive list of variables that the model can provide is reported in Appendix A, Table 19.

Table 12. Summary of output variables in OSeMOSYS

Output variable	Units
Power generation by energy source and fuel consumption by sector	PJ
Installed capacity by energy source	GW
Greenhouse gas emissions	Kton/year
Energy system cost (both investment and operating)	M$

8.3.5 Technical implementation

The model is written in Python or GLPK (GNU Linear Programming Kit).

Model results can be shared via the modelling interface, which is accessible to non-modellers. Results can also be provided using text files or csv files. It is possible to use the SSP template.

8.3.6 Baseline results: global level

Table 13 shows the main baseline results. More detailed results can be accessed in Project place: -> documents -> WP3 -> Task 3.3 Thematic Models -> D3.1.

Table 13. Summary of baseline results at the global level (OSeMOSYS)

Category	Item	Variable	Unit	2010	2030	2050
Cumulative Capacity	Electricity & Heat	Biomass	Terawatt	0.34	0.37	0.72
Cumulative Capacity	Electricity & Heat	Coal	Terawatt	2.81	3.96	5.13
Cumulative Capacity	Electricity & Heat	Oil	Terawatt	0.91	0.38	0.00
Cumulative Capacity	Electricity & Heat	Hydro	Terawatt	1.01	1.58	1.87
Cumulative Capacity	Electricity & Heat	Natural gas	Terawatt	1.93	2.83	1.53
Cumulative Capacity	Electricity & Heat	Geothermal	Terawatt	0.03	0.05	0.23
Cumulative Capacity	Electricity & Heat	Nuclear	Terawatt	0.39	0.24	0.51
Cumulative Capacity	Electricity & Heat	Ocean	Terawatt	0.00	0.00	0.00
Cumulative Capacity	Electricity & Heat	Solar	Terawatt	0.04	0.07	2.34
Cumulative Capacity	Electricity & Heat	Wind	Terawatt	0.16	0.75	2.27
Emissions	Energy Supply	CO2equiv	Gigatonne	30.87	36.58	47.11
Secondary Energy	Electricity	Biomass	Exajoule	0.81	4.20	12.33
Secondary Energy	Electricity	Coal	Exajoule	30.03	47.19	52.48
Secondary Energy	Electricity	Oil	Exajoule	2.64	1.57	3.23
Secondary Energy	Electricity	Hydro	Exajoule	12.56	22.40	26.64
Secondary Energy	Electricity	Natural gas	Exajoule	16.53	44.80	36.49
Secondary Energy	Electricity	Nuclear	Exajoule	10.84	6.50	13.92
Secondary Energy	Electricity	Geothermal	Exajoule	0.26	1.17	3.23
Secondary Energy	Electricity	Ocean	Exajoule	0.00	0.00	0.00
Secondary Energy	Electricity	Solar	Exajoule	0.23	0.44	21.77
Secondary Energy	Electricity	Wind	Exajoule	1.31	6.85	24.01
Secondary Energy	Heat	Biomass	Exajoule	8.32	13.48	29.54
Secondary Energy	Heat	Coal	Exajoule	41.95	64.58	90.95
Secondary Energy	Heat	Geothermal	Exajoule	0.39	0.07	2.04
Secondary Energy	Heat	Oil	Exajoule	13.01	2.06	2.04
Secondary Energy	Heat	Natural gas	Exajoule	23.89	37.32	14.50

9 SWIM

9.1 Main features of the SWIM model

Model name:	SWIM: Soil and Water Integrated Model
Model type:	Eco-hydrological semi-distributed model
Purpose:	Climate and land-use change impact assessment
Spatial coverage:	Several river basins in Europe, Asia, Africa and South America
Spatial resolution:	River sub-basins (typically 100–1000 km^2)
Temporal scale:	Until 2050 in daily time steps with annual aggregates as required

Website: https://www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/models/swim

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.

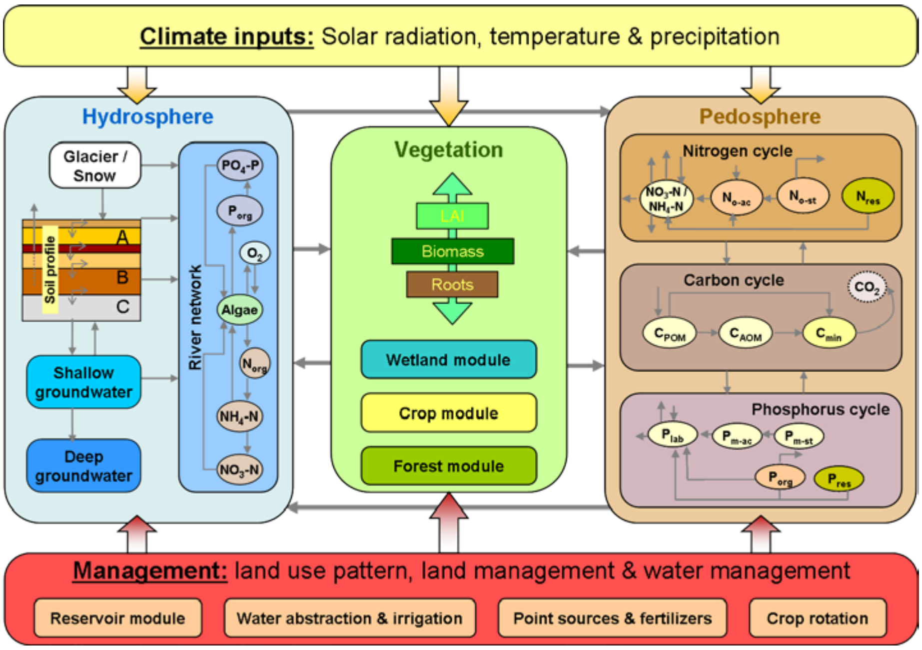


Figure 16: SWIM (Soil and Water Integrated Model)

The model can be applied for climate and land-use change impact assessment at the river basin scale. SWIM is coupled to GIS and has extensive data requirements. During the last decade SWIM was 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). After calibration and validation, SWIM can be applied for impact assessment.

The model has contributed to many regional and national impact and vulnerability assessments and adaptation frameworks (Conradt et al. 2013b, Krysanova et al. 2015). Regulations of the Water Framework Directive (i.e. for Germany, some German Federal States and various river basins: Elbe, Niger, Blue Nile, Rio San Francisco etc.) have been studied with SWIM. Most of SWIM´s applications are related to climate and land use change and adaptation strategies within the water Nexus (see Figure 17). Very recent applications include modelling of the water Nexus:

- in the Elbe basin (Czech Republic, Germany, including forecast) (Conradt et al. 2012a, Conradt et al. 2012b, Conradt et al. 2013a, Hattermann et al. 2014, Koch et al. 2014),
- in the Niger basin (Africa, including a vast wetland and rice production) (Aich et al. 2014),
- in the Tagus basin (Spain, Portugal, transboundary and reservoir management),
- in the Tarim basin (China, Kyrgyzstan, glacier dynamics) (Huang et al. 2015), and
- in the basin of the Rio San Francisco (Brazil, reservoir management).

All these applications integrate water resources, energy and biomass production, and in the case of the Elbe also navigation (Krysanova et al. 2015, Vetter et al. 2015).

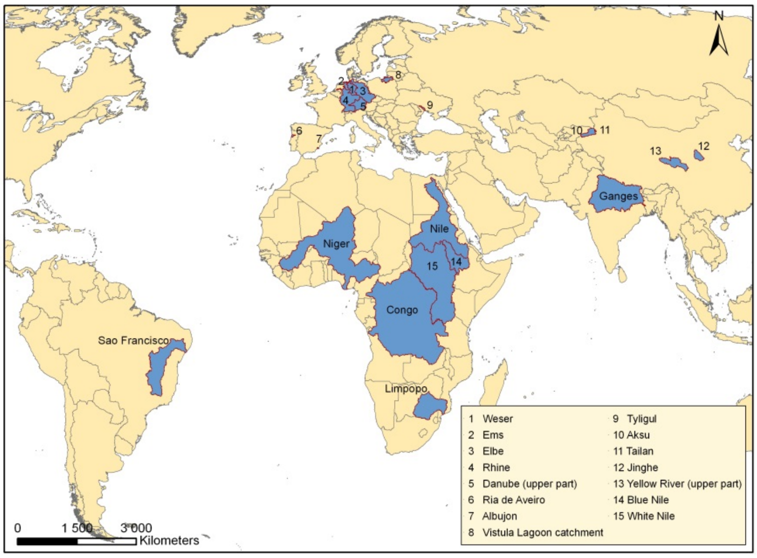


Figure 17: Regions where the SWIM model has been applied. (Note: somewhat elderly map not including i.e. the Danube, the Tagus, the Tay, Guanting (China) and the three Scandinavian basins)

9.2 Capacity to address the Nexus

Climate-land linkages

SWIM was specifically developed to investigate climate and land use change impacts at the regional scale, where the impacts are manifested and adaptation measures take place. The model simulates interlinked processes at the mesoscale such as runoff generation, plant and crop growth, nutrient and carbon cycling, and erosion. It provides numerous model outputs such as river discharge, crop yield, and nutrient concentrations and loads. The approach allows simulation of all interrelated processes within a single model framework at a daily time step using regionally available data (at least climate, land use and soil).

Water-energy linkages

SWIM models all water-related components of the Nexus at the sub-basin scale (see Figure 16) and helps estimating second-order effects (i.e. water-related energy production (hydropower, cooling of power plants). Climate and land use scenarios are needed as external drivers for water-energy scenario studies; the economy is only indirectly considered through the land use data input.

9.3 First application to case studies

9.3.1 Case studies

SWIM is a case-specific model and is being applied to the Elbe and parts of the Danube basin (Germany-Czech Republic-Slovakia case study). Simulation results have not been provided yet. In the Elbe basin, modelling of the water Nexus, impacts and adaptation strategies can be modelled with SWIM after the consideration of some new water users and reservoirs.

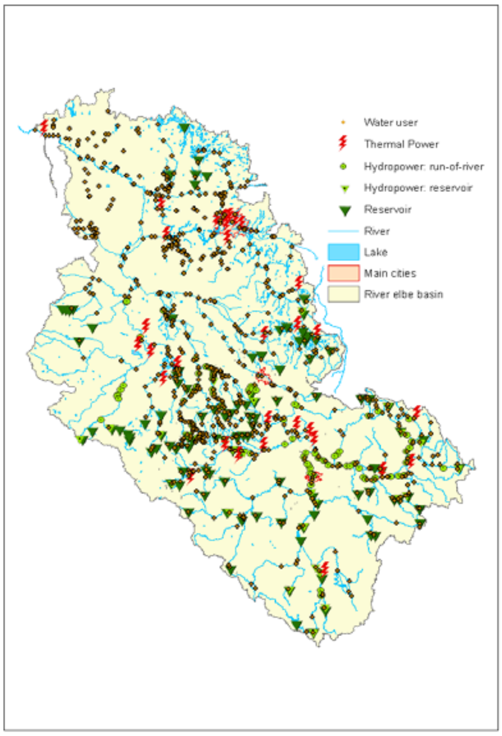


Figure 18: Map of the water Nexus in the Elbe basin (for reasons of visibility biomass production not included)

9.3.2 Simulation scenarios

Spatial and temporal scales

The reference time frame is 2001–2016, and the scenario time frame is 2006–2060. There will be daily and annual outputs, and the reference years (2010, 2030, 2050) can be averaged through separate time windows.

Results are provided for the river sub-basins, typically with sizes of 20–500 km^2.

Alignment with the scenario framework for climate change research

The model can partially be aligned with the SSP-RCP scenario framework; the SSP components are only indirectly considered by the input data (i.e. land use scenarios). A starting set of scenario data are available at the Potsdam Institute for Climate Research (PIK) and SWIM has already modelled impacts in many world regions using them.

Main assumptions used for the baseline scenario

Stable soil hydraulic conditions with land use including crop structure from around 2010 (CORINE Land Cover 2006 + regional agricultural statistics of 2010 or 2011). Other static inputs (i.e. groundwater table maps) should also be from 2010, because the baseline will be built on recent weather and runoff observations of the past two decades.

Additional data provided by the case studies

SWIM uses additional data from the Germany-Czech Republic-Slovakia case study. So far, additional data from the German part has been considered. There will also be contributions from the Czech Republic and Slovakia.

9.3.3 Input data

The minimum set of required data consists of:

- Climate data: daily values of
  - maximum
  - minimum
  - average air temperature
  - solar radiation
  - air humidity
  - precipitation

for each sub-basin (usually interpolated from station data)

- Four Maps:
  - Digital elevation model (DEM) of high resolution and accuracy
  - Sub-basin map in accordance with the DEM and man-made alterations of the natural flow paths
  - Land use data: 14 pre-defined classes, usually resampled from CORINE land cover data

- Soil map with detailed soil profile data down to 2 m depth

Possible extensions include:

- Groundwater table location
- Bedrock or sediment transmissivities
- Data on reservoirs (location, volume–surface relationship, operation schedule)
- Irrigation areas and water budget
- Crop structure with fertilizer applications, sowing and harvesting dates

9.3.4 Model outputs

The model uses a three-level disaggregation scheme: basin–sub-basins–hydrotopes. The results are presented as time series and maps for a number of variables.

No output provided yet, but there will be river discharges in m^3/s and agricultural yields in dt/ha, see Table 14.

Table 14. Summary of output variables in SWIM

Output variable	Units
River discharge at sub-basin outlet, time series	m^3/s
Agricultural yield of chosen crop (i.e. winter wheat map)	dt/ha

9.3.5 Technical implementation

The model setup and post-processing are supported by a GIS interface (based on GRASS GIS; there is an alternative using Map Window).

Model results will be provided in ASCII format or CSV tables in UTF-8 encoding.

It will be possible to use the SSP reporting format. However, as the output regions are river sub-catchments, these tables cannot easily be linked to administrative subdivision or grid cell based outputs. This reporting issue will be addressed in a subsequent report on downscaling (Deliverable 3.2).

9.3.6 Baseline results

SWIM is the only model unsuitable for providing results at the global level. Therefore, baseline results from this model are not reported here.

Results from the Germany-Czech Republic-Slovakia case study are not available yet. The former assessment of the Elbe River basin (Conradt et al. 2012a, Koch et al. 2014) projected largely decreasing river discharges and respective shortages in energy production. The climate scenario used back then seems, however, to be biased towards drought conditions.

10 MAgPIE

10.1 Overview of the MAgPIE model

Model name:	MAgPIE: Model of Agricultural Production and its Impact on the Environment
Model type:	Global land use allocation model
Purpose:	Provision of quantitative long-term scenarios of the agro-food system for decision making
Spatial coverage:	Global
Spatial resolution:	Detailed grids
Temporal scale:	Until 2100 in 5-year time steps
Website:	https://www.pik-potsdam.de/research/projects/activities/land-use-modelling/magpie

MAgPIE is a global socio-economic model of the agro-food system. Based on economic conditions, food demand, technological development, land and water constraints, MAgPIE derives specific land use patterns, crop yields and total costs of agricultural production at the grid scale.

MAgPIE is a 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°. It takes regional economic conditions such as demand for agricultural commodities, technological development and production costs as well as spatially explicit data on potential crop yields, land and water constraints (from LPJmL) into account. Based on these, the model derives specific land use patterns, yields and total costs of agricultural production for each grid cell. 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. Regional food energy demand is defined for an exogenously given population in 10 food energy categories, based on regional diets. Future trends in food demand are derived from a cross-country regression analysis, based on future scenarios on GDP and population growth.

Food and feed energy for the demand categories can be produced by 20 cropping activities and 3 livestock activities. Feed for livestock is produced as a mixture of crops, crop residuals, processing by-products, green fodder produced on crop land, and pasture. Variable inputs of production are labour, chemicals, and other capital (all measured in US$). Costs of production are derived from the Global Trade Analysis Project (GTAP) Database[3]. The model can endogenously decide to acquire yield-increasing technological change at additional costs. The costs for technological change for each economic region are based on its level of agricultural development, measured as agricultural land-use intensity. These costs grow with further investment in technological change. The use of technological change is either triggered by a better cost-effectiveness compared to other investments or as a response to resource constraints, such as land scarcity.

Recent contributions to Nexus related impact studies:

- Contribution to the development of the SSP Scenarios: SSP Database (Shared Socioeconomic Pathways). https://tntcat.iiasa.ac.at/SspDb
- Contribution to the AgMIP model intercomparison project (Lotze-Campen et al 2014, Popp et al. 2014)
- Contribution to several Worldbank reports: Schellnhuber et al. (2013). Turn down the heat: climate extremes, regional impacts, and the case for resilience. http://www.worldbank.org/en/topic/climatechange/publication/turn-down-the-heat-climate-extremes-regional-impacts-resilience
- Bioenergy (Lotze-Campen et al. 2014, Bonsch et al. 2014, Humpenöder et al. 2014)
- GHG emissions from agriculture (Popp et al. 2010, Bodirsky et al. 2012)
- Food-water Nexus (Schmitz et al. 2013)

10.2 Capacity to address the Nexus

The model includes the interactions between food, water and (bio)energy, as well as several other cobenefits (nutrient pollution, greenhouse gas emissions, climate impacts,…) 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, climate-induced changes in physical blue water availability and water-use, economic water-scarcity indicators, yield patterns of irrigated and non-irrigated agricultural production, bioenergy production and

[3] https://www.gtap.agecon.purdue.edu/

competition for biophysical resources, full endogenous interaction between food, water and bioenergy as well as optimization of resource use.

Energy-system dynamics and the influence of other non-agricultural sectors are not included.

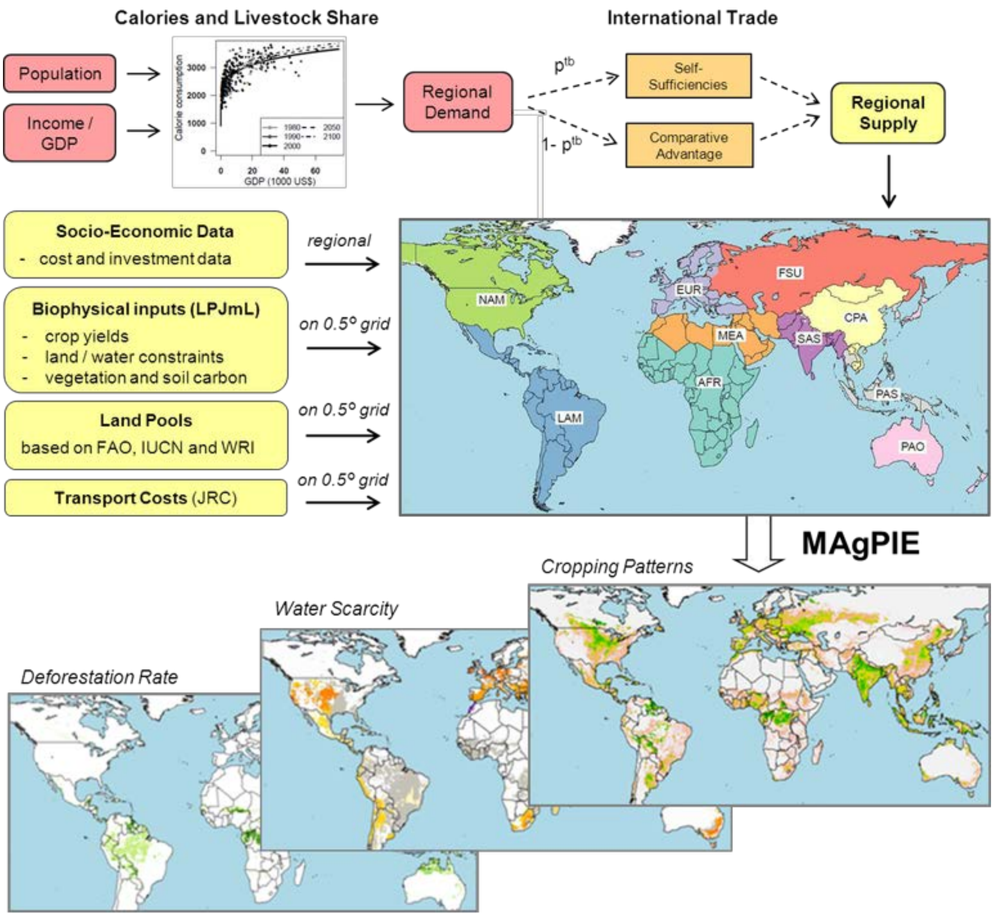


Figure 19: Simplified MAgPIE flowchart of key processes (demand and trade implementation, data inputs from LPJmL and spatially explicit water shadow prices).

With exogenous data about population and GDP development, MAgPIE calculates regional demand and the livestock share. The former is then translated to regional supply taking into account the international trade scenario. Further inputs for MAgPIE are socioeconomic data like production costs and biophysical inputs from LPJmL. After the optimization of MAgPIE, one of the outputs is cropping patterns of the different crops, which are the basis for the calculation of water shadow prices.

10.3 First application to case studies

10.3.1 Case studies

MAgPIE is being applied to two case studies, the global and the European cases. Simulation results have not been provided yet.

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 are in progress.

10.3.2 Baseline scenario

Temporal and spatial scales

The simulated period is 2005-2100. The model can provide results for 5-year time steps, including 2010, 2030 and 2050.

All outputs can be created at the spatial level of 10 world regions. A limited number of outputs (including land-use patterns) can be derived at a spatial scale of 0.5*0.5° grid cells covering the whole global land area.

Alignment with the scenario framework for climate change research

The model is aligned with the SSP-RCP scenario framework. MAgPIE is part of one of five integrated assessment modelling teams that provide the quantitative estimates for the SSP database. The SSP scenarios have already been simulated (SSP1 to SSP5).

Baseline scenario: Main assumptions

We simulate the SSP scenarios with the drivers being population, GDP, lifestyle assumptions, bioenergy needs, trade policies, land-use policies, assumptions on land-based mitigation, and assumptions on technological progress.

Relevant Literature:
Popp, Alexander, Katherine Calvin, Shinichiro Fujimori, Petr Havlik, Florian Humpenöder, Elke Stehfest, Benjamin Leon Bodirsky, et al. 2017. "Land-Use Futures in the Shared Socio-Economic Pathways." Global Environmental Change 42 (January): 331–45. doi:10.1016/j.gloenvcha.2016.10.002.

10.3.3 Input data

The main input data (units used are indicated in brackets) are:

- Population (Mio inhabitants)
- Income (US$05 MER per inhabitant)
- Bioenergy demand (EJ)
- Historical land-use patterns (Million hectares)
- Biophyiscal crop yield patterns (t/ha)
- Water use for crop production (cubic meters per ha)
- Water availability (cubic meters per grid cell)
- Production Utilization Balances (Million tons)
- Production Costs (Million Dollars)

10.3.4 Model outputs

The following table shows the main output variables in MAgPIE. The extensive list of variables that the model can provide is reported in Appendix A, Table 20.

Table 15. Summary of output variables in MAgPIE

Output variable	Units
Cropland area	Million hectares
Pasture area	Million hectares
Forest area	Million hectares
Crop production	Million tons
Crop utilization	Million tons
Bioenergy production	Million hectares
Water usage	Cubic meters
Irrigation area	Million hectares
Water shadow price	$/cubic meter
Livestock production	Million tons
Greenhouse Gas Emissions	Million tons CO2/N2O/CH4
Food Demand for plant products	kcal/capita/day
Food Demand for animal-based products	kcal/capita/day

10.3.5 Technical implementation

The model is implemented in R[4] and GAMS[5].

[4] R Project for Statistical Computing, https://www.r-project.org/.
[5] General Algebraic Modeling System (GAMS), https://www.gams.com.

Model results will be stored on a server as csv reporting file. Results are provided as csv tables, using the SSP template.

10.3.6 Baseline results: global level

The following Figures illustrate the main baseline results. More detailed results can be accessed in Project place: -> documents -> WP3 -> Task 3.3 Thematic Models -> D3.1.

Figure 20 shows changes in total land area at the global level. Focusing on cropland, Figure 21 shows area changes in different world regions. As indicator for water pressures, Figure 22 presents the change in irrigated area.

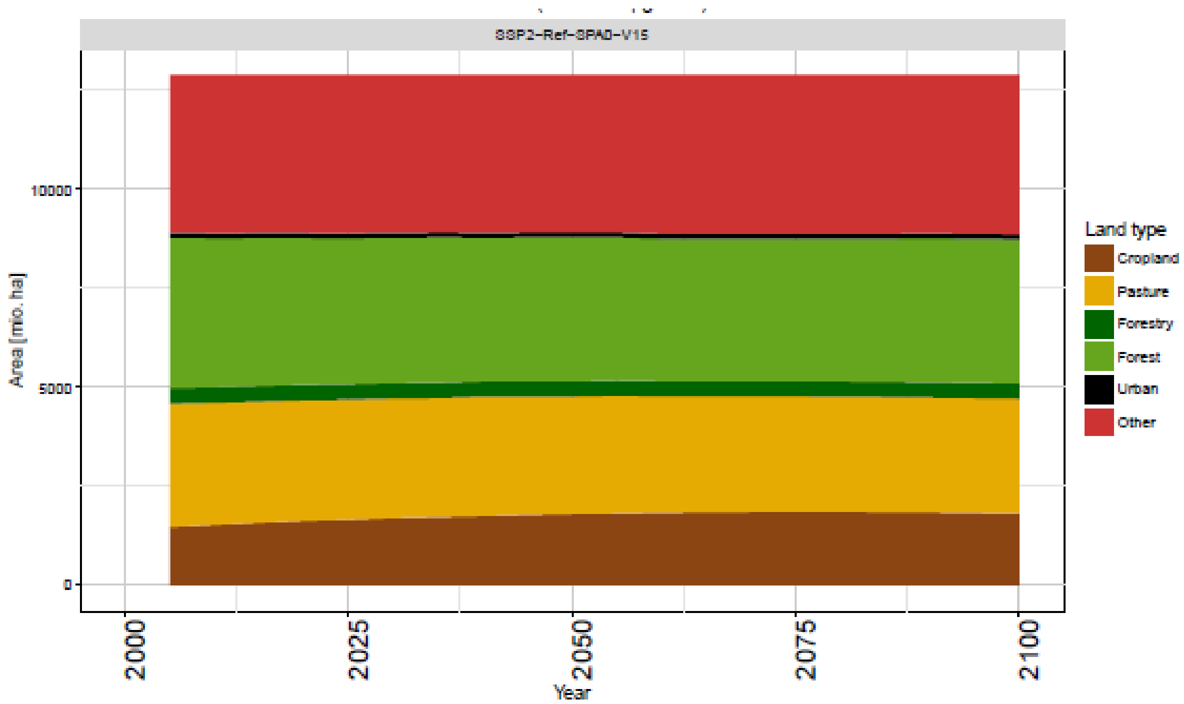


Figure 20: Change in total global land area (MAgPIE baseline).

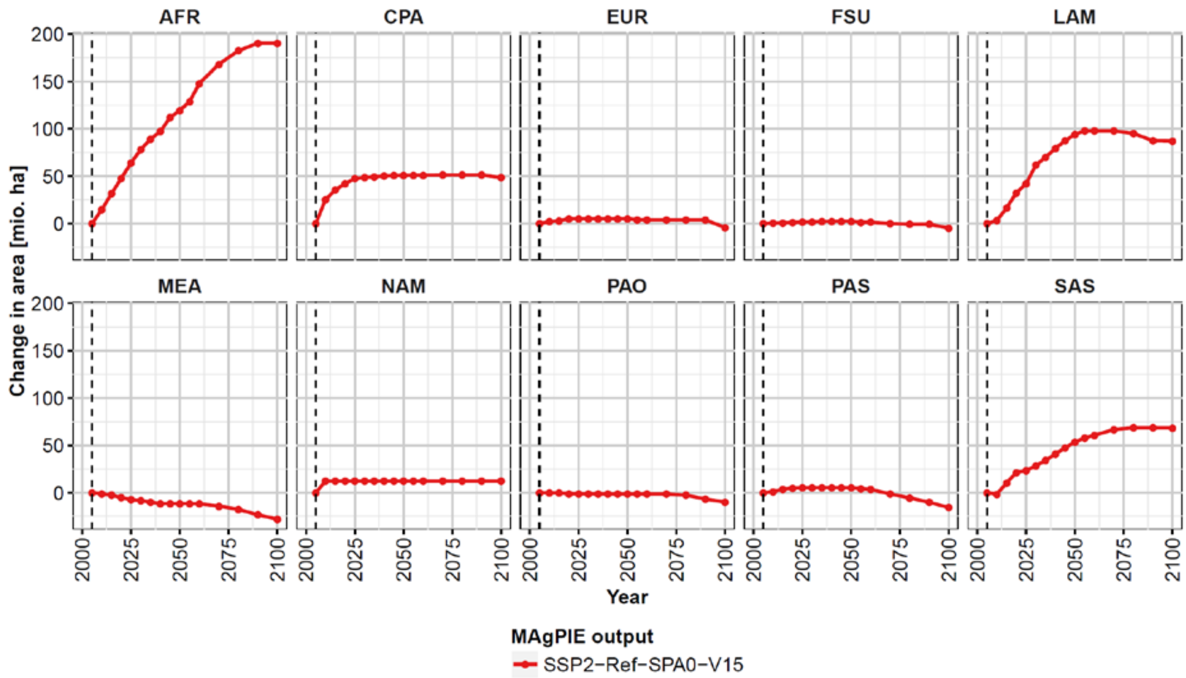


Figure 21: Change in cropland in MAgPIE world regions (MAgPIE baseline).

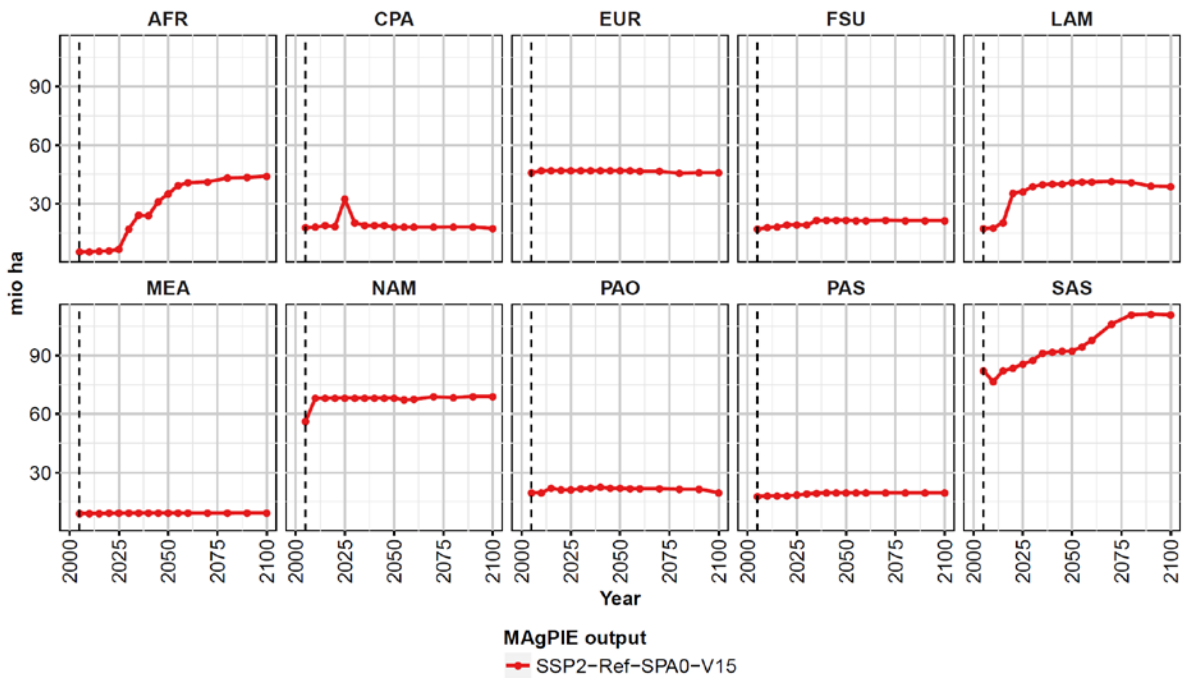


Figure 22: Change in irrigated area in MAgPIE world regions (MAgPIE baseline).

11 Lessons learned and future work

Data harmonisation

Using several thematic models – very diverse in nature – to analyse the Nexus in each case study requires additional efforts to harmonise the simulation settings. The thematic models use different spatial and temporal scales; some of them can be applied globally while others can only be applied at the national, regional or river basin scale.

Some models have already been used together in previous projects, which ease the process.

Alignment of scenarios and time horizons

The time horizon for the projections in SIM4NEXUS was decided at an early stage. In principle, all models will run up to 2050, providing results at least for 2010, 2030 and 2050.

The baseline scenario corresponds to the SSP2. Some of the models do not need additional data from the case studies to deliver the baseline (E3ME, MAGNET, CAPRI, IMAGE/GLOBIO and MAgPIE-LPJmL). In contrast, OSeMOSYS and SWIM are case-study specific and input data from the case studies may be required to apply these models.

Fast-track case study

A fast-track case study has been selected (the Sardinia case study) to test the modelling process. The fast-track is being very helpful to better understand what the thematic models can deliver and to what extent their outcomes fulfil the expectations of the case studies and the needs of the complexity models that are developed from them.

However, as much effort has been made in the fast-tack case study, the progress made in the rest of the case studies has been slowed down.

Common reporting template

Using a common reporting template is essential to combine model outputs and allow comparability of results. Discussions on the reporting format are on-going. A common agreement is to use the SSP reporting template, which will have to be complemented with additional variables depending on the specific model used.

Coverage of Nexus components

The thematic models have been selected for each case study in order to cover the main Nexus challenges. However, in some cases it might not be possible to cover all Nexus components with the available models. It is essential to identify the gaps to address the Nexus at an early stage. This task requires the interaction of the case studies knowing what are the main Nexus challenges and the modelling teams.

Coordination with other tasks

The application of the thematic models to the case studies is based on general requests and guidelines implied by WP5. Therefore, a careful coordination between T3.3 and T5.2 is required to reach the expectations of SIM4NEXUS. Any delay in identifying the Nexus challenges in the case study, or in contacting model developers, will also involve delays in providing model results.

In this sense, the present report can be used as guidance for the case studies on the applicability of the thematic models to address the main Nexus challenges as well as on the specific output variables provided by each model.

12 References

Ahmed S.A., Rose S.K., Hertel T.W., Irfanoglu Z.B. (2014). Development of the Version 8 Non-CO2 GHG Emissions Dataset. GTAP Data Documentation. Purdue University.

Aich V., Liersch S., Vetter T., Huang S., Tecklenburg J., Hoffmann P., Koch H., Fournet S., Krysanova V., Müller E.N., Hattermann F.F. (2014). Comparing impacts of climate change on streamflow in four large African river basins. Hydrology and Earth System Sciences, 18, 4, 1305-1321.

Alkemade R., Van Oorschot M., Miles L., Nellemann C., Bakkenes M., Ten Brink B. (2009). GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. Ecosystems, 12(3): 374-390.

Barker T., Alexandri E., Chewpreecha U., Ogawa Y., Pollitt H. (2015). GDP and Employment Effects of Policies to Close the 2020 Emissions Gap. Climate Policy, DOI:10.1080/14693062.2014.1003774.

Beusen A.H.W., Bouwman A.F., Van Beek L.P.H., Mogollón J.M., Middelburg J.J. (2016). Global riverine N and P transport to ocean increased during the 20th century despite increased retention along the aquatic continuum. Biogeosciences, 13, 2441–2451.

Blanco M., Ramos F., Van Doorslaer B., Martínez P, Fumagalli D., Ceglar A, Fernández F.J. (2017). Climate change impacts on EU agriculture: A regionalized perspective taking into account market-driven adjustments. Agricultural Systems, 156: 52–66. doi: 10.1016/j.agsy.2017.05.013.

Blanco M., Witzke H.P., Perez-Domínguez I., Salputra G., Martínez P. (2015). Extension of the CAPRI model with an irrigation sub-module. Luxembourg: Publications Office of the European Union, EUR 27737 EN. doi: 10.2791/319578.

Blanco M, Adenäuer M, Shrestha S, Becker A (2013). Methodology to assess EU Biofuel Policies: The CAPRI Approach. JRC Scientific and Policy Report EUR 25837 EN. Luxembourg: Publications Office of the European Union, 2013.

Blanco M., Burrell A., Gay S.H., Henseler M., Kavallari A., M'Barek R., Pérez Domínguez I., Tonini A. (2010). Impacts of the EU biofuel target on agricultural markets and land use: a comparative modelling assessment. European Commission Joint Research Centre, Reference Report EUR 24449. Luxembourg: Publications Office of the European Union. ISBN 978-92-79-16310-4. doi:10.2791/45105

Bodirsky B., Popp A., Weindl I., Dietrich J.P, Rolinski S., Scheiffele L., Schmitz C., Lotze-Campen H. (2012). N2O Emissions from the Global Agricultural Nitrogen Cycle – Current State and Future Scenarios. Biogeosciences 9 (10): 4169–97. doi:10.5194/bg-9-4169-2012.

Bonsch M., Humpenöder F., Popp A., Bodirsky B., Dietrich J.P., Rolinski S., Biewald A., et al. (2014). Trade-Offs between Land and Water Requirements for Large-Scale Bioenergy Production. GCB Bioenergy, November, n/a – n/a. doi:10.1111/gcbb.12226.

Britz W., Witzke P. (2014). Capri model documentation. http://www.capri-model.org

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

Calzadilla A., Rehdanz K., Tol R.S.J. (2011). The GTAP-W model: accounting for water use in agriculture. Kiel Working Paper No. 1745.

Cervigni R., Liden R., Neumann J. E., Strzepek K. M. (Eds.). (2015). Enhancing the climate resilience of Africa's infrastructure: the power and water sectors. World Bank Publications.

Conradt T., Roers M., Schröter K., Elmer F., Hoffmann P., Koch H., Hattermann F.F., Wechsung F. (2013a). Comparison of the extreme floods of 2002 and 2013 in the German part of the Elbe River basin and their runoff simulation by SWIM-live. Hydrologie und Wasserbewirtschaftung 57 (5):241-245. doi:10.5675/HyWa_2013,5_4

Conradt T., Wechsung F., Bronstert A. (2013b). Three perceptions of the evapotranspiration landscape: comparing spatial patterns from a distributed hydrological model, remotely sensed surface temperatures, and sub-basin water balances. Hydrology and Earth System Sciences 17 (7):2947-2966. doi:10.5194/hess-17-2947-2013

Conradt T., Koch H., Hattermann F.F., Wechsung F. (2012a). Spatially differentiated management-revised discharge scenarios for an integrated analysis of multi-realisation climate and land use scenarios for the Elbe River basin. Reg Environ Change 12(3) 633–648.

Conradt T., Koch H., Hattermann F.F., Wechsung F. (2012b). Precipitation or evapotranspiration? Bayesian analysis of potential error sources in the simulation of sub-basin discharges in the Czech Elbe River basin. Regional Environmental Change 12 (3):649-661. doi:10.1007/s10113-012-0280-y

Delincé J., Ciaian P., Witzke H.P. (2015). Economic impacts of climate change on agriculture: the AgMIP approach. J App Remote Sens 9: 097099.

Dellink R., Chateau J., Lanzi E., Magné B. (2017). Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environ. Change 42, 200–214.

Dixon P., van Meijl H., Rimmer M., Shutes L., Tabeau A. (2013). The Impact of Global RED and REDD Policies on European Land Markets. In J. Swinnen & L. Knops (Eds.): Land, Labour and Capital Markets in European Agriculture: Diversity under a Common Policy. Centre for European Policy Studies (CEPS), Brussels.

European Commission (2014a). 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 (2014b). Impact Assessment Accompanying the Communication "Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy". European Commission, Brussels, SWD(2014) 255 final.

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

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

EC (2015). Medium-term prospects for EU agricultural markets and income 2015-2025. European Commission, Brussels, D.G. Agriculture and Rural Development.

EC (2014). Medium-term prospects for EU agricultural markets and income 2014-2024. European Commission, Brussels, D.G. Agriculture and Rural Development.

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

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

Gocht A., Espinosa M., Leip A., Lugato E., Schroeder L.A., Van Doorslaer B., Gomez y Paloma S. (2016). A grassland strategy for farming systems in Europe to mitigate GHG emissions—An integrated spatially differentiated modelling approach, Land Use Policy 58 (15. Dezember 2016): 318–34. doi:10.1016/j.landusepol.2016.07.024

Hattermann F. F., Huang S., Burghoff O., Willems W., Österle H., Büchner M., Kundzewicz Z. W. (2014). Modelling flood damages under climate change conditions - a case study for Germany. - Natural Hazards and Earth System Sciences, 14, 12, 3151-3168

Howells M., Rogner H.H., Strachan N., Heaps C., Huntington H., Kypreos S., Hughes A., Silveira, S., DeCarolis J., Bazillian M., Roehrl A. (2011). OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development, Energy Policy, vol. 39 (10): 5850–5870.

Huang S., Krysanova V., Su B., Zhai J. (2015). Impact of intensive irrigation activities on river discharge under agricultural scenarios in the semi-arid Aksu River basin, northwest China. Water Resour. Manag. 29(3):945-959. DOI: 10.1007/s11269-014-0853-2

Humpenöder F., Popp A., Dietrich J.P., Klein D., Lotze-Campen H., Bonsch, M., Bodirsky B., Weindl I., Stevanovic M., Müller C. (2014). Investigating Afforestation and Bioenergy CCS as Climate Change Mitigation Strategies. Environmental Research Letters 9 (6): 064029. doi:10.1088/1748-9326/9/6/064029.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

ISRBC-UNECE (2015). Draft Report on the Water-Food-Energy-Ecosystems Nexus of the Sava River Basin.

Janse J.H., Kuiper J.J., Weijters M.J., Westerbeek E.P., Jeuken M.H.J.L., Bakkenes M., Alkemade R., Mooij W.M., Verhoeven J.T.A. (2015). GLOBIO-Aquatic, a global model of human impact on the biodiversity of inland aquatic ecosystems. Environmental Science & Policy 48, 99-114.

KC S., Lutz W. (2017). The human core of the shared socioeconomic pathways: population scenarios by age, sex and level of education for all countries to 2100. Global Environ. Change 42, 181–192.

Koch H., Vögele S., Kaltofen M., Grossmann M., Grünewald U. (2014): Security of Water Supply and Electricity Production: Aspects of Integrated Management. Water Resources Management, 28(6), 1767-1780.

Koopman J.F.L., Kuik O.J., Tol R.S.J., Brouwer R. (2015). The potential of water markets to allocate water between industry, agriculture and public water utilities as an adaptation mechanism to climate change. Mitigation and adaptation strategies for global change. DOI: 10.1007/s11027-015-9662-z

Kriegler E., O'Neill B.C., Hallegatte S., Kram T., Lempert R.J., Moss R.H., Wilbanks T. (2012). The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways. Global Environ Chang 22: 807-822.

Krysanova V., Hattermann F., Huang S., Hesse C., Vetter T., Liersch S., Koch H., Kundzewicz Z.W. (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.

KTH & UNECE (2014). Alazani/Ganikh RiverBasin Water-Food-Energy-Ecosystems Nexus assessment (Draft). Geneva. (Please see: http://www.unece.org/env/water/nexus.html)

KTH & UNECE (2015a). Sava River Basin Basin Water-Food-Energy-Ecosystems Nexus assessment (Draft). Geneva. (Please see: http://www.savacommission.org/announce_detail/55/2.)

KTH & UNECE (2015b). Syr Daria River Basin Water-Food-Energy-Ecosystems Nexus assessment (Draft). Geneva. (Please see: http://www.unece.org/env/water/nexus.html)

Leip A., Billen G., Garnier J., Grizzetti B., Lassaletta L., Reis S., Simpson D., Sutton M.A, de Vries W., Weiss F., Westhoek H. (2015). Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Environmental Research Letters 10: 115004

Lotze-Campen H., von Lampe M., Kyle P., Fujimori S., Havlik P., van Meijl, H., Hasegawa T., Popp A., Schmitz C., Tabeau A., Valin H., Willenbockel D., Wise, M. (2014). Impacts of increased bioenergy demand on global food markets: an AgMIP economic model intercomparison. Agricultural Economics, 45: 103–116. doi: 10.1111/agec.12092

Martínez, P., Blanco, M., Van Doorslaer, B., Ramos, F. and Stanca, L. (2015). What role does climate change play in agricultural market uncertainty? An integrated assessment taking into account market-driven adjustments. Communication accepted for oral presentation in the 29th International Conference of Agricultural Economists. August 2015, Milan. Italy.

Mercure J-F, Pollitt H., Chewpreecha U., Salas P., Foley A.M., Holden P.B., Edwards N.R. (2014) The dynamics of technology diffusion and the impacts of climate policy instruments in the decarbonisation of the global electricity sector. Energy Policy, Volume 73, pp 686–700, Elsevier.

Nelson G., Ahammad H., Deryng D., Elliott J., Fujimori S., Havlik P., Heyhoe E., Kyle P., von Lampe M., Lotze-Campen H., Mason d'Croz D., van Meijl H., van der Mensbrugghe D., Müller C., Robertson R., Sands R. D., Schmid E., Schmitz C., Tabeau A., Valin H., Willenbockel D. (2013). Assessing uncertainty along the climate-crop-economy modeling chain. Proceedings of the National Academy of Sciences U.S.A. 111(9): 3274-3279. http://www.pnas.org/content/early/2013/12/12/1222465110.abstract.

OECD (2012). OECD Environmental Outlook to 2050. OECD Publishing. http://www.oecd.org/environment/outlookto2050

O'Neill B.C., Kriegler E., Ebi K.L., Kemp-Benedict E., Riahi K., Rothman D.S., van Ruijven B.J., van Vuuren D.P., et al. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change, 42, 169–180.

Overmars K., Stehfest E., Tabeau A., van Meijl H., Mendoza Beltrán A., Kram T. (2014). Estimating the costs of reducing CO2 emission via avoided deforestation with integrated assessment modelling. Land Use Policy, Volume 41, November 2014, Pages 45–60.

PBL, 2014 (eds. M. Kok, R. Alkemade). How sectors can contribute to sustainable use and conservation of biodiversity. CBD Technical Series No. 79.

Pollitt H., Summerton P.,mKlaassen G. (2015). A Model-Based Assessment of First-Mover Advantage and Climate Policy. Environmental Economics and Policy Studies, Volume 17, Issue 2, pp 299-312.

Pollitt H., Alexandri E., Chewpreecha U., Klaassen G. (2014). Macroeconomic analysis of the employment impacts of future EU climate policies. Climate Policy, DOI:10.1080/14693062.2014.953907.

Popp A., Calvin K., Fujimori S., Havlik P., Humpenöder F., Stehfest E., et al. (2017). Land-use futures in the shared socio-economic pathways. Global Environmental Change, 42, 331-345.

Popp, A., Humpenöder F., Weindl I., Bodirsky B., Bonsch M., Lotze-Campen H., Müller C., et al. (2014). Land-Use Protection for Climate Change Mitigation. Nature Climate Change 4 (November): 1095–98. doi:10.1038/nclimate2444.

Popp A., Lotze-Campen H., Leimbach M., Knopf B., Beringer T., Bauer N., Bodirsky B. (2011). On Sustainability of Bioenergy Production: Integrating Co-Emissions from Agricultural Intensification. Biomass and Bioenergy 35 (12): 4770–80. doi:10.1016/j.biombioe.2010.06.014.

Popp A., Lotze-Campen H., Bodirsky B. (2010). Food Consumption, Diet Shifts and Associated Non-CO2 Greenhouse Gases from Agricultural Production. Global Environmental Change 20 (3): 451–62. doi:10.1016/j.gloenvcha.2010.02.001.

Riahi K., Van Vuuren D. P., Kriegler E., Edmonds J., O'Neill B. C., Fujimori, S., et al. (2017). The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Global Environmental Change, 42, 153-168.

Schellnhuber H. J., Hare B., Serdeczny O., Schaeffe, M., Adam, S., Baarsch, F. et al. (2013). Turn down the heat: climate extremes, regional impacts, and the case for resilience. Washington DC ; World Bank.

Schmitz C., van Meijl H., Kyle P., Nelson G. C., Fujimori S., Gurgel A., Havlik P., Heyhoe E., d'Croz D. M., Popp A., Sands R., Tabeau A., van der Mensbrugghe D., von Lampe M., Wise, M., Blanc E., Hasegawa T., Kavallari A., Valin, H. (2014). Land-use change trajectories up to 2050: insights from a global agro-economic model comparison. Agricultural Economics, 45: 69–84. doi: 10.1111/agec.12090

Schmitz C., Lotze-Campen H., Gerten D., Dietrich J.P., Bodirsky B., Biewald A., Popp A. (2013). Blue Water Scarcity and the Economic Impacts of Future Agricultural Trade and Demand. Water Resources Research 49 (6): 3601–17. doi:10.1002/wrcr.20188.

Shrestha S., Ciaian P., Himics M., Van Doorslaer B. (2013).Impacts of climate change on EU agriculture. Review of Agricultural and Applied Economics, Vol. 16 (2), pp. 24-39.

Smeets E., Vinyes C., Tabeau A., Van Meijl H., Corjan B., Prins A.G. (2014a). Evaluating the macroeconomic impacts of bio-based applications in the EU. Luxembourg: Publications Office of the European Union. http://dx.doi.org/10.2791/10930.

Smeets E., Tabeau A., van Berkum S., van Meijl H., Woltjer G., Moorad J. (2014b). The impact of the rebound effect of the use of first generation biofuels in the EU on greenhouse gas emissions, Renewable and Sustainable Energy Reviews 10/2014; 38:393–403.

Stehfest E., van Vuuren D., Kram T., Bouwman L., Alkemade R., Bakkenes M., Biemans H., Bouwman A., den Elzen M., Janse J., Lucas P., van Minnen J., Muller M., Prins A. (2014). Integrated assessment of global environmental change with IMAGE 3.0. Model description and policy applications. PBL Netherlands Environmental Assessment Agency.

Taliotis C., Weirich W., Howells M. (2013). The Global Least- cost User-friendly CLEWs Open-Source Exploratory (GLUCOSE) Model, Background paper for United Nations Department of Economic and Social Affairs (DESA).

United Nations (2014). Prototype Global Sustainable Development Report. Chapter 6: Special Theme: The Climate, Land, Energy, Water, Development (CLEW-D) Nexus. PP 93-103. New York: United Nations Department of Economic and Social Affairs. http://sustainabledevelopment.un.org/globalsdreport/

Van den Berg M., Bakkes J., Bouwman L., Jeuken M., Kram T., Neumann K., Van Vuuren D., Wilting H. (2011). EU Resource efficiency perspectives in a global context. PBL publication number: 555085001. ©European Union 2011.

Van Meijl H., Havlik P., Lotze-Campen H., Stehfest E., Witzke P.,..., Valin H. (2017). Challenges of Global Agriculture in a Climate Change Context by 2050. AgCLIM50 Study. Luxembourg: Publications Office of the European Union. DOI: 10.2760/772445.

Van Vuuren D. P., Stehfest E., Gernaat D. E., Doelman J. C., Van den Berg M., Harmsen M., et al. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. Global environmental change, 42, 237-250.

Van Vuuren D., Stehfest E., Gernaat D., Doelman J., van den Berg M., Harmsen M., de Boer H.S, Bouwman L., Daioglou V., Edelenbosch O., Girod B., Kram T., Lassaletta L., Lucas P., Van Meijl H., Muller C., Van Ruijven B., Van der Sluis S. (2016). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm, Global Environmental Change.

Van Vuuren D.P., Kok M.T.J., Lucas P.L., Prins A.G., Alkemade R., van den Berg M., Bouwman A.F., van der Esch S., Jeuken M., Kram T., Stehfest E. (2015). Pathways to achieve a set of ambitious global sustainability objectives by 2050. Explorations using the IMAGE integrated assessment model. Technological Forecasting and Social Change. doi:10.1016/j.techfore.2015.03.005.

Van Vuuren D.P., Riahi K., Moss R., Edmonds J., Thomson A., Nakicenovic N., Arnell N. (2012). A proposal for a new scenario framework to support research and assessment in different climate research communities. Global Environ Chang 22: 21-35.

Van Vuuren D.P., Edmonds J., Kainuma M., Riahi K., Thomson A., Hibbard K., Rose S.K. (2011). The representative concentration pathways: an overview. Climatic change 109: 5-31.Vetter T., Huang S. , Aich V., Yang T., Wang X., Krysanova V., Hattermann F. (2015). Multi-model climate impact assessment and intercomparison for three large-scale river basins on three continents. Earth Syst. Dynam., 6, 17-43, 2015, doi:10.5194/esd-6-17-2015

Von Lampe M., Willenbockel D., Ahammad H., Blanc E., Cai Y., Calvin K., Fujimori S., Hasegawa T., Havlik P., Heyhoe E., Kyle P., Lotze-Campen H., Mason d'Croz D., Nelson G. C., Sands R. D., Schmitz C., Tabeau A., Valin H., van der Mensbrugghe D., van Meijl H. (2014). Why do global long-term scenarios for agriculture differ? An overview of the AgMIP Global Economic Model Intercomparison. Agricultural Economics, 45: 3–20. doi: 10.1111/agec.12086

Ward P. J., Jongman B., Sperna Weiland F., Weiland A.A., Bouwman A., van Beek R., Bierkens M. F. P., Ligtvoet W., Winsemius H. C. (2013). Assessing flood risk at the global scale: model setup, results, and sensitivity. Environmental Research Letters, pp. 8044019 (DOI: 10.1088/1748-9326/8/4/044019).

Weiss F., Leip A. (2012). Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. Agriculture, Ecosystems & Environment, vol. 149, 124–134.

Wiebe K.,Lotze-Campen H., Sands R., Tabeau A., van der Mensbrugghe D., Biewald A., Bodirsky B., Islam S., Kavallari A., Mason-D'Croz D., Mueller C., Popp A., Robertson R., Robinson S., van Meijl H., Willenbockel D. (2015). Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios, Environmental Research Letters, ERL-100988, Vol. 10, Nr. 8, pp. 85010-85024.

Woltjer G., Kuiper M., Kavallari A., van Meijl H., Powell J., Rutten M., Shutes L., Tabeau A. (2014). The MAGNET model - Module description. LEI Report 14-057. The Hague: LEI - part of Wageningen UR (University & Research centre).

Appendix A: List of outcome variables from the thematic models

Hereafter we present a detailed list of output variables for each thematic model. The definition of each variable, as well as the commodities and regions, is available in ProjectPlace: -> documents -> WP3 -> Task 3.3 Thematic Models -> D3.1.

Table 16. Detailed list of output variables in E3ME

Variable	Unit
Consumption	billion US$2005/yr
Emissions|CH4	Mt CH4/yr
Emissions|CH4|AFOLU	Mt CH4/yr
Emissions|CH4|AFOLU|Aggregate - Agriculture and Biomass Burning	Mt CH4/yr
Emissions|CH4|AFOLU|Agriculture	Mt CH4/yr
Emissions|CH4|AFOLU|Agriculture|Livestock|Enteric Fermentation	Mt CH4/yr
Emissions|CH4|AFOLU|Agriculture|Rice	Mt CH4/yr
Emissions|CH4|AFOLU|Land|Forest Burning	Mt CH4/yr
Emissions|CH4|AFOLU|Land|Grassland Burning	Mt CH4/yr
Emissions|CH4|AFOLU|Land|Grassland Pastures	Mt CH4/yr
Emissions|CH4|Energy	Mt CH4/yr
Emissions|CH4|Energy|Demand	Mt CH4/yr
Emissions|CH4|Energy|Demand|Industry	Mt CH4/yr
Emissions|CH4|Energy|Demand|Residential	Mt CH4/yr
Emissions|CH4|Energy|Demand|Transportation	Mt CH4/yr
Emissions|CH4|Energy|Demand|Transportation|Aviation	Mt CH4/yr
Emissions|CH4|Energy|Demand|Transportation|Aviation|Domestic	Mt CH4/yr
Emissions|CH4|Energy|Demand|Transportation|Aviation|International	Mt CH4/yr
Emissions|CH4|Energy|Demand|Transportation|Rail	Mt CH4/yr
Emissions|CH4|Energy|Demand|Transportation|Road	Mt CH4/yr
Emissions|CH4|Energy|Demand|Transportation|Shipping	Mt CH4/yr
Emissions|CH4|Energy|Supply	Mt CH4/yr
Emissions|CH4|Fossil Fuel Fires	Mt CH4/yr
Emissions|CH4|Product Use|Solvents	Mt CH4/yr
Emissions|CH4|Waste	Mt CH4/yr
Emissions|CO	Mt CO/yr
Emissions|CO2	Mt CO2/yr
Emissions|CO2|AFOLU	Mt CO2/yr
Emissions|CO2|AFOLU|Aggregate - Agriculture and Biomass Burning	Mt CO2/yr
Emissions|CO2|AFOLU|Agriculture	Mt CO2/yr
Emissions|CO2|AFOLU|Agriculture|Livestock|Enteric Fermentation	Mt CO2/yr
Emissions|CO2|AFOLU|Agriculture|Rice	Mt CO2/yr
Emissions|CO2|AFOLU|Land|Forest Burning	Mt CO2/yr
Emissions|CO2|AFOLU|Land|Grassland Burning	Mt CO2/yr
Emissions|CO2|AFOLU|Land|Grassland Pastures	Mt CO2/yr

Emissions|CO2|Energy	Mt CO2/yr
Emissions|CO2|Energy|Demand	Mt CO2/yr
Emissions|CO2|Energy|Demand|Industry	Mt CO2/yr
Emissions|CO2|Energy|Demand|Residential	Mt CO2/yr
Emissions|CO2|Energy|Demand|Transportation	Mt CO2/yr
Emissions|CO2|Energy|Demand|Transportation|Aviation	Mt CO2/yr
Emissions|CO2|Energy|Demand|Transportation|Aviation|Domestic	Mt CO2/yr
Emissions|CO2|Energy|Demand|Transportation|Aviation|International	Mt CO2/yr
Emissions|CO2|Energy|Demand|Transportation|Rail	Mt CO2/yr
Emissions|CO2|Energy|Demand|Transportation|Road	Mt CO2/yr
Emissions|CO2|Energy|Demand|Transportation|Shipping	Mt CO2/yr
Emissions|CO2|Energy|Supply	Mt CO2/yr
Emissions|CO2|Fossil Fuel Fires	Mt CO2/yr
Emissions|CO2|Product Use|Solvents	Mt CO2/yr
Emissions|CO2|Waste	Mt CO2/yr
Emissions|CO|AFOLU	Mt CO/yr
Emissions|CO|AFOLU|Aggregate - Agriculture and Biomass Burning	Mt CO/yr
Emissions|CO|AFOLU|Agriculture	Mt CO/yr
Emissions|CO|AFOLU|Agriculture|Livestock|Enteric Fermentation	Mt CO/yr
Emissions|CO|AFOLU|Agriculture|Rice	Mt CO/yr
Emissions|CO|AFOLU|Land|Forest Burning	Mt CO/yr
Emissions|CO|AFOLU|Land|Grassland Burning	Mt CO/yr
Emissions|CO|AFOLU|Land|Grassland Pastures	Mt CO/yr
Emissions|CO|Energy	Mt CO/yr
Emissions|CO|Energy|Demand	Mt CO/yr
Emissions|CO|Energy|Demand|Industry	Mt CO/yr
Emissions|CO|Energy|Demand|Residential	Mt CO/yr
Emissions|CO|Energy|Demand|Transportation	Mt CO/yr
Emissions|CO|Energy|Demand|Transportation|Aviation	Mt CO/yr
Emissions|CO|Energy|Demand|Transportation|Aviation|Domestic	Mt CO/yr
Emissions|CO|Energy|Demand|Transportation|Aviation|International	Mt CO/yr
Emissions|CO|Energy|Demand|Transportation|Rail	Mt CO/yr
Emissions|CO|Energy|Demand|Transportation|Road	Mt CO/yr
Emissions|CO|Energy|Demand|Transportation|Shipping	Mt CO/yr
Emissions|CO|Energy|Supply	Mt CO/yr
Emissions|CO|Fossil Fuel Fires	Mt CO/yr
Emissions|CO|Product Use|Solvents	Mt CO/yr
Emissions|CO|Waste	Mt CO/yr
Emissions|F-Gases	Mt CO2-equiv/yr
Emissions|Kyoto Gases	Mt CO2-equiv/yr
Emissions|N2O	kt N2O/yr
Emissions|N2O|AFOLU	kt N2O/yr
Emissions|N2O|AFOLU|Aggregate - Agriculture and Biomass Burning	kt N2O/yr
Emissions|N2O|AFOLU|Agriculture	kt N2O/yr
Emissions|N2O|AFOLU|Agriculture|Livestock|Enteric Fermentation	kt N2O/yr

Emissions|N2O|AFOLU|Agriculture|Rice	kt N2O/yr
Emissions|N2O|AFOLU|Land|Forest Burning	kt N2O/yr
Emissions|N2O|AFOLU|Land|Grassland Burning	kt N2O/yr
Emissions|N2O|AFOLU|Land|Grassland Pastures	kt N2O/yr
Emissions|N2O|Energy	kt N2O/yr
Emissions|N2O|Energy|Demand	kt N2O/yr
Emissions|N2O|Energy|Demand|Industry	kt N2O/yr
Emissions|N2O|Energy|Demand|Residential	kt N2O/yr
Emissions|N2O|Energy|Demand|Transportation	kt N2O/yr
Emissions|N2O|Energy|Demand|Transportation|Aviation	kt N2O/yr
Emissions|N2O|Energy|Demand|Transportation|Aviation|Domestic	kt N2O/yr
Emissions|N2O|Energy|Demand|Transportation|Aviation|International	kt N2O/yr
Emissions|N2O|Energy|Demand|Transportation|Rail	kt N2O/yr
Emissions|N2O|Energy|Demand|Transportation|Road	kt N2O/yr
Emissions|N2O|Energy|Demand|Transportation|Shipping	kt N2O/yr
Emissions|N2O|Energy|Supply	kt N2O/yr
Emissions|N2O|Fossil Fuel Fires	kt N2O/yr
Emissions|N2O|Product Use|Solvents	kt N2O/yr
Emissions|N2O|Waste	kt N2O/yr
Emissions|NOx	Mt NOx/yr
Emissions|NOx|AFOLU	Mt NOx/yr
Emissions|NOx|AFOLU|Aggregate - Agriculture and Biomass Burning	Mt NOx/yr
Emissions|NOx|AFOLU|Agriculture	Mt NOx/yr
Emissions|NOx|AFOLU|Land|Forest Burning	Mt NOx/yr
Emissions|NOx|AFOLU|Land|Grassland Burning	Mt NOx/yr
Emissions|NOx|AFOLU|Land|Grassland Pastures	Mt NOx/yr
Emissions|NOx|Energy	Mt NOx/yr
Emissions|NOx|Energy|Demand	Mt NOx/yr
Emissions|NOx|Energy|Demand|Industry	Mt NOx/yr
Emissions|NOx|Energy|Demand|Residential	Mt NOx/yr
Emissions|NOx|Energy|Demand|Transportation	Mt NOx/yr
Emissions|NOx|Energy|Demand|Transportation|Aviation	Mt NOx/yr
Emissions|NOx|Energy|Demand|Transportation|Aviation|Domestic	Mt NOx/yr
Emissions|NOx|Energy|Demand|Transportation|Aviation|International	Mt NOx/yr
Emissions|NOx|Energy|Demand|Transportation|Rail	Mt NOx/yr
Emissions|NOx|Energy|Demand|Transportation|Road	Mt NOx/yr
Emissions|NOx|Energy|Demand|Transportation|Shipping	Mt NOx/yr
Emissions|NOx|Energy|Supply	Mt NOx/yr
Emissions|NOx|Fossil Fuel Fires	Mt NOx/yr
Emissions|NOx|Product Use|Solvents	Mt NOx/yr
Emissions|NOx|Waste	Mt NOx/yr
Emissions|Sulfur	Mt SO2/yr
Emissions|Sulfur|AFOLU	Mt SO2/yr
Emissions|Sulfur|AFOLU|Aggregate - Agriculture and Biomass Burning	Mt SO2/yr
Emissions|Sulfur|AFOLU|Agriculture	Mt SO2/yr

Emissions|Sulfur|AFOLU|Agriculture|Livestock|Enteric Fermentation	Mt SO2/yr
Emissions|Sulfur|AFOLU|Agriculture|Rice	Mt SO2/yr
Emissions|Sulfur|AFOLU|Land|Forest Burning	Mt SO2/yr
Emissions|Sulfur|AFOLU|Land|Grassland Burning	Mt SO2/yr
Emissions|Sulfur|AFOLU|Land|Grassland Pastures	Mt SO2/yr
Emissions|Sulfur|Energy	Mt SO2/yr
Emissions|Sulfur|Energy|Demand	Mt SO2/yr
Emissions|Sulfur|Energy|Demand|Industry	Mt SO2/yr
Emissions|Sulfur|Energy|Demand|Residential	Mt SO2/yr
Emissions|Sulfur|Energy|Demand|Transportation	Mt SO2/yr
Emissions|Sulfur|Energy|Demand|Transportation|Aviation	Mt SO2/yr
Emissions|Sulfur|Energy|Demand|Transportation|Aviation|Domestic	Mt SO2/yr
Emissions|Sulfur|Energy|Demand|Transportation|Rail	Mt SO2/yr
Emissions|Sulfur|Energy|Demand|Transportation|Road	Mt SO2/yr
Emissions|Sulfur|Energy|Demand|Transportation|Shipping	Mt SO2/yr
Emissions|Sulfur|Energy|Supply	Mt SO2/yr
Emissions|Sulfur|Fossil Fuel Fires	Mt SO2/yr
Emissions|Sulfur|Product Use|Solvents	Mt SO2/yr
Emissions|Sulfur|Waste	Mt SO2/yr
Emissions|VOC	Mt VOC/yr
Emissions|VOC|AFOLU	Mt VOC/yr
Emissions|VOC|AFOLU|Aggregate - Agriculture and Biomass Burning	Mt VOC/yr
Emissions|VOC|AFOLU|Agriculture	Mt VOC/yr
Emissions|VOC|AFOLU|Agriculture|Livestock|Enteric Fermentation	Mt VOC/yr
Emissions|VOC|AFOLU|Agriculture|Rice	Mt VOC/yr
Emissions|VOC|AFOLU|Land|Forest Burning	Mt VOC/yr
Emissions|VOC|AFOLU|Land|Grassland Burning	Mt VOC/yr
Emissions|VOC|AFOLU|Land|Grassland Pastures	Mt VOC/yr
Emissions|VOC|Energy	Mt VOC/yr
Emissions|VOC|Energy|Demand	Mt VOC/yr
Emissions|VOC|Energy|Demand|Industry	Mt VOC/yr
Emissions|VOC|Energy|Demand|Residential	Mt VOC/yr
Emissions|VOC|Energy|Demand|Transportation	Mt VOC/yr
Emissions|VOC|Energy|Demand|Transportation|Aviation	Mt VOC/yr
Emissions|VOC|Energy|Demand|Transportation|Aviation|Domestic	Mt VOC/yr
Emissions|VOC|Energy|Demand|Transportation|Aviation|International	Mt VOC/yr
Emissions|VOC|Energy|Demand|Transportation|Rail	Mt VOC/yr
Emissions|VOC|Energy|Demand|Transportation|Road	Mt VOC/yr
Emissions|VOC|Energy|Demand|Transportation|Shipping	Mt VOC/yr
Emissions|VOC|Energy|Supply	Mt VOC/yr
Emissions|VOC|Fossil Fuel Fires	Mt VOC/yr
Emissions|VOC|Product Use|Solvents	Mt VOC/yr
Emissions|VOC|Waste	Mt VOC/yr
Final Energy	EJ/yr
Final Energy|Electricity	EJ/yr

Final Energy|Gases	EJ/yr
Final Energy|Heat	EJ/yr
Final Energy|Industry	EJ/yr
Final Energy|Industry|Electricity	EJ/yr
Final Energy|Industry|Gases	EJ/yr
Final Energy|Industry|Heat	EJ/yr
Final Energy|Industry|Liquids	EJ/yr
Final Energy|Industry|Solids	EJ/yr
Final Energy|Industry|Solids|Biomass	EJ/yr
Final Energy|Industry|Solids|Coal	EJ/yr
Final Energy|Liquids	EJ/yr
Final Energy|Residential and Commercial	EJ/yr
Final Energy|Residential and Commercial|Electricity	EJ/yr
Final Energy|Residential and Commercial|Gases	EJ/yr
Final Energy|Residential and Commercial|Heat	EJ/yr
Final Energy|Residential and Commercial|Liquids	EJ/yr
Final Energy|Residential and Commercial|Solids	EJ/yr
Final Energy|Residential and Commercial|Solids|Biomass	EJ/yr
Final Energy|Residential and Commercial|Solids|Coal	EJ/yr
Final Energy|Solids	EJ/yr
Final Energy|Solids|Biomass	EJ/yr
Final Energy|Solids|Coal	EJ/yr
Final Energy|Transportation	EJ/yr
Final Energy|Transportation|Electricity	EJ/yr
Final Energy|Transportation|Gases	EJ/yr
Final Energy|Transportation|Liquids	EJ/yr
Final Energy|Transportation|Liquids|Biomass	EJ/yr
Final Energy|Transportation|Liquids|Oil	EJ/yr
Final Energy|Transportation|Other	EJ/yr
GDP|MER	billion US$2005/yr
Population	million
Price|Carbon	US$2005/t CO2
Price|Primary Energy|Coal	US$2005/GJ
Price|Primary Energy|Gas	US$2005/GJ
Price|Primary Energy|Oil	US$2005/GJ
Price|Secondary Energy|Electricity	US$2005/GJ
Primary Energy	EJ/yr
Primary Energy|Biomass	EJ/yr
Primary Energy|Coal	EJ/yr
Primary Energy|Fossil	EJ/yr
Primary Energy|Gas	EJ/yr
Primary Energy|Hydro	EJ/yr
Primary Energy|Oil	EJ/yr

Table 17. Detailed list of output variables in MAGNET

Output variable	Units
Total population	Mln people
Total GDP (MER)	Bln USD 2011 MER
Real producer price /input price	Paasche index 2011=1
Real export price	Paasche index 2011=1
Area harvested	1000 ha
Crop yield	USD / ha
Exogenous crop yield	USD / ha
Livestock yield (endogenous)	USD / ha
Exogenous livestock yield trend	USD / ha
Food use	Mln / USD
Feed use	Mln / USD
Other use	Mln / USD
Imports	Mln / USD
Exports	Mln / USD
Per capita calorie availability	Kcal / cap / day
Production	Mln / USD
Domestic use	Mln / USD
Net trade	Mln / USD
Feed use ruminant meat	Mln / USD
Feed use non-ruminant	Mln / USD
Feed use dairy	Mln / USD
Feed fish sector	Mln / USD

Table 18. Detailed list of output variables in CAPRI

Variable	Commodity	Unit
Land use	Agricultural utilized area	1000 hectares
	Other area	1000 hectares
	Cropland	1000 hectares
	Grassland	1000 hectares
	Fallow land	1001 hectares
Area harvested	Cereals (*)	1000 hectares
	Oilseeds	1000 hectares
	Other arable field crops	1000 hectares
	Vegetables and Permanent crops	1000 hectares
	Coffee, Teas and Cocoa	1000 hectares
	All other crops	1000 hectares
Crop yield	Cereals	1000 hectares
	Oilseeds	1000 hectares
	Other arable field crops	1000 hectares
	Vegetables and Permanent crops	1000 hectares
Irrigated area	Cereals	1000 hectares
	Oilseeds	1000 hectares
	Other arable field crops	1000 hectares
	Vegetables and Permanent crops	1000 hectares
Irrigated crop yield	Cereals	1000 hectares
	Oilseeds	1000 hectares
	Other arable field crops	1000 hectares
	Vegetables and Permanent crops	1000 hectares
Irrigation water use	Cereals	1000 cubic meters
	Oilseeds	1000 cubic meters
	Other arable field crops	1000 cubic meters
	Vegetables and Permanent crops	1000 cubic meters
Production	Cereals	1000 tonnes
	Oilseeds	1000 tonnes
	Other arable field crops	1000 tonnes
	Vegetables and Permanent crops	1000 tonnes
Consumption for food	Cereals	1000 tonnes
	Oilseeds	1000 tonnes
	Other arable field crops	1000 tonnes
	Vegetables and Permanent crops	1000 tonnes
Consumption for feed	Cereals	1000 tonnes
	Oilseeds	1000 tonnes
	Other arable field crops	1000 tonnes
	Vegetables and Permanent crops	1000 tonnes
Processing	Cereals	1000 tonnes
	Oilseeds	1000 tonnes
	Other arable field crops	1000 tonnes

	Vegetables and Permanent crops	1000 tonnes
Biofuels processing	Cereals	1000 tonnes
	Vegetables and Permanent crops	1000 tonnes
Imports	Cereals	1000 tonnes
	Oilseeds	1000 tonnes
	Other arable field crops	1000 tonnes
	Vegetables and Permanent crops	1000 tonnes
Exports	Cereals	1000 tonnes
	Oilseeds	1000 tonnes
	Other arable field crops	1000 tonnes
	Vegetables and Permanent crops	1000 tonnes
Producer price	Cereals	Euros per tonne
	Oilseeds	Euros per tonne
	Other arable field crops	Euros per tonne
	Vegetables and Permanent crops	Euros per tonne
Consumer price	Cereals	Euros per tonne
	Oilseeds	Euros per tonne
	Other arable field crops	Euros per tonne
	Vegetables and Permanent crops	Euros per tonne
Fertilizer use	Cereals	Kg/ha
	Oilseeds	Kg/ha
	Other arable field crops	Kg/ha
	Vegetables and Permanent crops	Kg/ha
GHG emissions	Cereals	Kt CO2 equivalent
	Oilseeds	Kt CO2 equivalent
	Other arable field crops	Kt CO2 equivalent
	Vegetables and Permanent crops	Kt CO2 equivalent

(*) Results are provided for around 50 individual crops/commodities as well as for their aggregates.

Table 19. Detailed list of output variables in OSeMOSYS

Category	Item	Variable	Unit
Costs	Technology Cost	Biomass	Giga-dollar
Costs	Technology Cost	Coal	Giga-dollar
Costs	Technology Cost	Oil	Giga-dollar
Costs	Technology Cost	Hydro	Giga-dollar
Costs	Technology Cost	Natural gas	Giga-dollar
Costs	Technology Cost	Geothermal	Giga-dollar
Costs	Technology Cost	Nuclear	Giga-dollar
Costs	Technology Cost	Ocean	Giga-dollar
Costs	Technology Cost	Solar	Giga-dollar
Costs	Technology Cost	Wind	Giga-dollar
Cumulative Capacity	Electricity and Heat	Biomass	Terawatt
Cumulative Capacity	Electricity and Heat	Coal	Terawatt
Cumulative Capacity	Electricity and Heat	Oil	Terawatt
Cumulative Capacity	Electricity and Heat	Hydro	Terawatt
Cumulative Capacity	Electricity and Heat	Natural gas	Terawatt
Cumulative Capacity	Electricity and Heat	Geothermal	Terawatt
Cumulative Capacity	Electricity and Heat	Nuclear	Terawatt
Cumulative Capacity	Electricity and Heat	Ocean	Terawatt
Cumulative Capacity	Electricity and Heat	Solar	Terawatt
Cumulative Capacity	Electricity and Heat	Wind	Terawatt
Emissions	Energy Supply	CO2equivalent	Gigatonne
Secondary Energy	Electricity	Biomass	Exajoule
Secondary Energy	Electricity	Coal	Exajoule
Secondary Energy	Electricity	Oil	Exajoule
Secondary Energy	Electricity	Hydro	Exajoule
Secondary Energy	Electricity	Natural gas	Exajoule
Secondary Energy	Electricity	Nuclear	Exajoule
Secondary Energy	Electricity	Geothermal	Exajoule
Secondary Energy	Electricity	Ocean	Exajoule
Secondary Energy	Electricity	Solar	Exajoule
Secondary Energy	Electricity	Wind	Exajoule
Secondary Energy	Heat	Biomass	Exajoule
Secondary Energy	Heat	Coal	Exajoule
Secondary Energy	Heat	Geothermal	Exajoule
Secondary Energy	Heat	Oil	Exajoule
Secondary Energy	Heat	Natural gas	Exajoule

Table 20. Detailed list of output variables in MAgPIE

Output variable	Units
Agricultural Demand	million t DM/yr
Agricultural Demand|Bioenergy	million t DM/yr
Agricultural Demand|Bioenergy|1st generation	million t DM/yr
Agricultural Demand|Bioenergy|2nd generation	million t DM/yr
Agricultural Demand|Crops|Feed	million t DM/yr
Agricultural Demand|Crops|Food	million t DM/yr
Agricultural Demand|Crops|Other	million t DM/yr
Agricultural Demand|Feed	million t DM/yr
Agricultural Demand|Food	million t DM/yr
Agricultural Demand|Livestock|Feed	million t DM/yr
Agricultural Demand|Livestock|Food	million t DM/yr
Agricultural Demand|Livestock|Other	million t DM/yr
Agricultural Demand|Other	million t DM/yr
Agricultural Production	million t DM/yr
Agricultural Production|Crops|Energy	million t DM/yr
Agricultural Production|Crops|Non-Energy	million t DM/yr
Agricultural Production|Crops|Non-Energy|Cereals	million t DM/yr
Agricultural Production|Livestock	million t DM/yr
Emissions|BC|Land Use|Agricultural Waste Burning	Mt BC/yr
Emissions|BC|Land Use|Forest Burning	Mt BC/yr
Emissions|BC|Land Use|Savannah Burning	Mt BC/yr
Emissions|CH4|Land Use|Agricultural Waste Burning	Mt CH4/yr
Emissions|CH4|Land Use|Agriculture	Mt CH4/yr
Emissions|CH4|Land Use|Agriculture|AWM	Mt CH4/yr
Emissions|CH4|Land Use|Agriculture|Enteric Fermentation	Mt CH4/yr
Emissions|CH4|Land Use|Agriculture|Rice	Mt CH4/yr
Emissions|CH4|Land Use|Forest Burning	Mt CH4/yr
Emissions|CH4|Land Use|Savannah Burning	Mt CH4/yr
Emissions|CO|Land Use|Agricultural Waste Burning	Mt CO/yr
Emissions|CO|Land Use|Forest Burning	Mt CO/yr
Emissions|CO|Land Use|Savannah Burning	Mt CO/yr
Emissions|CO2|Land Use	Mt CO2/yr
Emissions|N2O|Land Use|Agricultural Waste Burning	kt N2O/yr
Emissions|N2O|Land Use|Agriculture	kt N2O/yr
Emissions|N2O|Land Use|Agriculture|AWM	kt N2O/yr
Emissions|N2O|Land Use|Agriculture|Cropland Soils	kt N2O/yr
Emissions|N2O|Land Use|Agriculture|Pasture	kt N2O/yr
Emissions|N2O|Land Use|Forest Burning	kt N2O/yr
Emissions|N2O|Land Use|Savannah Burning	kt N2O/yr
Emissions|NH3|Land Use|Agricultural Waste Burning	Mt NH3/yr
Emissions|NH3|Land Use|Agriculture	Mt NH3/yr
Emissions|NH3|Land Use|Forest Burning	Mt NH3/yr
Emissions|NH3|Land Use|Savannah Burning	Mt NH3/yr
Emissions|NOx|Land Use|Agricultural Waste Burning	Mt NOx/yr
Emissions|NOx|Land Use|Agriculture	Mt NOx/yr
Emissions|NOx|Land Use|Forest Burning	Mt NOx/yr

Emissions|NOx|Land Use|Savannah Burning	Mt NOx/yr
Emissions|OC|Land Use|Agricultural Waste Burning	Mt OC/yr
Emissions|OC|Land Use|Forest Burning	Mt OC/yr
Emissions|OC|Land Use|Savannah Burning	Mt OC/yr
Emissions|Sulfur|Land Use|Agricultural Waste Burning	Mt SO2/yr
Emissions|Sulfur|Land Use|Forest Burning	Mt SO2/yr
Emissions|Sulfur|Land Use|Savannah Burning	Mt SO2/yr
Emissions|VOC|Land Use|Agricultural Waste Burning	Mt VOC/yr
Emissions|VOC|Land Use|Forest Burning	Mt VOC/yr
Emissions|VOC|Land Use|Savannah Burning	Mt VOC/yr
Fertilizer Use|Nitrogen	Tg N/yr
Food Energy Supply	EJ/yr
Food Energy Supply|Crops|Per Capita	kcal/cap/day
Food Energy Supply|Livestock	EJ/yr
Food Energy Supply|Livestock|Per Capita	kcal/cap/day
Food Energy Supply|Per Capita	kcal/cap/day
GDP per capita|MER	US$2005/cap/yr
GDP|MER	billion US$2005/yr
Land Cover	million ha
Land Cover|Built-up Area	million ha
Land Cover|Cropland	million ha
Land Cover|Cropland|Cereals	million ha
Land Cover|Cropland|Energy Crops	million ha
Land Cover|Cropland|Energy Crops|Irrigated	million ha
Land Cover|Cropland|Irrigated	million ha
Land Cover|Forest	million ha
Land Cover|Forest|Forestry	million ha
Land Cover|Forest|Natural Forest	million ha
Land Cover|Other Natural Land	million ha
Land Cover|Pasture	million ha
Population	million
Price|Agriculture|Non-Energy Crops and Livestock|Index (Index	2005 = 1)
Price|Agriculture|Non-Energy Crops|Index (Index	2005 = 1)
Price|Primary Energy|Biomass	US$2005/GJ
Water|Withdrawal|Irrigation	million m3/yr
Yield|Cereal	t DM/ha/yr
Yield|Oilcrops	t DM/ha/yr
Yield|Sugarcrops	t DM/ha/yr

Appendix B: Model Factsheets

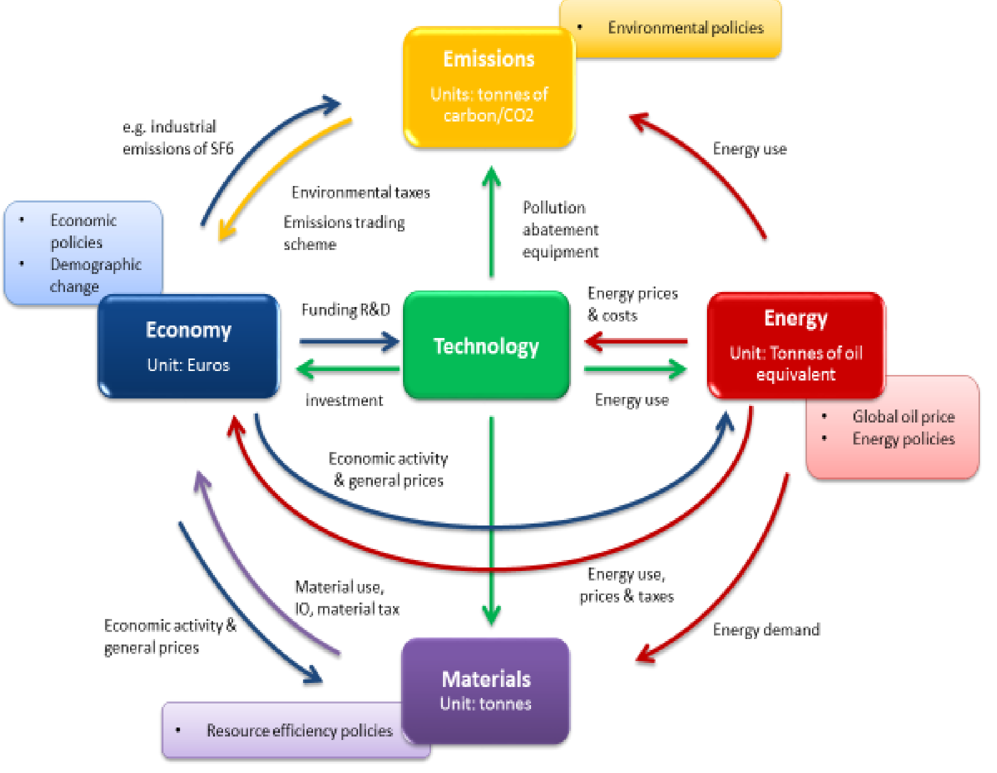
Model E3ME-FTT

SIM4NEXUS

The model

E3ME – global E3 (Energy-Environment-Economy) macro-econometric model – is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for **assessment of long-term impacts of climate and energy policy on economic activity and employment**. The current version of E3ME comprises 59 global regions.

E3ME is fully integrated with the FTT (Future Technology Transitions) model of technology diffusion. FTT simulates the uptake rates of new technologies based on evolutionary theory. Currently FTT covers the power and passenger transport sectors.



Spatial and temporal coverage

Spatial coverage: Global

Spatial resolution: National (covering all EU-28 Member States)

Temporal scale: Until 2050 in annual time steps

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

e3me SIM4NEXUS

Nexus coverage

E3ME has been designed from the outset to handle interactions between the economy and the energy system. Its two-way linkages make it well placed to provide a detailed analysis of the macroeconomic impacts of energy policy. A land use module is currently under development, which will allow a better assessment of biofuels, including feedbacks to food prices.

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. E3ME can also be linked to climate models.

Inputs

- Energy policy (e.g. energy technology-specific transport and electricity sector regulations, etc.)
- Energy/carbon price/taxes, ETS coverage
- Additional exogenous investment assumptions
- Optional exogenous energy technology scenarios.

Outputs

- GDP and other macroeconomic indicators
- Employment
- Sectoral production
- Energy consumption by source and sector
- GHG emissions from fuel combustion

Recent applications

E3ME is used to assess the impacts of climate and energy policy on economic activity and employment.

- European Commission (2014). A policy framework for climate and energy in the period from 2020 to 2030. Brussels: European Commission.
- Mercure, J-F, H Pollitt, U Chewpreecha, P Salas, A M Foley, P B Holden, N R Edwards (2014) 'The dynamics of technology diffusion and the impacts of climate policy instruments in the decarbonisation of the global electricity sector', Energy Policy, Volume 73, pp 686–700, Elsevier.

Further information

E3ME website

Model manual

Contact:

Hector Pollitt
hp@camecon.com

Jean-François Mercure
J.Mercure@science.ru.nl

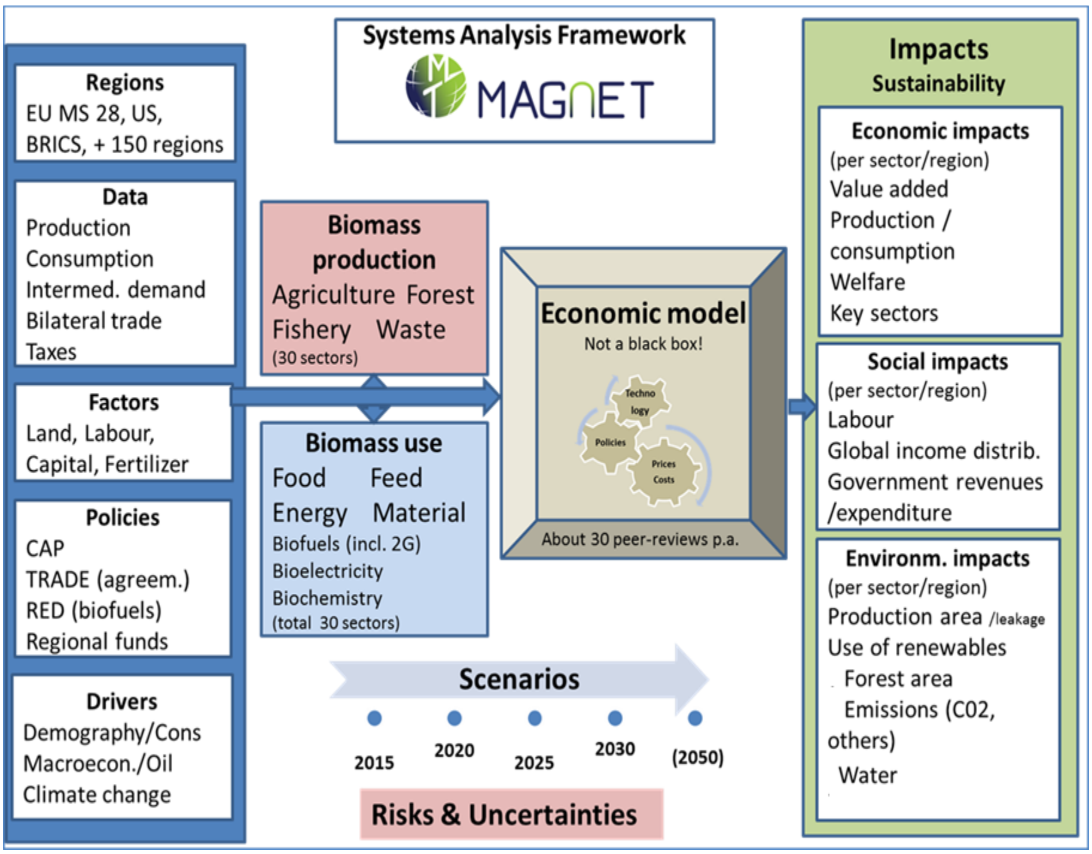
cambridge econometrics — clarity from complexity

Radboud University

The model

MAGNET

MAGNET (Modular Agricultural GeNeral Equilibrium Tool) is a general computable equilibrium model, with an additional focus on agriculture, designed for **economic impact assessment**. MAGNET builds on the global general equilibrium Global Trade Analysis Project (GTAP) model MAGNET is a tool for analysis of trade, agricultural, climate and bioenergy policies.



Spatial and temporal coverage

Spatial coverage: Global

Spatial resolution: National

Temporal scale: Until 2050 in flexible time steps (2100 is possible)

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

MAGNET SIM4NEXUS

Nexus coverage

Food-energy links: quantitative analysis in the area of agricultural policies, international trade policies and bio-economy policies (including bioelectricity, 2nd generation biofuels and biochemical policies). Next to various agricultural sectors, two additional biomass producing sectors are added, namely a residue producing sector and an energy crop sector.

Food-water links: In 2017 virtual water flows will be integrated within the magnet model (including biophysical water flows).

Inputs

- GDP and population developments
- Policy changes
- Changes in productivity of land, labour and capital as well as efficiency changes in the economic sectors themselves (in percent change).
- Changes in patterns of consumption preferences such as a shift to a more meat based diet for example.

Outputs

- GDP, value added, employment, trade balances, self-sufficiency rates
- Changes in prices and quantities of units produced and consumed
- Changes in C02 emissions and the market price for emission permits
- New land brought into production
- Energy produced and consumed from various fossil fuel and clean energy sources.

Recent applications

MAGNET is used to study the macro-economic contributions of the emerging bioeconomy as well as the impact of agricultural, trade, bioeconomy and climate policies on various dimensions of food security.

- Koopman, J.F.L., Kuik, O.J., Tol, R.S.J. and R. Brouwer (2015). The potential of water markets to allocate water between industry, agriculture and public water utilities as an adaptation mechanism to climate change. *Mitigation and adaptation strategies for global change.* DOI: 10.1007/s11027-015-9662-z.
- Smeets E., Vinyes C., Tabeau A., Van Meijl H., Corjan B. and Prins A.G. (2014) Evaluating the macroeconomic impacts of bio-based applications in the EU. Luxembourg: Publications Office of the European Union. http://dx.doi.org/10.2791/10930.

Further information

MAGNET website

Documentation

Software

LEI WAGENINGEN UR

Contact:

Hans Van Meijl
Hans.vanmeijl@wur.nl

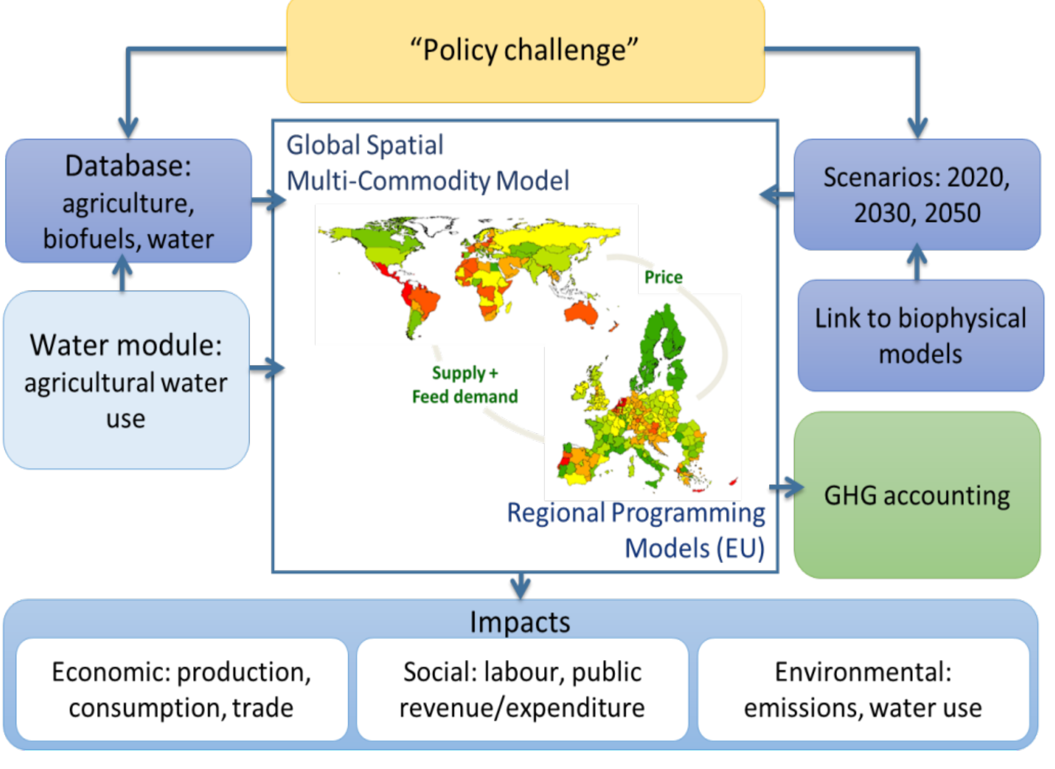
Jason Levin-Koopman
jason.levin-koopman@wur.nl

The model

CAPRI

The Common Agricultural Policy Regionalised Impact modelling system (CAPRI) is a global agro-economic model designed for the **ex-ante impact assessment of agricultural, environmental and trade policies with a focus on the European Union**. It is a global spatial partial equilibrium model, solved by sequential iteration between supply and market modules. The unique combination of regional supply-side models with a global market model for agricultural products provides simulated results for the EU at subnational level, whilst, at the same time, simulating global agricultural markets.

The main strength of the CAPRI modelling system is the fact that it is based on a **unified, complete and consistent data base**, and integrates economic, physical and environmental information in a consistent way.



Spatial and temporal coverage

Spatial coverage: Global

Spatial resolution: National and regional within the EU

Temporal scale: Until 2050 in flexible time steps

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

CAPRI

SIM4NEXUS

Nexus coverage

Food-water links: 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 (water pricing).

Food-energy links: Biofuel markets as well as their interlinkages with biofuel feedstock are represented in CAPRI.

Inputs

CAPRI exploits wherever possible well-documented, official data sources from EUROSTAT, FAOSTAT, OECD and extractions from de Farm Accounting Data Network (FADN).

Specific modules of the model ensure that the data used are compatible and complete in time and space

Outputs

- Areas , herd sizes, income and environmental indicators (NPK balances, GHE) for each agricultural activity and each region
- Producer and consumer prices, bilateral trade flows, transport costs and tariffs globally for each trade block
- Spatial downscaling part to 1x1 km, which covers crop shares, yield, the environmental indicators.

Recent applications

CAPRI is **extensively used** to assess agricultural policy measures, GHG emissions from the agricultural sector, food-water-energy linkages and climate change impacts.

- Blanco M., Witzke H.P., Perez-Domínguez I., Salputra G., Martínez P. (2015). Extension of the CAPRI model with an irrigation sub-module. Luxembourg: Publications Office of the European Union, EUR 27737 EN. doi: 10.2791/319578.
- 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

Further information

Get CAPRI model

Technical documents

Training material

Contact:

Maria Blanco
maria.blanco@upm.es

Pilar Martinez
mpilar.martinez@upm.es

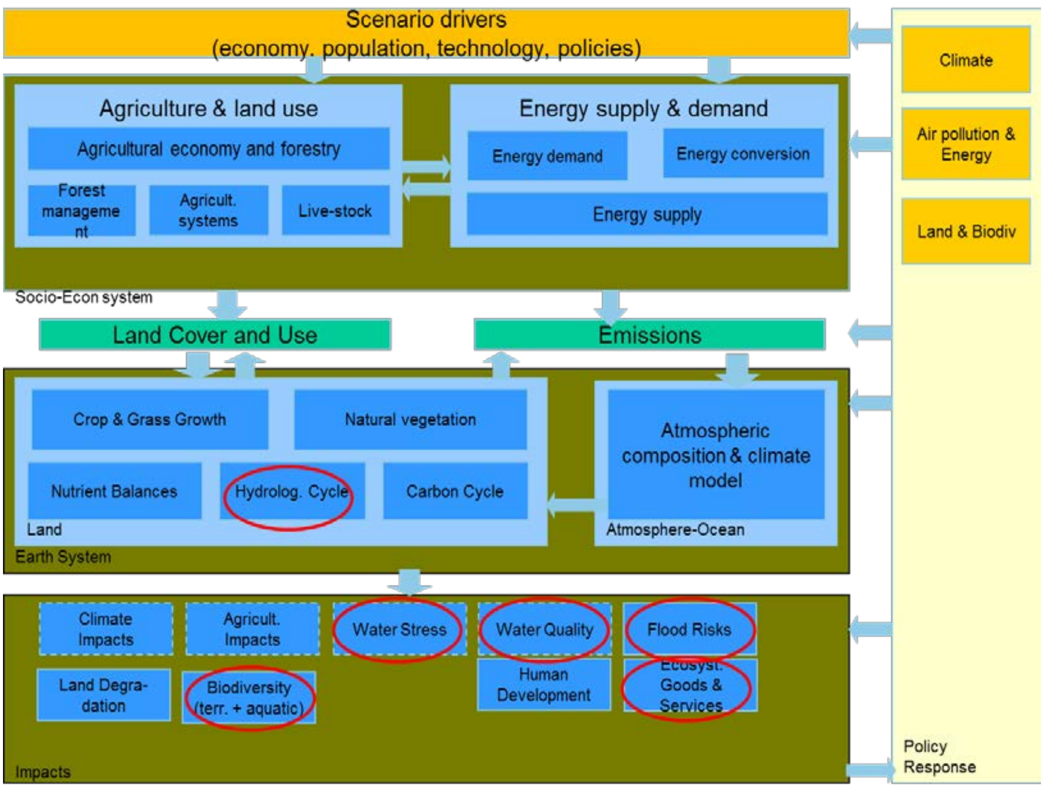
POLITÉCNICA

The model

IMAGE-GLOBIO

IMAGE (Integrated Model to Assess the Global Environment) 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. Coupled to IMAGE, the GLOBIO (Global Biodiversity) model is used to assess the consequences of global environmental change on biodiversity (terrestrial and aquatic), and ecosystem services (GLOBIO-ES) .

A strength of the model is its integrated nature, securing globally balanced flows of material, a weakness is its technically complex model structure which hampers easy links with other thematic models.



Spatial and temporal coverage

Spatial coverage: Global

Spatial resolution : 30 or 5 arcminutes grids

Temporal scale: Until 2100 in annual steps

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

IMAGE-GLOBIO

SIM4NEXUS

Nexus coverage

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.

Some feedback between water and crop growth is incorporated via LPJmL. Other feedbacks and trade-offs will be dealt with via the water quality, biodiversity and ecosystem services modules.

Inputs

- IMAGE: population, economic growth, dietary preferences, technological change (agriculture and energy system)and policy assumptions.
- GLOBIO and GLOFRIS: P and N emissions, precipitation, evaporation, global mean temperature , land use and water maps, river dams (location, capacity).

Outputs

- IMAGE: mean global temperature; GHG emissions; food production and allocation; land use (grid scale); carbon and water dynamics (grid scale).
- GLOBIO and GLOFRIS: biodiversity intactness (MSA) per pixel, terrestrial and aquatic per water type; water discharge; total P and N; wetland area per pixel; water temperature; daily or monthly nutrient retention; C sequestration; flood risk per km2.

Recent applications

The model is 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.

- PBL, 2014 (eds. M. Kok, R. Alkemade). How sectors can contribute to sustainable use and conservation of biodiversity. CBD Technical Series No. 79.
- Stehfest, E., van Vuuren, D., Kram, T., Bouwman, L., Alkemade, R., Bakkenes, M., Biemans, H., Bouwman, A., den Elzen, M., Janse, J., Lucas, P., van Minnen, J., Muller, M., Prins, A., 2014. Integrated assessment of global environmental change with IMAGE 3.0. Model description and policy applications. PBL Netherlands Environmental Assessment Agency.

Further information

IMAGE website

User Support System for IMAGE

GLOBIO website

Get GLOBIO BETA version

Contact:

Jan Janse
Jan.Janse@pbl.nl

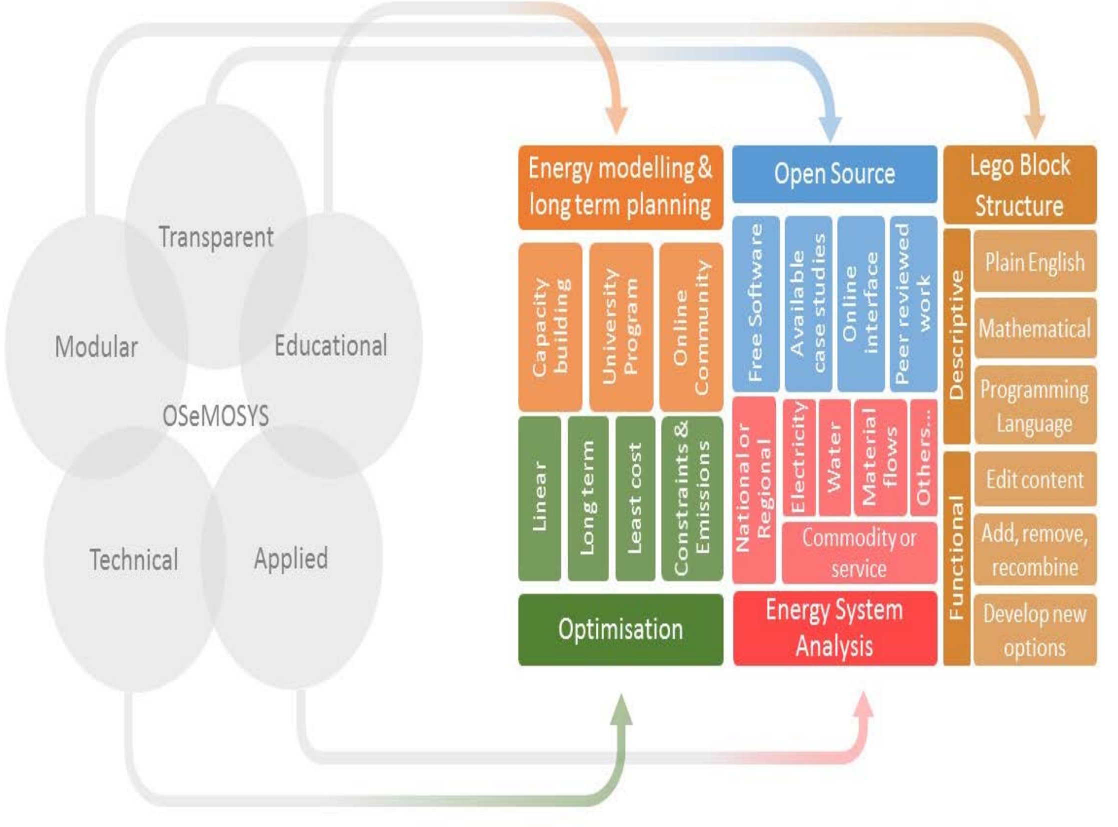
Elke Stehfest
Elke.Stehfest@pbl.nl

PBL Netherlands Environmental Assessment Agency

The model

OSeMOSYS
Open Source Energy Modelling System

The Open Source Energy Modelling Systmes (OSeMOSYS) is a is an open-source energy system optimisation model with a medium- to long-term time horizon and **designed to inform the development of national and multi-regional energy strategies**. The model has been designed to fill a gap in the analytical toolbox available to the energy research community and energy planners in developing countries.



Spatial and temporal coverage

Spatial coverage: Flexible (local to global)

Spatial resolution: No inherent resolution

Temporal scale: Flexible, up to 2100 in sub-hourly steps

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

Nexus coverage

The 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.

Inputs

- Costs for all technologies and fuels
- Input and output fuels and efficiencies for all technologies
- Emissions for all fuels
- Disaggregated demand values
- Existing capacities and installation absolute and rate limits
- Renewable energy targets, emissions targets, other scenario factors

Outputs

Cost minimised solution with capacity installations and energy outputs for all technologies, with associated costs

Recent applications

OSeMOSYS is applied in different studies of different spatial spans, from global, regional to country-level, and featuring multiple nexus approaches.

- KTH & UNECE, 2015. Sava River Basin Basin Water-Food-Energy-Ecosystems Nexus assessment (Draft). Geneva. http://www.savacommission.org/announce_detail/55/2
- UN, United Nations, 2014. Prototype Global Sustainable Development Report . Chapter 6: Special Theme: The Climate, Land, Energy, Water, Development (CLEW-D) Nexus. PP 93-103. https://sustainabledevelopment.un.org/content/documents/1454Prototype%20Global%20SD%20Report2.pdf

Further information

OSeMOSYS website

OSeMOSYS download

Model management infrastructure (MoManI)

Contact:

Mark Howells
mark.howells@energy.kth.se

Eunice Pereira Ramos
epramos@kth.se

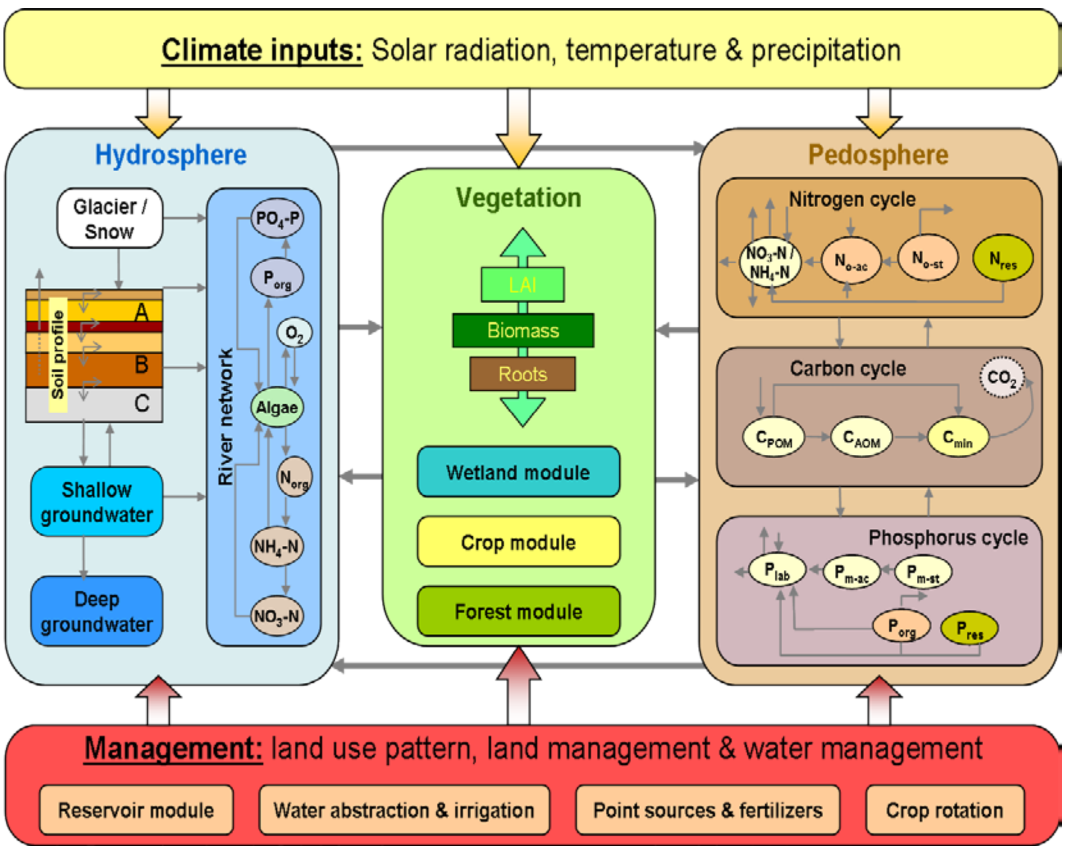
Christopher Arderne
arderne@kth.se

KTH VETENSKAP OCH KONST

The model

SWIM

The Soil and Water Integrated Model (SWIM) is an eco-hydrological semi-distributed model designed for **climate and land-use change impact assessment**.. SWIM integrates hydrological processes, crop/vegetation growth, nutrients and erosion at the river basin and regional scales. The management of land and water resources is also considered.



Spatial and temporal coverage

Spatial coverage: Several river basins in Europe, Africa, Latin America and East Asia

Spatial resolution: Regional and river basin; adjustable sub-units

Temporal scale: Until 2050 (2100) in daily time step

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

SWIM

SIM4NEXUS

Nexus coverage

SWIM was specifically developed to investigate **climate and land use change** impacts at the regional scale, where the impacts are manifested and adaptation measures take place. The model simulates interlinked processes at the mesoscale such as runoff generation, plant and crop growth, nutrient and carbon cycling, and erosion. The approach allows simulation of all interrelated processes within a single model framework at a daily time step using regionally available data (climate, land use and soil) and considering feedbacks.

SWIM models all components of the NEXUS at the regional and water basin scale and related feedbacks, also water related energy production (hydropower, cooling of power plants) and riverine ecology.

Inputs

Outputs

The model uses 3-level disaggregation scheme: basin – subbasins – hydrotopes.

The results are presented as time series and maps for a number of variables.

Recent applications

SWIM is mostly used for climate and land use change applications and definition of adaptation strategies within the water nexus

- Hattermann, F. F., Huang, S., Koch, H. (2014 (Accepted November)): Climate change impacts on hydrology and water resources in Germany. - Meteorologische Zeitschrift
- Koch, H., Vögele, S., Kaltofen, M., Grossmann, M., Grünewald, U. (2014): Security of Water Supply and Electricity Production: Aspects of Integrated Management. Water Resources Management, 28(6), 1767-1780.

Further information

SWIM website

Model manual

Contact:

Fred Hattermann
hattermann@pik-potsdam.de

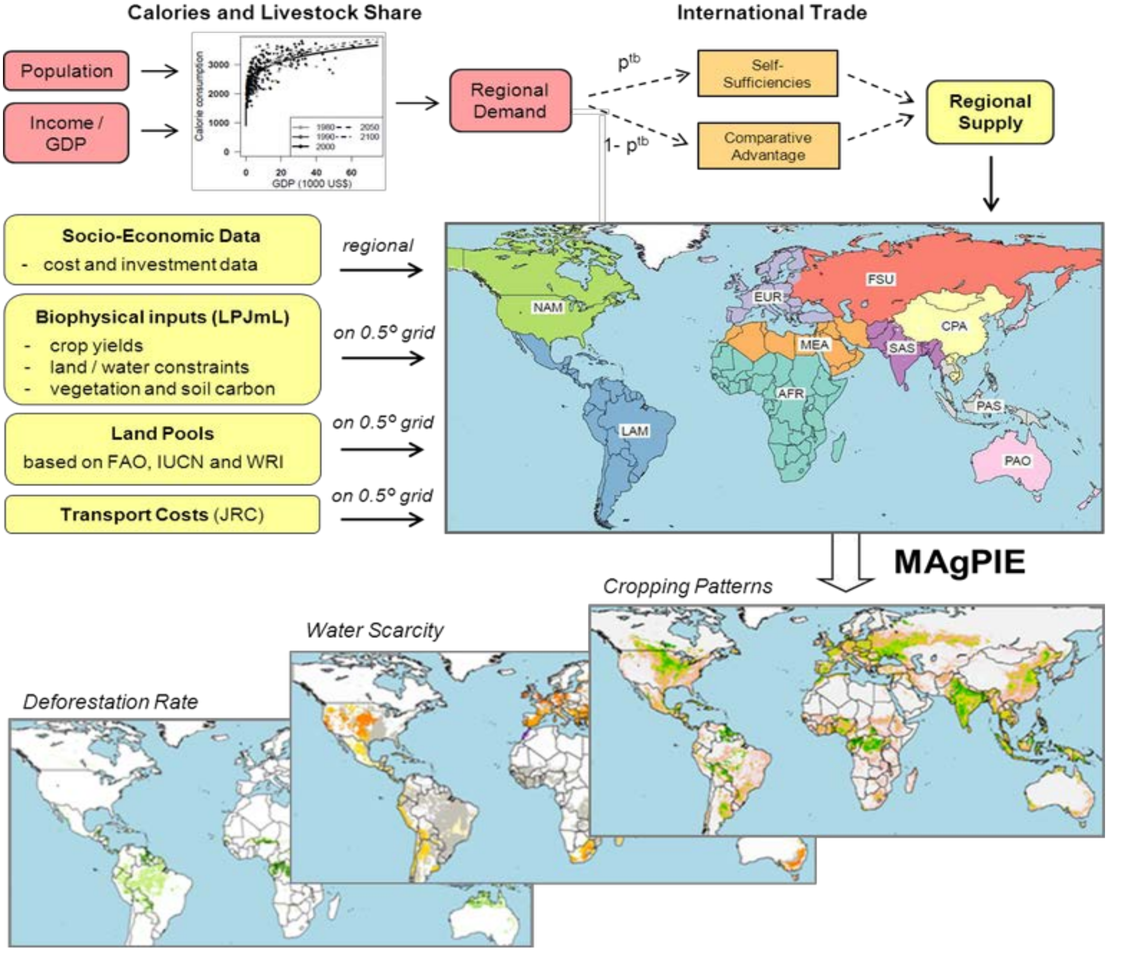
Hagen Koch
hagen.koch@pik-potsdam.de

P I K

The model

MAgPIE

The Model of Agricultural Production and its Impact on the Environment (MAgPIE) is a **global land use allocation model** to derive long-term scenarios. Based on developments in population, economy, technology and climatic conditions, MAgPIE derives spatial-explicit land use patterns, crop yields and total costs of agricultural production at the grid scale.



Spatial and temporal coverage

Spatial coverage: Global

Spatial resolution: Detailed grids

Temporal scale: Until 2100 in 5-year time steps

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

MAgPIE

SIM4NEXUS

Nexus coverage

Interactions between food, water, land, climate and (bio)energy, as well as several other cobenefits (nutrient pollution, air pollution, production costs) in the agricultural sector. It includes socio-economic dynamics of the food value chain, international food availability, food trade, impact of biophysical resources (land, water, nutrients) on the agro-economic system, climate-induced changes in physical blue water availability and water-use, economic water-scarcity indicators, yield patterns of irrigated and non-irrigated agricultural production, bioenergy production and competition for biophysical resources, full endogenous interaction between food, water and bioenergy as well as optimization of resource use.

Inputs

- Population
- Income
- Bioenergy demand
- Historical land-use patterns
- Biophyiscal crop yield patterns
- Water use for crop production
- Water availability
- Production Costs

Outputs

- Cropland pasture and forest area
- Crop and livestock production
- Bioenergy production
- Water usage
- Irrigation area
- Water shadow price
- Greenhouse Gas Emissions
- Food demand for plant products and for animal-based products

Recent applications

- Bonsch, Markus, Florian Humpenöder, Alexander Popp, Benjamin Bodirsky, Jan Philipp Dietrich, Susanne Rolinski, Anne Biewald, et al. 2014. “Trade-Offs between Land and Water Requirements for Large-Scale Bioenergy Production.” GCB Bioenergy, November, n/a – n/a. doi:10.1111/gcbb.12226.
- Popp, Alexander, Florian Humpenöder, Isabelle Weindl, Benjamin Leon Bodirsky, Markus Bonsch, Hermann Lotze-Campen, Christoph Müller, et al. 2014. “Land-Use Protection for Climate Change Mitigation.” Nature Climate Change 4 (November): 1095–98. doi:10.1038/nclimate2444.

Further information

MAgPIE website

Documentation

Contact:

Alexander Popp
popp@pik-potsdam.de

Benjamin Bodirsky
bodirsky@pik-potsdam.de

P I K