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

D5.2: THE MAIN NEXUS CHALLENGES IN 12 CASE STUDIES

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DATE: (29 – 12 – 2017)

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AUTHOR(S)	Authors of the 12 case studies are indicated in the reports
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INTERNAL REVIEWER	The two editors have interviewed all case studies in October and November (plans regarding the first workshop? Are there any questions regarding the guidance for workshop organisation; any questions regarding the outline provided for the deliverable). Interview reports are available on Project place. Bilateral contacts between the case study lead and one of the editors of the report remained until submission. The case study reports are internally reviewed, in consultation with the editor assigned to the case study.

DOCUMENT HISTORY

VERSION	INITIALS/NAME	DATE	COMMENTS-DESCRIPTION OF ACTIONS
1	FMB	28.12.2017	COLLECTION OF THE INDIVIDUAL CASE STUDY REPORTS

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Executive summary

Changes with respect to the DoA

No changes with respect to the DoA. The deliverable was planned for submission in Month 15 (August 2017). The Periodic Report (RP1) proposed to extend submission to Month 19 (December 2017). The case studies are going to have workshops after August 2017, and such workshop would address the Nexus challenges to be addressed in the cases. Taking into account the stakeholders' perspective would enrich the presentation of the Nexus challenges be addressed in the cases. This A will not affect other work packages, as it allows to streamline with the planning of WP3 and WP4. WP5 has no other deliverables until Month 36, and an extended version of D5.2 will offer more up-to-date information for the review during RP2 (until Month 30).

Dissemination and uptake

The overall deliverable is mainly served for the project, to inform consortium about the status of work in the 12 case studies. Individual reports are used in the case studies.

Short Summary of results (<250 words)

Each case study will follow a step-wise approach in supporting Nexus-compliant decision making. In doing so, we will address the following questions:

a. What are the main Nexus challenges that are to be addressed in the case study?
b. How can the existing thematic models can help to understand these challenges? And what are the main gaps in understanding the Nexus that arise from the application of these thematic models?

This report is the deliverable of Sub-Task 5.2.1 and Sub-Task 5.2.2, with a first assessment in applying the thematic models in the case studies. The subsequent deliverables (Deliverable D5.3 – Using the modelling approaches in 12 case studies due for Month 36 and Deliverable D5.5 – Twelve reports (one report per case study), but combined in a single document, presenting the outcome of Task 5.2 due for Month 42) will extend the work on the application of the complexity science modelling framework and of the Serious Game.

The current case study report (due for submission by the end of 2017) will be further updated for the next deliverables in WP5. D5.3 ('Using the modelling approaches in 12 case studies') (due for Month 36, May 2019) and D5.5 ('12 reports, presenting the outcome of Task 5.2') will follow-up on the current deliverable.

Evidence of accomplishment

Submission of report. Publication of report on SIM4NEXUS website

1 Introduction

1.1 Objectives of the report

Guidance for the 12 case studies in WP5 is aimed at helping teams to present progress in their effort to support decision making. Each case study will follow a step-wise approach in supporting Nexus-compliant decision making. In doing so, we will address the following questions:

a. What are the main Nexus challenges that are to be addressed in the case study?
b. How can the existing thematic models can help to understand these challenges? And what are the main gaps in understanding the Nexus that arise from the application of these thematic models?

Each case study report will introduce the case in three parts:

a. The case study in short. What is the main question at stake and how did you involve stakeholders to reach this stage? Which societal challenges are addressed?
b. The nexus sectors in short (e.g. energy, food, water, land, climate). What are the links with policies related to resource efficiency, circular economy, climate change or others?
c. Background of the case, including spatial scale (regional, national, etc.), time path (2010, 2020, 2030, 2040, 2050).

Cases to present:

1. What are the main trends in the case study area for each of the nexus sectors? Cover the Nexus sectors water, land, food, energy and climate. Where possible, present base-line trends from the thematic models (2010, 2020, 2030, 2040, 2050). Use results of the SSP2-scenario ('middle-of-the-road').
2. What are the interlinkages between the Nexus sectors? What is the impact of 'water' for 'food' and vice-versa the impact of 'food' for 'water' in the specific context of the case study. The interlinkages between the Nexus sectors are presented in Deliverable D1.1.
3. Could you identify trade-offs (e.g. an increase in food production at the expense of scarce water resources). An increase in biomass production, for example, might increase the share of renewable energy and mitigate climate change. However, there might be trade-offs with the Nexus sectors water, land and food. This is worth to elaborate. In addition, SIM4NEXUS is very much interested to learn more about synergies across the Nexus sectors. Could you elaborate on synergies between any of the Nexus sectors?

Each case study to define a pathway for specific Nexus sectors (and possible policy measures), including time dimension until 2050. A case study might define different pathways. They are beyond the baseline (SSP2 scenario). This section to present the pathway(s) in 1 page.

The conceptual model will be drafted and finalised with WP3/WP4. This is an essential step, since the conceptual model will define the context of the System Dynamics Model. All case studies will establish the structure of the conceptual models for each Case Study –preferably the same structure for 2010, 2020, 2030, 2040 and 2050. The case study teams prepare the Conceptual model.

How can existing thematic models help understanding these challenges? And what are the main gaps in understanding the Nexus that arise from the application of these thematic models? What is the best combination of models to address the Nexus challenges?

Summarise the stakeholders’ process in the case study.

- Preliminary contacts: What steps did you take before the 1st workshop
- Please describe surveys / focus groups / interviews with key experts, stakeholders’ representatives or decision makers. What did you learn from these preliminary steps (stakeholders’ roles, change in the Nexus issues of the case study, expectations on SIM4Nexus results ...)?

Horizon 2020 Societal challenge 5

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D5.2: THE MAIN NEXUS CHALLENGES IN 'ANDALUSIA (SPAIN)'

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Glossary / Acronyms

CAPRI	COMMON AGRICULTURAL POLICY REGIONALISED IMPACT MODELLING SYSTEM
CCRR	CERTIFICATES OF COMPLIANCE WITH REGULATORY REQUIREMENTS
E3ME	GLOBAL MACRO-ECONOMETRIC MODEL
ESYRCE	SPANISH SURVEY OF SURFACES AND CROP YIELDS
GDP	GROSS DOMESTIC PRODUCT
GHG	GREENHOUSE GAS
GVA	GROSS VALUE ADDED
IECA	ANDALUSIAN INSTITUTE OF STATISTICS AND CARTOGRAPHY
IFAPA	ANDALUSIAN INSTITUTE OF AGRICULTURAL AND FISHERIES RESEARCH AND TRAINING
INE	NATIONAL INSTITUTE OF STATISTICS
MAGRAMA	MINISTRY OF AGRICULTURE, FOOD AND ENVIRONMENT
REDIAM	ANDALUSIAN ENVIRONMENTAL INFORMATION NETWORK
SAR	SPECIFIC ABSORPTION RATE
SDM	SYSTEM DYNAMICS MODEL
SO	STANDARD OUTPUT
UAA	UTILISED AGRICULTURAL AREA
VAT	VALUE ADDED TAX
WFD	WATER FRAMEWORK DIRECTIVE

1 Introduction

The objective of this Deliverable is to report on stakeholders´ engagement in identifying the major nexus challenges and to provide a first assessment in applying the thematic models in the Andalusian case study. This process is the initial step of the case-study work in SIM4NEXUS towards the building of a Serious Game through system dynamic modelling. The overall modeling process is conducted in close collaboration with stakeholders, which have been engaged in identifying the nexus challenges and will be engaged in validating the models and using the Serious Game.

Through interviews, individual and group mapping as well as round-table discussions, stakeholders identified the water-agriculture linkage as the most crucial nexus component in Andalusia, where irrigated agriculture provides more than 64% of food production, represents 67% of farm income and accounts for 63% of the agricultural employment (European Parliament 2016). Furthermore, stakeholders emphasized that energy cost is a limiting factor in irrigated agriculture because of increases in energy demand and energy prices. Altogether the stakeholders have identified six general challenges in the nexus domain in Andalusia:

- Sustainable management of water resources
- Mitigation and adaptation to climate change
- Energy efficiency and promotion of renewable energies
- Fight against soil erosion and desertification
- Resource efficient food production
- Sustainable socioeconomic development

The general view is that these challenges have to be addressed through holistic management that are sustainable, intelligent and inclusive. Consequently, emphasis will be placed on integrating agricultural and environmental policies to cope with pressures on soil and water, so as to promote economic development with a more sustainable use of resources.

We selected the thematic models CAPRI and E3ME to analyse the major nexus challenges that were identified by the stakeholders. The outcomes of both models will feed into the System Dynamics Model (SDM) that is currently under development for the Andalusian case study. CAPRI is used to analyse food-water linkages (irrigation and livestock) and food-energy linkages (biofuel markets). E3ME is used to analyse the energy-food linkages (energy use in agriculture and biomass production) and the energy-water linkages (hydropower). Baseline scenarios are already available at the scale of Andalusia (CAPRI results for 2010 and 2030; E3ME results on a yearly basis from 2000 to 2050).

The report is organized as follows. Section 2 describes the nexus components in Andalusia and highlights future trends. Section 3 explains how stakeholders were engaged in the process of identifying the major nexus challenges; it includes a description of the stakeholders, the preliminary interview process and the first workshop. Section 4 then describes the nexus challenges that were identified with stakeholders, followed by a discussion of the nexus pathways (policy scenarios) in Section 5. Section 6 presents the thematic models CAPRI and E3ME that were selected for the Andalusian case study. Section 7 describes how the SDM will be build. The section shows the conceptual model addressing the interrelationships in the nexus followed by a first draft of the SDM. In chapter 8 we summarize the main achievements of the Andalusian case study and point out the next steps.

2 Description of the nexus components

2.1 Basic characteristics

- Location: South of Spain, includes the provinces of Almeria, Cadiz, Cordoba, Granada, Huelva, Jaen, Malaga and Seville.
- Area: 87.200 Km^2 (17% of Spain)
- Population: 8.4 million (18% of Spain)
- Regional Government (Junta De Andalucía) has legislative powers in Agriculture, Water, Land Planning, Environment and Tourism
- Economy: Agriculture and Tourism are major economic sectors (representing 5.3% and 76.2% GDP in 2015)

Andalusia is one of the 17 autonomous regions of Spain. It includes the provinces of Almeria, Cadiz, Cordoba, Granada, Huelva, Jaen, Malaga and Seville. It is the second largest region in Spain with an **area** of 87 200 km^2, which is 17% of the total national area.

Figure 1: Location and regions of Andalusia

Source: Junta de Andalucia (2015b)

Andalusia is the most populated region in Spain with approximately 8.4 million inhabitants that represent 18% of the national population. It is predominantly rural in nature with approximately 55% of the population living in rural areas. Population density changes depending on the area: higher density in capital cities and coastal areas, where population densities can be as high as 150 inhabitants/km², whilst lower density in inland areas of East Andalusia and North of the region (Figure 2).

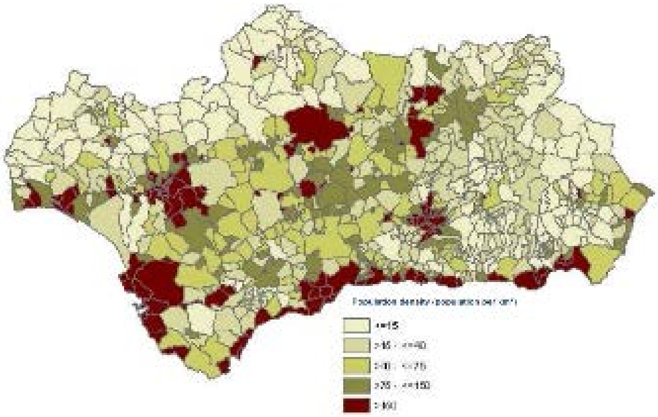
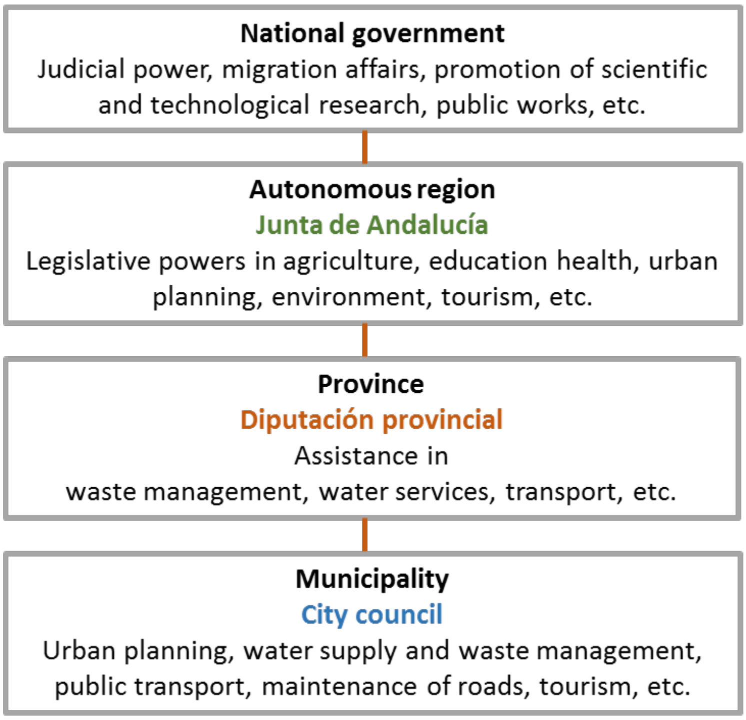


Figure 2: Population density

Source: Junta de Andalucia (2015b)

Concerning governance, each autonomous region in Spain has its own government and parliament. In the particular case of Andalusia, as shown in Figure 3, administration at the regional level is carried out by the Regional Government (Junta de Andalucía); at the provincial level, there is an institution in which all the town/city councils in the province are represented (Diputación Provincial); at the local level, administration belongs to the elected municipalities.



National government
Judicial power, migration affairs, promotion of scientific and technological research, public works, etc.

Autonomous region
Junta de Andalucía
Legislative powers in agriculture, education health, urban planning, environment, tourism, etc.

Province
Diputación provincial
Assistance in waste management, water services, transport, etc.

Municipality
City council
Urban planning, water supply and waste management, public transport, maintenance of roads, tourism, etc.

Figure 3: Governance structure

Source: Junta de Andalucia

With regards to the economy, according to data from the National Institute of Statistics (INE), Andalusia contributed with 130,500 M€ to the national GVA and employed 2.8 million people in 2015 (13.4% of the Spanish GVA and 15.5% of national employment). As a result of the international financial crisis, the Andalusian economy experienced a recessive trend as of 2008 and subsequent years (e.g., Andalusian economic sectors in 2013 registered 10.4% less GVA values than in 2008, Figure 4).

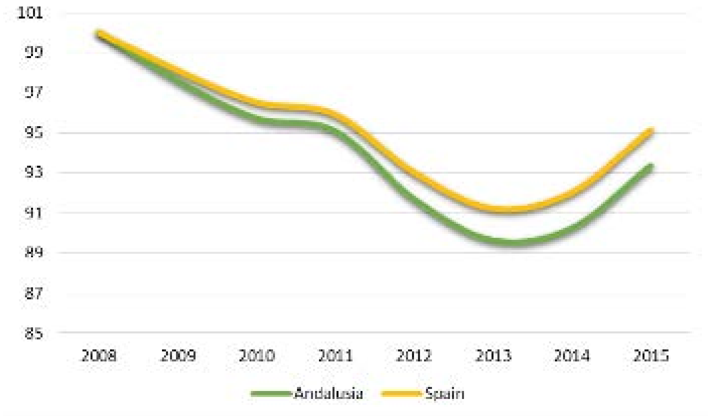


Figure 4: Evolution of the total GVA in Andalusia and Spain (2008-2015, index 100 = 2008)

Source: INE (2015)

In terms of **employment**, trends have been much more critical. During the period from 2008-2015, Andalusia and Spain faced a drastic drop in the number of employees, reaching in 2013 a decrease of 18.6% and 16.3%, respectively, compared to 2008 (Figure 5). However, there has been a slight positive trend since 2013 in accordance with the GVA shown above.

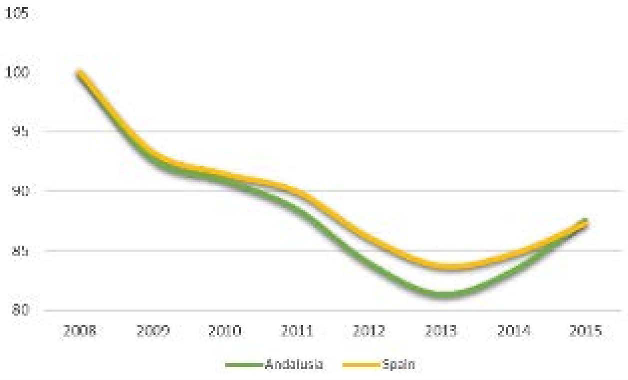


Figure 5: Evolution of employed persons in Andalusia and Spain (2008-2015, index 100 = 2008)

Source: INE (2015)

Looking at **economic sectors**, the contribution of each economic sector to the Andalusian GVA has experienced changes over the last decade (Figure 6). During the period from 2006-2015, the service sector has particularly increased its regional GVA, going from 67.3% to 76.2% (an increase of 8.9 points).

The secondary sector, however, has reduced its contribution significantly (9.2 points). The primary sector has increased slightly during the same period (0.2 points).

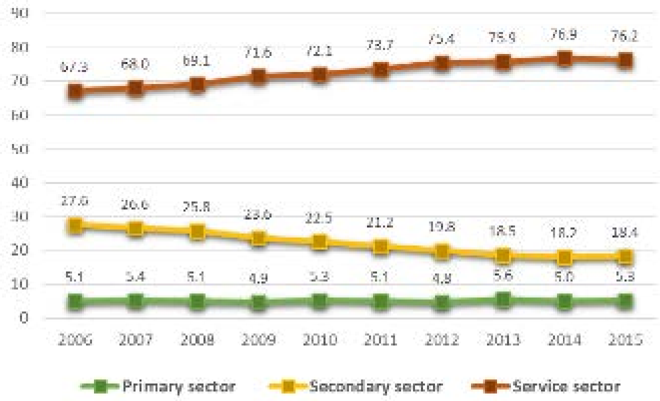


Figure 6: Evolution of GVA by economic sector in Andalusia (2006-2015)

Source: INE (2015)

The trend of the contribution of each economic sector to the Andalusian employment is similar to the contribution of the regional GVA. The service sector has increased by 8.7 points between 2008 and 2015 (from 69.7% to 78.4%). Similarly, the secondary sector has decreased by 9.6 points (from 23.3% to 13.7%) and the primary sector has increased slightly by 0.9 points (Figure 7).

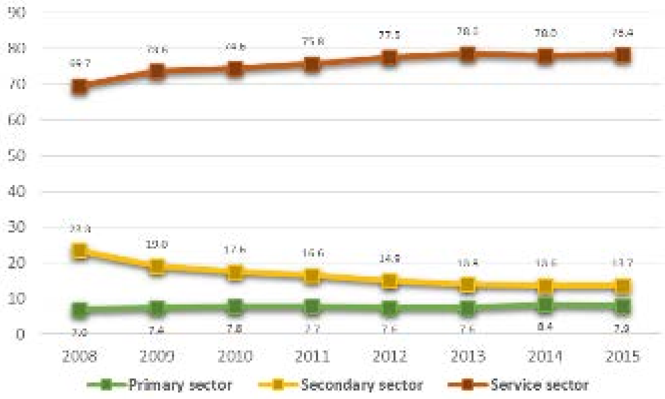


Figure 7: Evolution of employed persons in Andalusia (2008-2015)

Source: INE (2015)

2.2 Description of the Nexus components

2.2.1 Climate

Seven types of geographic areas with different climate types can be distinguished in Andalusia (Figure 8):

- Atlantic coastline climate: along the Atlantic coast, Oceanic Mediterranean climate with average annual temperatures of 17-19°C and average annual precipitation of 500-700 mm.

- Guadalquivir depression: Continental Mediterranean climate in the Guadalquivir Delta, with average annual temperatures of 17-18°C and precipitation of 500-700 mm.
- Sierra Morena: Semi-arid Mediterranean climate with average annual temperatures of 16-17ºC and precipitation of 600-800 mm.
- Mediterranean cost: Subtropical Mediterranean climate characterised by average annual temperatures of 17-19°C and precipitation of 400-900 mm.
- Mediterranean coast and southeast: Sub-desert Mediterranean climate, with average temperatures of 17-21°C and average precipitation of 300 mm.
- Intrabetic depression: Continental Mediterranean climate with temperatures between 13-15°C and precipitation of 300-600 mm.
- Betic Mountains range: Mountain climate with average annual temperatures of 11-15°C and precipitation of 400-1000 mm.

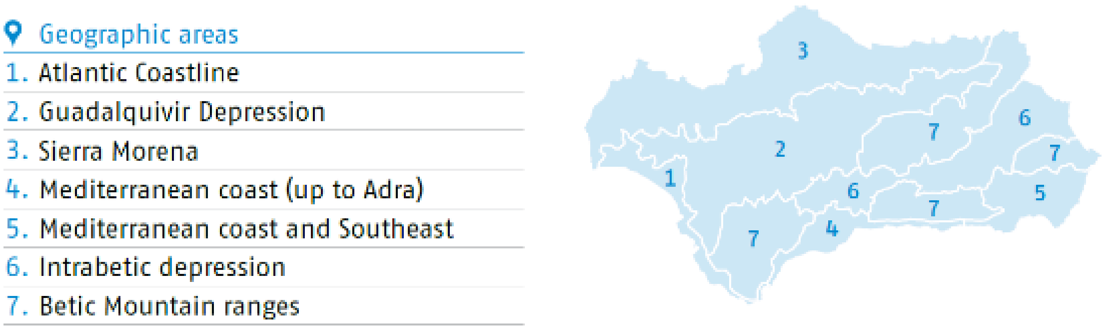


Figure 8: Climatic geographic areas in Andalusia

Source: Junta de Andalucía (2014a)

As shown in Figure 9, rainfall deviations and changes in average temperature as a consequence of climate change are already substantial.

Figure 9: Total rainfall deviations and average temperatures in 2013 compared to the average values during the period 1971–2000 in Andalusia

Source: Junta de Andalucía (2014a)

2.2.2 Water

Andalusia encompasses six River Basin Districts (RBD), three of them at the intra-community level (Tinto, Odiel, Piedras RBD; Guadalete, Barbate RBD; and Andalusian Mediterranean RBD), two of them at the inter-community level (Guadalquivir RBD and Segura RBD) and one transnational (Guadiana RBD) (Figure 9). The management of intra-community RBD lies with the Autonomous Hydraulic Administration, the Andalusian Water Agency. In the case of inter and transnational RBD, powers are exercised by the River Basin Authority (Guadalquivir River Basin Authority, Segura River Basin Authority, and Guadiana River Basin Authority). The River Basin Authorities[1] are public corporations with legal personality, assigned for administrative purposes to the Ministry of Agriculture, Food and Environment and with full functional autonomy. The main functions of these institutions are the development of River Basin Management Plans; the management and control of public water; and the design, construction and operation of the works carried out under the Agency's own funds, and assigned to them by the state.

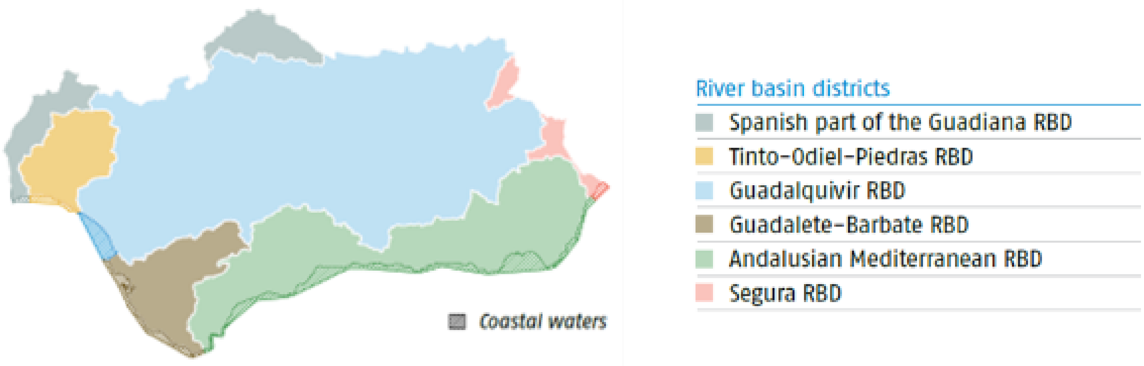


Figure 10: River basin districts

Source: Junta de Andalucía (2014a)

The Guadalquivir RBD is the main river basin of Andalusia with a watershed area of 51 500 Km^2, that represents 58.8% of the geographic area of Andalusia. The total watershed area is 57 180 Km^2, which implies that Andalusia is the main region involved in the Guadalquivir RBD with a participation in the watershed area that reaches 90.1%, followed by Castilla-La Mancha (7.1%), Extremadura (2.7%) and Murcia (0.2%) (Figure 10).

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[1] Further information in Centre of Studies and Experimentation on Public Works (CEDEX)

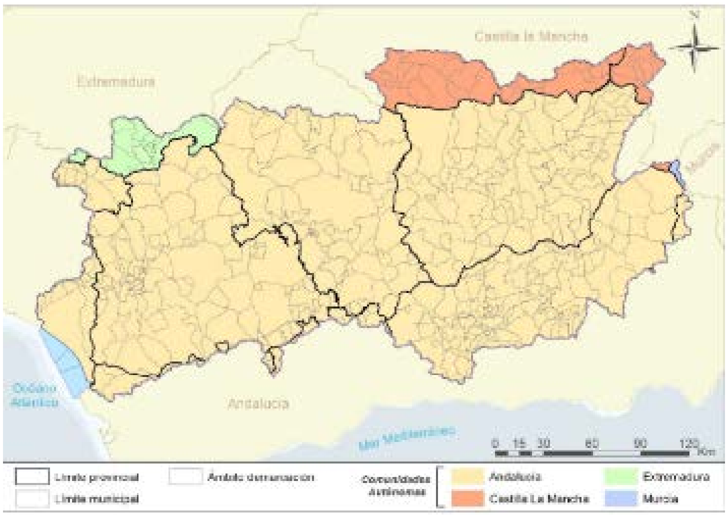

Figure 11: Territorial area of the Guadalquivir RBD

Source: Confederación Hidrográfica del Guadalquivir (2015)

Total water demand in the Guadalquivier RBD is estimated to be 3 815 hm^3 in 2015 with agriculture being the main water user with 3 356 hm^3 (88% of the total demand) (Table 1). With regard to the origin of water, approximately 2 498 hm^3 correspond to surface water (74.0% of the total water demand).

Table 1: Estimated water demand by use in the Guadalquivir river basin. Values in hm^3.

	Surface	Groundwater	Desalinisation	Reuse	Transfer	Total
Water supply	339.00	40.45	0	0	0	379.45
Agriculture	2497.92	858.84	0	0	0	3356.77
Industry	29.70	13.70	0	0	0	43.40
Energy production	35.84	0	0	0	0	35.84
Transfer	0	0	0	0	0	0
Total	2902.46	912.99	0	0	0	3815.46

Source: Confederación Hidrográfica del Guadalquivir (2015)

Even though the Guadalquivir RBD is the main river basin district and has the highest water demand in Andalusia, the river basin at the intra-community level (Tinto, Odiel, Piedras RBD; Guadalete, Barbate RBD; and Andalusian Mediterranean RBD) are also very significant within the region. This is because most high value added agricultural crops in the region are produced in these areas. Furthermore, major tourist areas are concentrated within the limits of these river basins. Therefore, data on water demand by sector and type of source for the three RBD are presented in Tables 2 to 4.

Table 2: Estimated water demand by use in the Cuencas Mediterráneas river basin. Values in hm^3.

	Surface	Groundwater	Desalinisation	Reuse	Transfer	Total
Supply	167.75	145.05	20.27	0.00	11.79	344.85
Agriculture	396.22	361.36	21.07	11.73	30.89	821.27

Industry	13.76	3.61	2.25	0.00	0.00	19.62
Energy production	3.23	0.04	5.29	0.64	0.00	9.20
Other uses	1.11	18.37	0.00	10.27	0.00	29.75
Transfer	0	0	0	0	57.10	0.00
Total	582.06	528.43	48.88	22.64	42.68	1224.69

Source: Junta de Andalucia (2015c)

Table 3: Estimated water demand by use in the Guadalete and Barbate river basin. Values in hm3.

	Surface	Groundwater	Desalinisation	Reuse	Transfer	Total
Supply	101.75	20.05	0	0	68.48	121.53
Agriculture	272.79	39.02	0	8.12	0	319.95
Industry	0	0	0	0	0	0
Energy production	15.24	0	0	0	0	15.24
Transfer	0	0	0	0	0	0
Other uses	0.78	4.03	0	1.56	0	6.37
Total	390.57	63.107	0	9.68	68.48	463.10

Source: Junta de Andalucia (2015d)

Table 4: Estimated water demand by use in the Tinto, Odiel and Piedras river basin. Values in hm^{3}.

	Surface	Groundwater	Desalinisation	Reuse	Transfer	Total
Supply	51.43	3.72	0	0	2.44	56.17
Agriculture	118.57	30.51	0	0	0	149.08
Industry	45.73	0	0	0	0	45.73
Energy production	0	0	0	0	0	0
Transfer	0	0	0	0	0	-0
Other uses	0.195	1.75	0	0	0	1.95
Total	215.93	35.99	0	0	2.44	252.93

Source: Junta de Andalucia (2015e)

The reservoir water in the main river basins varies strongly over the years depending mainly on the precipitations, as shown in Figure 12.

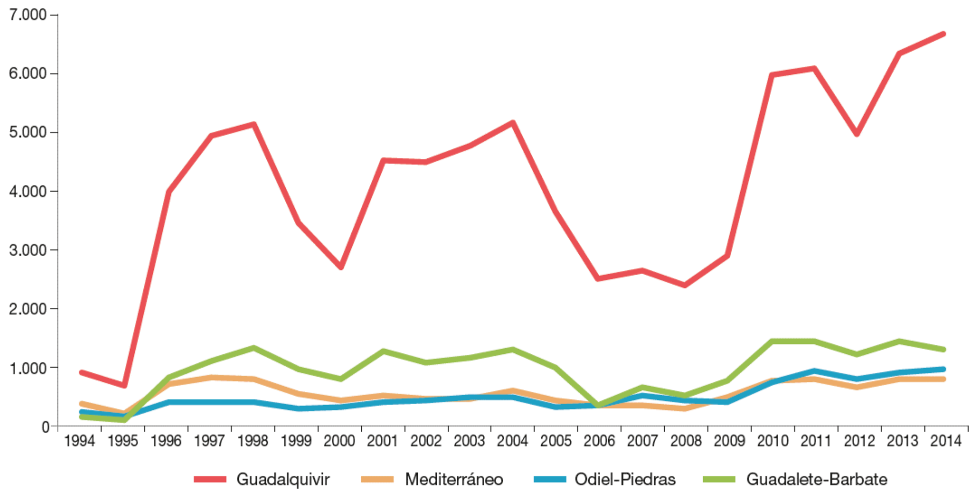

Figure 12: Evolution of reservoir water in the main River Basin Districts of Andalusia 1994-2014

Source: Junta de Andalucia (2015a)

2.2.3 Land

Andalusian land contains mainly of natural and forest areas (50.1% of the total surface) and agriculture (41.7% of the total surface). Constructed and altered areas represent 4.6% of the total surface and water areas represent 3.6% (Figure 13). Among natural and forest areas, scrublands with trees and without trees are predominant (24.0 and 22.7% respectively), followed by pasture lands with trees (18.5%) (Figure 14). Within the agricultural areas, arable crops and olive trees are mainly used, representing 46.4% and 40.5% of the total agricultural surface, respectively.

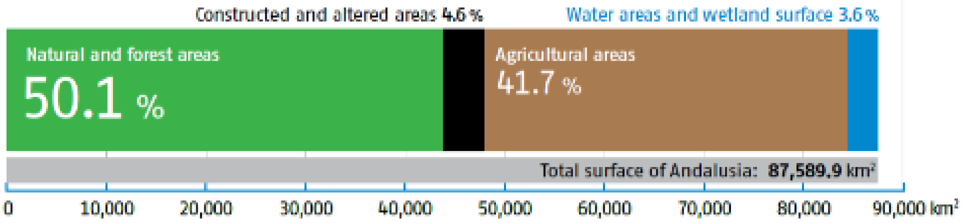

Figure 13: Distribution of land cover 2011

Source: Junta de Andalucía (2014a)

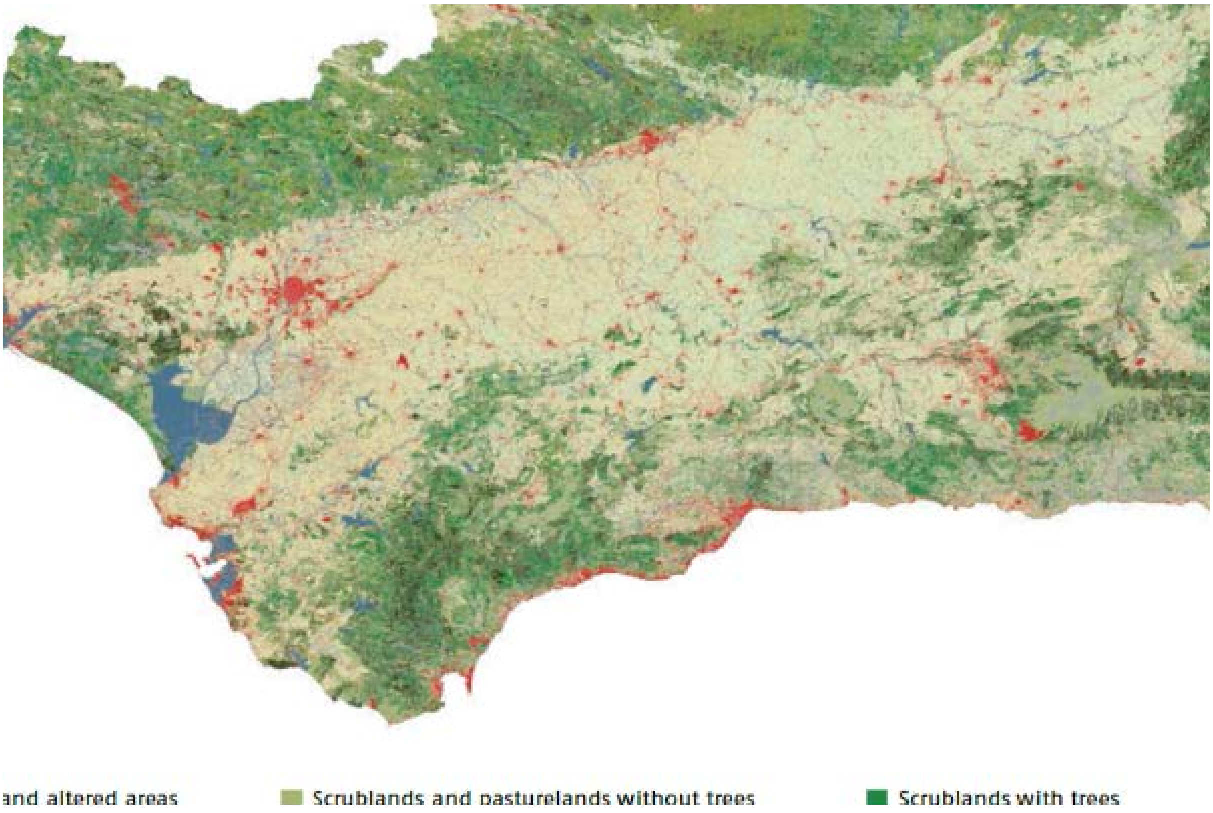

Figure 14: Landcover map 2011

Source: Junta de Andalucía (2014a)

With regards to land use changes over the period 2005-2011, natural and forest areas have decreased by 4%, while agricultural areas have increased by 3%. The most substantial change is observed in constructed areas that have enlarged by 13%.

2.2.4 Agriculture

2.2.4.1 Overview of agriculture in the region

Andalusia has approximately 4.4 million ha of utilised agricultural area (UAA) (18.7% of the national total), of which one million are irrigated (29.3% of the total irrigated land in Spain). In terms of number of farms, according to the Farm Structure Survey 2013, there are 244 566 farm holdings in Andalusia that represent 25.3% of the total in Spain. The average UAA per holding is 18.2 ha, lower than the national average of 24.7 ha. Nevertheless, 56% of all farms have less than five hectares of UAA (7.1% of the total surface area). In contrast, only 3.5% of the holdings have over 100 hectares of UAA, but these correspond to 50.8% of the total UAA in Andalusia.

As shown in Table 5, that presents data from the Spanish Survey of Surfaces and Crop Yields (ESYRCE), in 2015, predominant crops are olives, generally for oil (1.5 million hectares); cereals, mainly wheat (755

652 ha); industrial crops, especially sunflower and cotton (391 375 ha); and stone fruits, particularly almonds (152 621 ha). Irrigation is mainly used for olives, cereals, industrial crops, fruits and vegetables.

Table 5: UAA distribution in Andalusia (ha).

Crop	Rain fed	Irrigation	Greenhouse	Total
Cereals	632 995	122 657		755 652
Protein crops	53 133	1 831		54 964
Tuber	82	7 138		7 220
Industrial crops	298 779	92 595		391 375
Fodder crops	52 736	15 546		68 282
Vegetables	4 622	36 046	14 930	55 598
Fallow land	247 861	13 746		261 607
Citrus fruits	5 804	76 968		82 772
Stone fruits	180 250	45 776	1 713	227 739
Vineyard	22 663	4 202		26 865
Olive	980 667	586 708		1 567 375
Grassland	923 435	208		923 643
Total	**3 403 026**	**1 003 422**	**16 643**	**4 423 091**

Source: MAGRAMA (2015)

The average economic size of a farm in Andalusia in terms of Standard Output (SO) is 33 178 €; it is below the national average of 37 284 €. The majority of farms (70%) are below 15 000 €, 24% is between 15 000 and 100 000 € and 6% of farm holdings are over 100 000 €. The most profitable farms are linked to greenhouse production while those with lower income concentrate mainly on rain fed crops production. Looking at the different agricultural sectors, the highest contributing sectors in 2014 were: olive oil (2 301 million €; vegetables in general (2 878 million €); table olives and for pressing (620 million €); citrus fruits (566 million €); and cereals (543 million €) (European Parliament 2016).

It is necessary to highlight that irrigated agriculture generates more than 64% of production in Andalusia, represents 67% of farm income and accounts for 63% of the agricultural employment (European Parliament 2016).

2.2.4.2 Irrigation agriculture

Irrigated land in the region is mainly concentrated in the Guadalquivir RBD (856 429 ha), which contains of approximately 86% of the total irrigated land in the region. Figure 15 shows the distribution of irrigated crops within the Guadalquivir RBD: olive trees (in green) are the most predominant (52%), followed by extensive crops (30% -in orange-), fruit trees (7% -in red-) and rice (4% -in blue-).

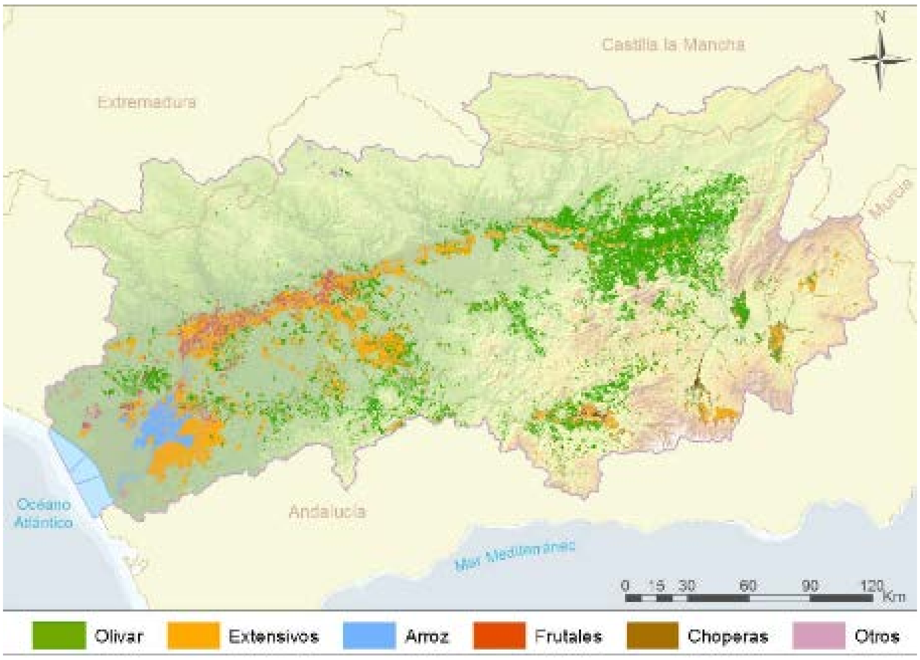

Figure 15: Irrigated crops in the Guadalquivir RBD

Source: Confederación Hidrográfica del Guadalquivir (2015)

Total agriculture net water demand in the basin reaches 2 741 hm3, mainly distributed among olive trees (21%), rice (13%), cotton (9%), vegetables (9%) and fruits (8%) (Table 6). The gross water demand is 3 357 hm^3 taken into consideration the efficiency of water transport, distribution and application (type of irrigation system). According to the estimations of the Guadalquivir River Basin Authority, this gross water demand will decrease to approximately 3 328 hm^3 in 2021 and to 3 227 hm^3 in 2027. Approximately 74% corresponds to surface water and 26.0% to groundwater.

Table 6: Estimated net water demand by crop in the Guadalquivir RBD in 2015

Crop	Irrigated land (ha)	Water available (m3/ha)	Net demand (hm^3)
Cotton	56 280	4 500	253
Rice	35 180	14 450	368
Citrus fruit	38 020	5 400	205
Winter extensive crops	68 770	1 900	131
Strawberry	1 114	4 500	5
Fruit trees	24 639	5 400	133
Sunflower	23 901	2 600	62
Vegetables	54 081	4 500	243
Greenhouse	948	4 500	4
Maize	17 900	5 000	89
Olive trees	387 697	1 500	582

Sugar beet	12 230	4 500	55
Others	135 667	4 500	611
Total	**856 429**		**2 741**

Source: Confederación Hidrográfica del Guadalquivir (2015)

Approximately 74% of the irrigated land in Andalusia currently uses localised irrigation systems, 17% drop irrigation and to a lesser extent sprinkler irrigation. The evolution of the irrigated land from 2005 to 2015 shows a steady increase in localised irrigation systems.

2.2.5 Energy

2.2.5.1 Energy resources in the region

Main energy resources in Andalusia include coal production in the area of the Valle del Guadiato, natural gas extraction from deposits in the Gulf of Cadiz and Valle del Guadalquivir, and renewable resources mainly located in Seville (solar energy), in Cadiz (wind energy), and in Jaen and Cordoba (biomass production). Andalusia has no own oil reserves and is highly dependent on oil imports.

Andalusia possesses excellent natural resources for wind, solar and biomass energy. Therefore, the total renewable installed capacity in Andalusia is 6 119 MW and 39% of the electric energy comes from renewable sources. The current power generation from renewable energy resources includes (Junta de Andalucía, 2016):

- 17 biogas production plants with a total power of 30 MW
- Leader in national biomass energy production with 18 biomass production facilities amounting a total power of 257 MW
- Considerable growth of wind industry in the last decade, with a total power of 3 324 MW
- Hydroelectric energy less developed due to high demand of water for other uses (irrigation, water supply). Nonetheless, there are 90 plants in operation with 620 MW.
- Andalusia is the region with the largest thermosolar installed capacity, with 22 plants and 997 MW.
- Solar energy is becoming more and more relevant in Andalusia, with 876 MW installed.

With regards to thermal energy generation, Andalusia is the Spanish region with the largest surface covered by solar thermal collectors, 932 462 m^2 that represents 28% of the national total. Likewise, biomass for thermal energy production is also very important in the region, with a thermal power installed of 1 717 MW.

2.2.5.2 Energy demand

As shown in Figure 16, the decreasing energy consumption over the last years changed in 2014 with an increase of 3.2% in primary energy consumption. Regarding energy self-sufficiency, 19.9% of the energy consumed is produced in the region.

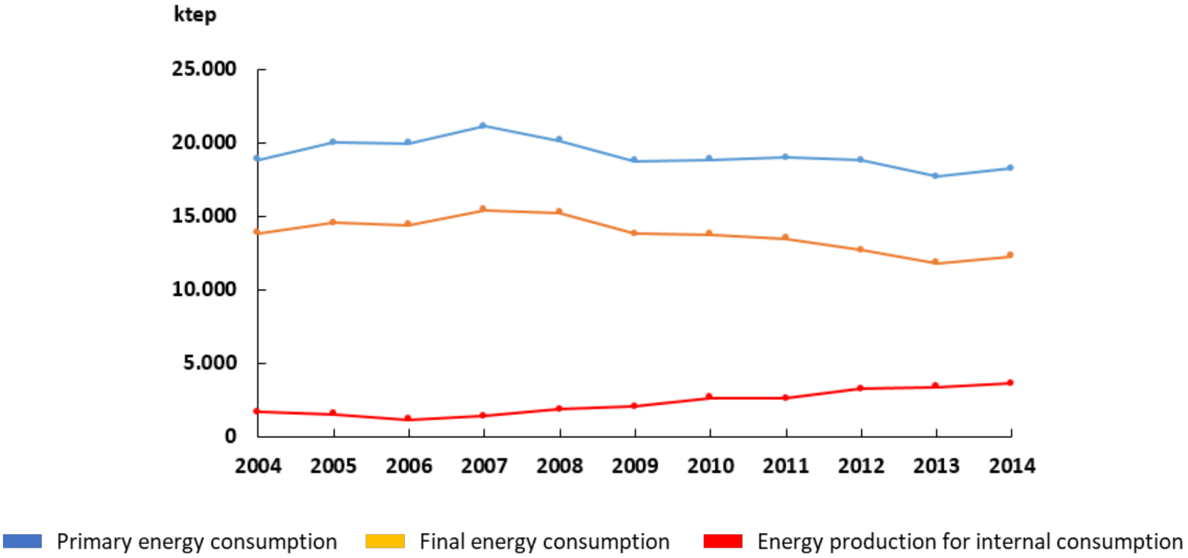

Figure 16: Evolution of internal energy production and consumption

Source: Junta de Andalucía (2014b)

Looking at the evolution of energy consumption by source, in 2014 petrol was the main source of energy (43.6%) followed by natural gas (20.7%). Nonetheless, energy consumption from renewable sources increased by 8.1%, representing 20.1% of primary energy consumption (Figure 17). The increase is particularly significant for biomass and thermosolar energy. Looking at renewable energy consumption by sector, industry represents 47.1% of total consumption, followed by household use (28.2%). However, the primary sector, service sector, and transport represent only 2.6%, 8.0% and 14.1%, respectively, in renewable energy use (Figure 18), indicating potential increases in future.

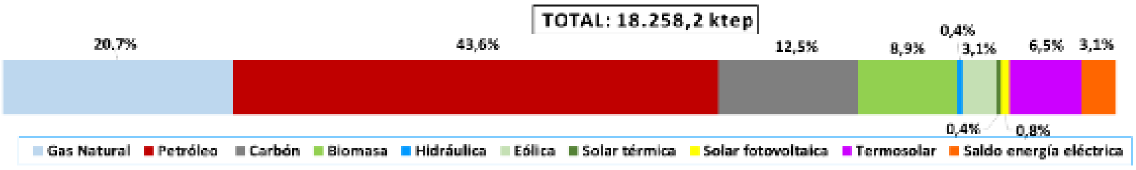

Figure 17: Primary energy consumption in Andalusia by source, 2014

Source: Junta de Andalucía (2014b)

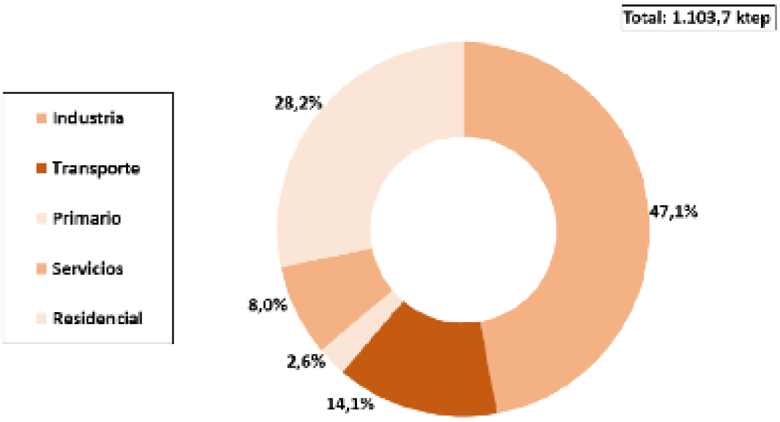

Figure 18: Final renewable energy consumption by sector, 2014

Source: Junta de Andalucía (2014b)

2.3 Future trends of the nexus sectors

The geographical location of Andalusia makes the region particularly vulnerable to climate change. According to the Spanish Agency of Meteorology, forecasts from different climate models under different Representative Concentration Pathways (RCPs) show long-term variations in average maximum temperatures in the region that ranges between -1 and 7ºC (Figure 19). Regarding precipitations, forecasts also predict significant changes over the next few years (Figure 20).

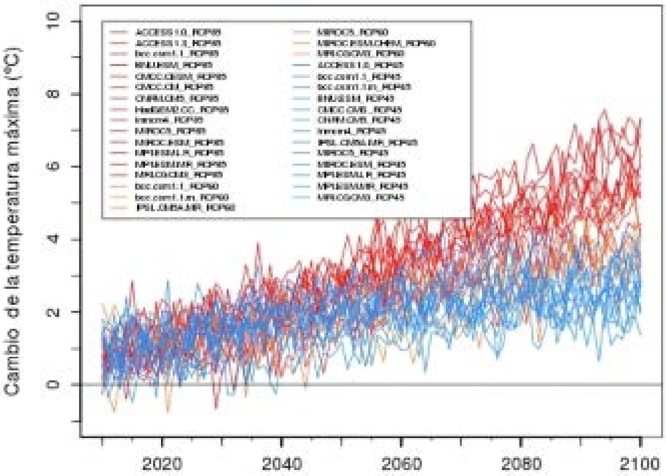

Figure 19: Long-term changes in average maximum temperatures in Andalusia according to different RCP and climate models

Source: AEMET

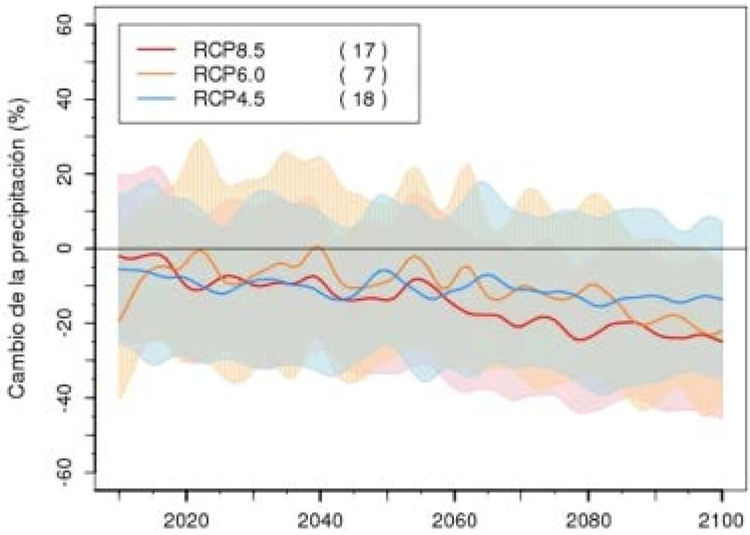

Figure 20: Long-term changes in average precipitations in Andalusia according to different RCPs

Source: AEMET

Regarding changes in water over the next years, climate change will affect water availability in the region leading to a reduction of 8% by 2027, according to the different River Basin Management Plans.

With respect to agriculture, outcomes from the CAPRI baseline for 2030 highlight a significant increase in the area allocated to soft wheat, sunflower and sugar beet, while a decline in the area devoted to vegetables is expected (Figure 21). Focusing on irrigated agriculture, olive will remain the main crop in terms of total water use, followed by fruits (Figure 22).

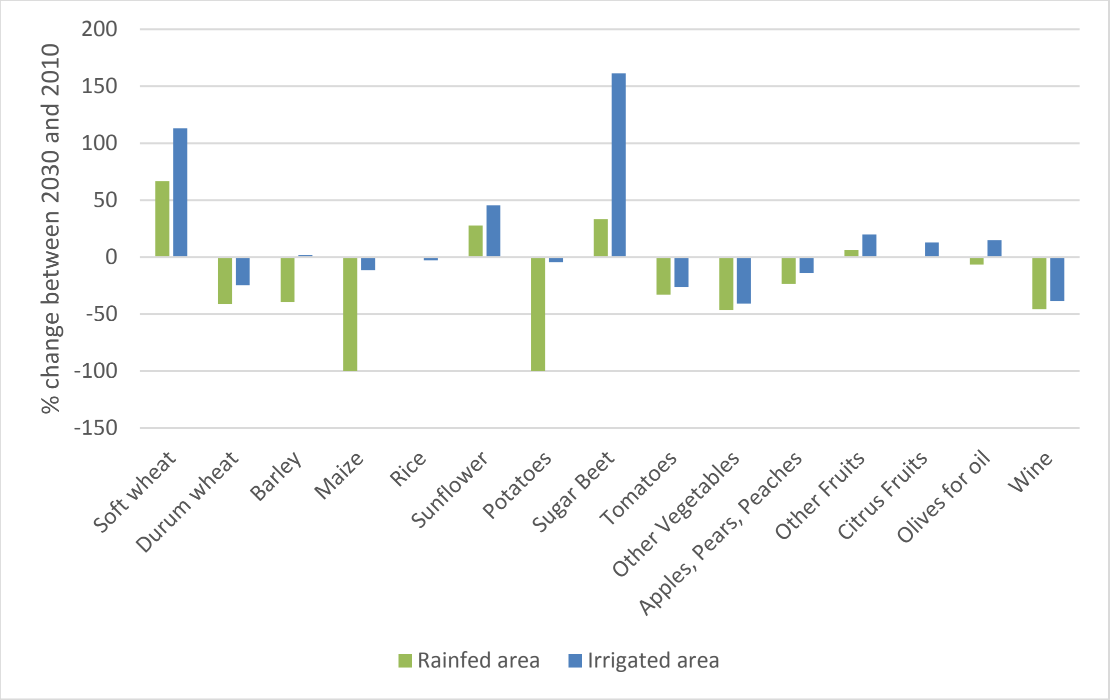

Figure 21: Changes in crop area between 2030 and 2010

Source: CARPI model

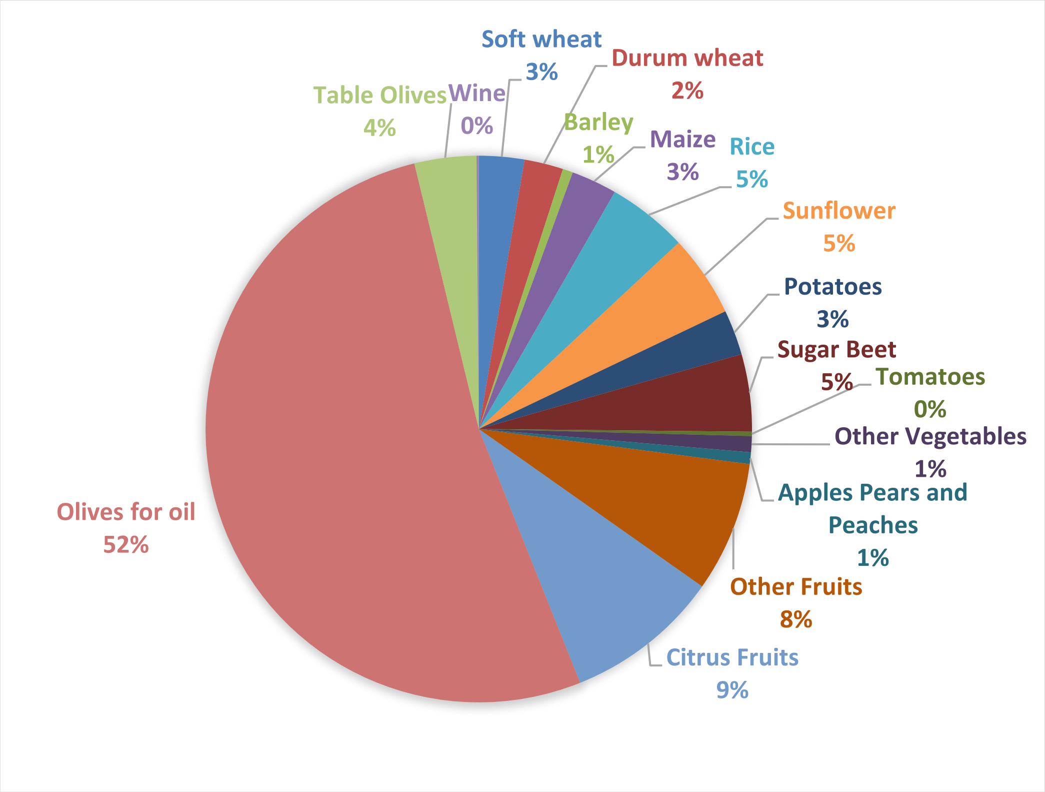

Figure 22: Total irrigation water use share in Andalusia by crop in 2030 (values in %)

Source: CAPRI model

Looking at the energy sector, renewable and non-renewable energy production trends provided by the E3ME model show an increase in renewable energies over the next years (particularly for solar energy), while non-renewable energies tend to decrease (Figures 23 and 24).

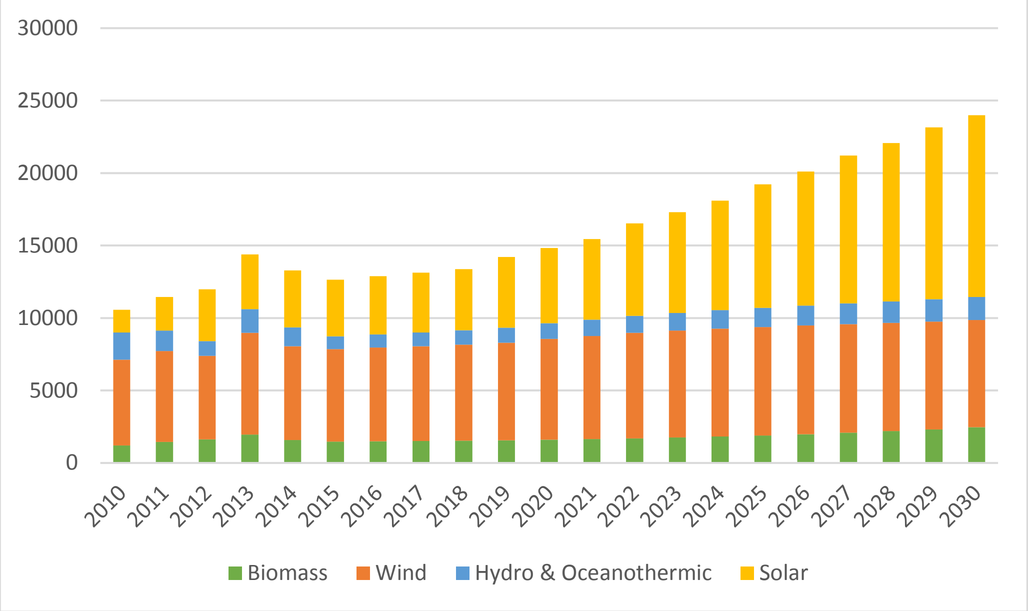

Figure 23: Projected renewable energy production by technology in Andalusia (values in GWh)

Source: E3ME model

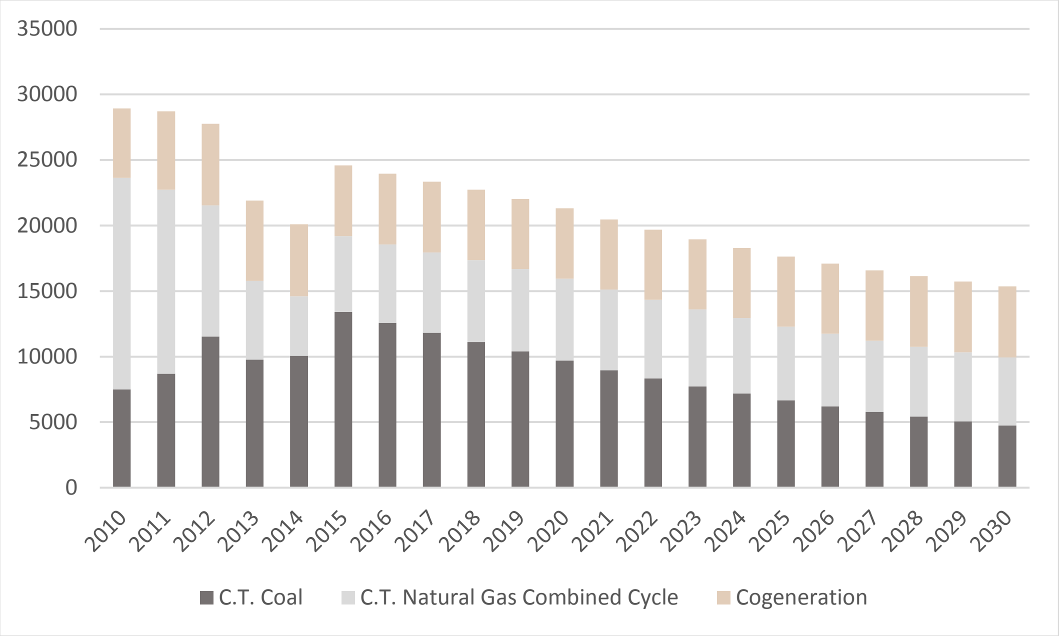

Figure 24: Projected non-renewable energy production by technology in Andalusia (values in GWh)

Source: E3ME model

3 Engaging stakeholders in the nexus analysis

Within the Andalusian case-study, stakeholders have been engaged in identifying the nexus challenges, and will be engaged in validating the models and using the Serious Game. This section describes stakeholders' engagement in identifying the nexus challenges and policy scenarios through preliminary interviews, individual and group mapping as well as round-table discussions. Finally, the next steps will be described.

3.1 Preliminary interviews

Stakeholders were identified through an online investigation and snowball sampling. All stakeholders have received the SIM4NEXUS flyer in digital form (25 flyers distributed) and have been informed about the project and the case study by phone in the first quarter of 2017.

The principal stakeholders were selected and 14 institutions were contacted again by phone/skype for semi-structured interviews. Seven guiding questions have been developed to get a first understanding of stakeholders' views on major NEXUS challenges (see the questionnaire in Appendix 1). The guiding questions were sent via email to the stakeholders before the interview. The semi-structured interviews lasted for approximately 45 min to one hour. Altogether 14 stakeholders were interviewed, including six from the public sector (1. Regional Ministry of the Environment and Territory Planning (RMETP), 2. Regional Ministry of the Agriculture, Fishing and Rural Development (RGAFRD), 3. Environment and Water Agency of Andalusia (EWAA), 4. Andalusian Energy Agency (AEA), 5. Provincial Council (PC), 6. Guadalquivir River Basin Authority (GRBA)); four from the private sector (7. National Federation of Water Users Associations (FENACORE), 8. Andalusian Federation of Water User Associations (FERAGUA), 9. Farmer Organisation Coordinator (CAOAG), 10. Andalusian Association of Promoters and Producers of Renewable Energy (APREAN); one NGO (11. WWF), and three from the research and university sector (12. Andalusian Institute of Agricultural and Fisheries Research and Training (IFAPA), 13. University of Cordoba (UCO), 14. University of Almeria (UAL)). A brief description of the stakeholders and their roles is provided in Appendix 2.

We learned from these preliminary steps that the stakeholders see the nexus issues pertinent to their own interests as most relevant to be tackled. For example, those stakeholders in charge of water believe that water is the main nexus issue, while those stakeholders in charge of energy believe energy is the main nexus issue. Moreover, some stakeholders mentioned land use change as a pressing nexus issue, while others believe land use change is no pressing issue.

3.2 Workshop 1

The 1st workshop took place on 26th October 2017 in Seville (Andalusia).

The workshop started with an opening address followed by a presentation of the SIM4NEXUS project and the Andalusian case study. Written information was handed out to each participant, including the workshop´s schedule, nexus flyer, and factsheets of the E3ME and CAPRI models. The actual steps of the workshop were then described. The goal of the workshop was to obtain stakeholder's views on nexus relationships and challenges. It was roughly divided into three sessions: 1) individual mapping, 2) group mapping, 3) round-table discussion of nexus challenges and policy scenarios. A confidentiality agreement was read aloud and was agreed on by all participants.

At the end of the workshop, the participants evaluated the workshop based on a pre-defined questionnaire. The evaluation was largely positive; except for the low attendance in the afternoon, no other major critique was raised. After the workshop, the participants received a short "thank-you message" via email.

3.2.1 Individual mapping

Each participant had to draw his/her vision of the nexus interlinkages by selecting the variables, signs (+/-) and magnitudes of relationships (-1 to +1). The draft SDM (section 7.2) was not presented during the workshop, because the goal was to get stakeholders views without influencing them. The goal was to use an inductive approach similar to grounded theory.

Altogether eleven individual maps were produced. Figure 25 shows an example of an individual map. Without providing additional information, each participant included an average of 18 self-defined variables in his/her individual map. In total we obtained 142 variables that are now combined to categories for further analysis (fuzzy cognitive mapping and SD modelling).

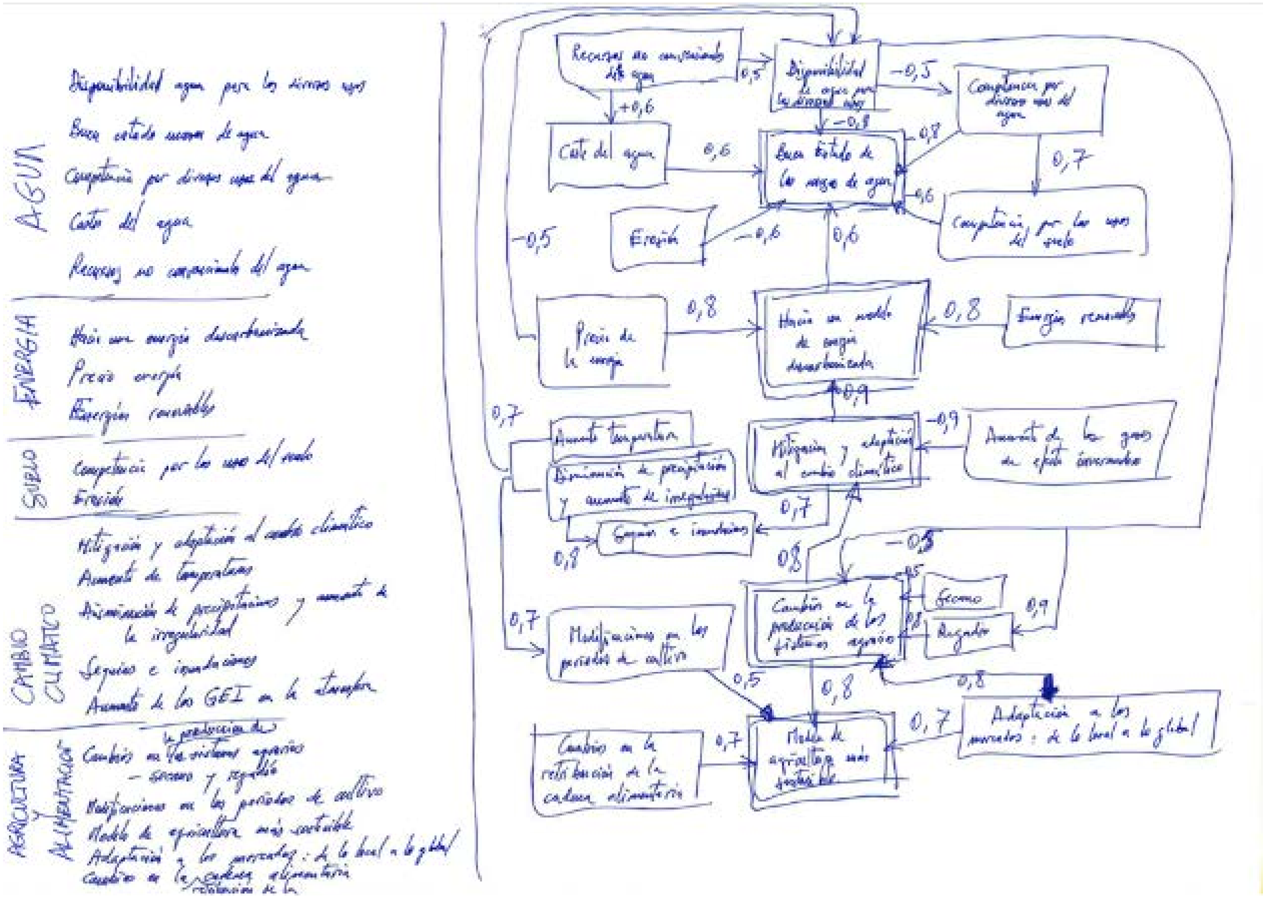

Figure 25: Example of an individual map

Source: Stakeholder´s elaboration

3.2.2 Group mapping

After each participant had terminated his/her individual map, a group map based on the input of all stakeholders was derived. Figures 26 and 27 show a picture of the group map and a photo of the group mapping activity, respectively. The variables of the group map and their linkages will be analysed and juxtaposed with the individual maps to get a complete picture of all nexus relationships. The conceptual model (section 7.1) will be refined accordingly. The revised conceptual model will be discussed with stakeholders in the next workshop.

Figure 26: Group map

Source: Stakeholders’ elaboration

Figure 27: Photo of group mapping activity

Source: Own photo

3.2.3 Identifying the nexus challenges and policy scenarios

After the individual and group mapping activities, the nexus challenges and policy objectives were discussed with all participants. First, the nexus challenges were summarized on a blackboard. Second, participants were asked to propose policy scenarios (objective and measures) that have the potential to meet the nexus challenges in Andalusia in the medium and long term. The major nexus challenges and policy scenarios (pathways) are discussed in section 4 and 5, respectively.

3.3 Next steps

The individual and group maps will be used to revise the conceptual model and to provide a basis for the SD model. Additionally, first attempts (variable selection, assumptions) will be made to address the three policy scenarios in the SDM. The revised conceptual model and respective SDM considering scenarios of the three crucial policy changes will be checked with the participants in the next workshop.

4 Description of the nexus challenges

This chapter provides a discussion about the nexus challenges that are based on preliminary interviews with stakeholders and on the outcomes from the round-table discussion of the first stakeholders' workshop. As follows, we first provide a general overview (brainstorming) of the interrelationships among nexus components as seen by the stakeholders. After that the most important challenges of the case study will be summarized.

4.1 Overview of interrelationships among nexus components

Climate – Water

- Climate change will affect water availability in the region in such a way that runoff will decrease by 8% in 2027, according to the river basin management plans, and by 10-12% according to other studies from the Regional Government. Furthermore, an increase in extreme events has already been observed, particularly more and longer droughts.
- Reduction in water availability together with the rise in temperatures will lead to an increase in water demand and, therefore, to more pressure on water resources.

Climate – Agriculture

- Changes in temperatures and precipitation will produce an increase in crop evapotranspiration that will affect crop water requirement and crop yields. The impact will be higher in rain-fed agriculture, which is more reliant on precipitations than irrigated agriculture. Therefore, crop yields are expected to decrease in rainfed crops and increase in irrigated crops (if there is water available). In a context of climate change and scarce water resources, shifting towards more cost-effective crops (e.g., almonds) is likely to occur.
- Changes in climate may also affect sowing and harvesting dates and induce introduction of new crop varieties.

Climate – Land

- Irregular precipitation will increase the current soil erosion problems in Andalusia.

Climate – Energy

- The increase in wind and radiation, together with the need to reduce fossil fuels consumption, may lead to an increase in solar and wind energy production. Furthermore, changes in energy demand are also likely to occur in the future because of climate change.

Water – Climate

- Water bodies may affect climate at local level. According to Guadalquivir River Basin Authority, 25% of precipitation in the basin come from evaporation in internal water bodies.

Water – Agriculture

- Irrigation increases crop yields and production, if there is water available. However, considering the reduction in water availability, the agricultural sector must optimise water use and might most probably reduce the irrigated area by 10-15%.

Water – Land

- Soil erosion and salinization because of agricultural activities
- Land use change as a result of variation in water availability: reduction in irrigated area, shift to rain-fed agriculture and even to forest use.

Water – Energy

- Reduction in water availability will negatively affect hydropower production and energy production (cooling systems).

Agriculture – Climate

- Agriculture emits and absorbs greenhouse gases, although the balance is ambiguous (depending on the person interviewed).

Agriculture – Water

- Overexploitation of water resources, particularly in the main basin (Guadalquivir river). In terms of water quality, pollution of water resources by nitrates in agricultural areas is very significant. Nowadays, only 50% of water bodies present a good environmental status, while the Water Framework Directive (WFD) set the target of 100% by 2010.
- In coastal areas, overexploitation of groundwater resources is leading to aquifer salinization (e.g., in Almeria).

Agriculture – Land

- Agricultural activities contribute to soil pollution and soil productivity losses. Promotion of conservation agriculture may help to protect the soil.

Agriculture – Energy

- The current agricultural model is highly dependent on energy (irrigation, machinery, fertiliser production, transport). Irrigation energy demand has trebled in the last years from 200-300 Kwh/ha to 1100-1200 Kwh/ha. This is not only an environmental issue but also an economic issue as it may challenge the economic sustainability of agriculture highly dependent on energy. Energy cost (300-400 €/ha) has turned into a more limiting factor than water cost (60-90 €/ha).

Land – Climate

- Carbon sink capacity is closely linked to land use: agriculture and forest uses contribute to the absorption of greenhouse gases (GHGs).

Land – Water

- Competition over water resources between different uses is significant or not significant depending on the person interviewed. This is because 1) high agricultural water demand is concentrated in winter (greenhouses) whilst tourist water demand is concentrated in summer; and 2) coastal areas have access to desalinated water. Nevertheless, desalinated water is expensive (0.6-0.7 €/m^3) and the majority of desalination plants work far below capacity.

Land – Agriculture

- Competition over land use between agriculture and urbanization in tourist areas (mainly coastal areas).

Land – Energy

- Land planning affect energy production (fracking, mining, renewable plants installations, etc.).

Energy – Climate

- Energy production emits great quantities of GHGs. At the same time, promotion of renewable energies can help to reduce this type of emissions.

Energy – Water

- Energy is used in water pumping (groundwater, water supply, and pressure on irrigation systems) and in desalination and water reuse

Energy – Agriculture

- Energy cost has turned into a liming factor in irrigated agriculture because of increases in energy demand and energy prices. The energy price has increased substantially over the last years.

Therefore, there is a need to improve energy use efficiency as well as to introduce renewable energies in agriculture.

Energy – Land

- Land use to install renewable energy plants.

4.2 Identification of the major nexus challenges

The major nexus challenges that had been raised during the interviews were discussed and amended further in the workshop. Altogether six general challenges, including major measures to overcome these challenges, were discussed:

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

5 Identifying the nexus pathways

The first workshop with stakeholders also helped to identify three crucial policy scenarios (pathways) to meet the nexus challenges in Andalusia in the medium and long term. A complete list of policies and analysis has been available in ProjectPlace since May 2017: -> documents -> WP2.2 -> Andalusia: Policy Analysis.

Three crucial policy scenarios (objective and measures) were proposed to meet the nexus challenges in Andalusia in the medium and long term:

- Reduction of diffuse emissions of 18% in 2030
    - Efficient agricultural machinery
    - Crop management practices (carbon capture, reduction of tillage, precision agriculture, use of sensors, smart agriculture)
    - Modernization of irrigation (e.g., pumping)
    - Reduction of methane emissions
    - Energy audit of CCRR
    - Sustainable biogas/biodiesel production
    - Reuse of resources (e.g., water)
- Reduction of demand for irrigation water
    - Improvement of management and services (infrastructure has largely been renewed)
        - Water management in line with CCRR
        - Advisory service to irrigators by the Andalusian Institute of Agricultural and Fisheries Research and Training (IFAPA)
        - Reconsideration of existing measures due to limited success (CCRR)
        - Increase of administrative management from Gestagua (www.gestagua.es)
        - Calculation of specific absorption rate (SAR)
    - Reduction of diffuse pollution
- Improvement of governance, transparency, and information
    - SmartAgriculture similar to the concept of “SmartCities”
    - Inclusive water management

The first policy scenario (changes in diffuse emissions) will be analysed with E3ME, because E3ME includes several emission specific data for the Andalusian case (see section 6.1.2). The second policy scenario (reduction of demand for irrigation water) will be analysed with CAPRI, because CAPRI´s water module includes information on irrigation agriculture in Andalusia (see section 6.1.1). At this point of analysis, it seems that all crucial variables are available in CAPRI and E3ME to analyse the first and second policy scenario. The third objective regarding the improvement of governance, transparency, and information is, however, rather general and requires more thoughts on its measurability and relationship with the nexus components.

6 Addressing the nexus with thematic models

Initially we were planning to apply three thematic-models for analysing the major nexus challenges in Andalusia. While the CAPRI and E3ME thematic-models are still our major choices, we reconsidered using the MAGNET model because the water module is insufficient for our purposes and, therefore, cannot fully explain the main nexus challenges in Andalusia. As follows we, thus, briefly describe how the CAPRI and E3ME models are used to better understand the six nexus challenges and the three policy scenarios as mentioned before.

6.1 Analysing the nexus challenges with CAPRI and E3ME

6.1.1 CAPRI thematic-model

CAPRI is applied to the Andalusian case study to analyse **food-water linkages** in terms of agricultural water use (irrigation and livestock) and crop irrigation and yields. Furthermore, we use CAPRI to explore **food-energy linkages** in Andalusia, especially the biofuel markets (ethanol and biodiesel). In particular, CAPRI will help understanding the six different challenges identified:

- Sustainable management of water resources
    - CAPRI enables the analysis of water use in agriculture in terms of irrigated area and total water use per crop. The model is also able to simulate policy measures addressing water management such as water pricing or irrigation efficiency and the impact of climate change on water availability and agricultural production.
- Mitigation and adaptation to climate change
    - GHG emission balance in the agricultural sector provided by CAPRI offers insight into the contribution of agriculture to the total GHG emissions. Furthermore, CAPRI can simulate both the impact of climate change on agriculture (changes in crop production and prices) and the effect of specific measures addressing mitigation and adaptation to climate change in the agricultural sector (irrigation, environmental practises, etc.)
- Energy efficiency and promotion of renewable energies
    - CAPRI provides data on biofuel production and can simulate policies in this field.
- Fight against soil erosion and desertification

    - CAPRI provides data on environmental indicators linked to this challenge, such as nutrient balance.
- Resource efficient food production
    - CAPRI provides data on food production for a number of primary and secondary products.
- Sustainable socioeconomic development
    - CAPRI provides data about some of the indicators that can be used to analyse this challenge, like agricultural income and welfare.

Baseline results have been provided at the regional level for Andalusia for the base year 2010 and the simulation year 2030. Outcomes include crop areas and yields (rainfed and irrigated) and total irrigation water use per crop in the region. Crop prices (producer and consumer), supply, demand and trade outcomes are provided at the national level for Spain.

We are planning to use the outcomes of CAPRI to feed the SDM. The stakeholders will be informed about the first modelling results in the second workshop (expected to take place in 2018). The modelling results will also serve to guide the discussion in the second workshop and to evaluate the main Nexus challenges and the corresponding output variables to assess them.

6.1.2 E3ME thematic-model

E3ME is applied to the Andalusian case study to analyse the **energy-food nexus** with regards to energy use by the agricultural sector and energy production from biomass. Furthermore, E3ME will be very helpful in exploring the **water-energy linkages** in terms of hydropower production. Other variables provided by the model are GHG emissions by sector and employment.

E3ME will help then to address three of the six nexus challenges:

- Energy efficiency and promotion of renewable energies
    - Renewable and non-renewable energy production (by technology) and consumption (by technology and sector) derived from the model are crucial to analyse the energy sector and the effect of any policy measure aimed at reducing energy consumption or enhancing renewable energies.
- Mitigation and adaptation to climate change
    - E3ME provides data on GHG emissions by sector that will help to assess the effect of policies dealing with climate change.
- Sustainable socioeconomic development

    - E3ME provides data on employment by sector that can help analysing socioeconomic development.

Baseline results have been provided at the regional level for Andalusia from 2000 to 2050 on an annual basis. Considering that E3ME provides results at the national level, the E3ME team have desegregated outcomes from the model for Spain to the regional level for Andalusia based on EUROSTAT and regional statistics. Baseline results contain data on energy gross production by technology, final energy consumption by sector and technology, GHG emissions by sector, GVA by sector, Andalusian GDP, and employment by sector. We are planning to use the outcomes of the E3ME model to feed the SDM.

7 Building a system dynamic model

The goal of the case-study work in SIM4NEXUS is the building of a Serious Game through system dynamic modelling. This section describes how the SDM will be build. First, the section shows the conceptual model addressing the interrelationships in the nexus. Second, first drafts of the SDM considering these interrelationships are shown.

7.1 Conceptual model

Figure 28 provides a first draft of the overall conceptual model, including all nexus components. Figures 29 to 32 show the preliminary conceptual frameworks for the subsectors water, food, energy, and land, respectively. All conceptual models will be amended and further elaborated after the stakeholders' individual and group maps are fully taken into consideration.

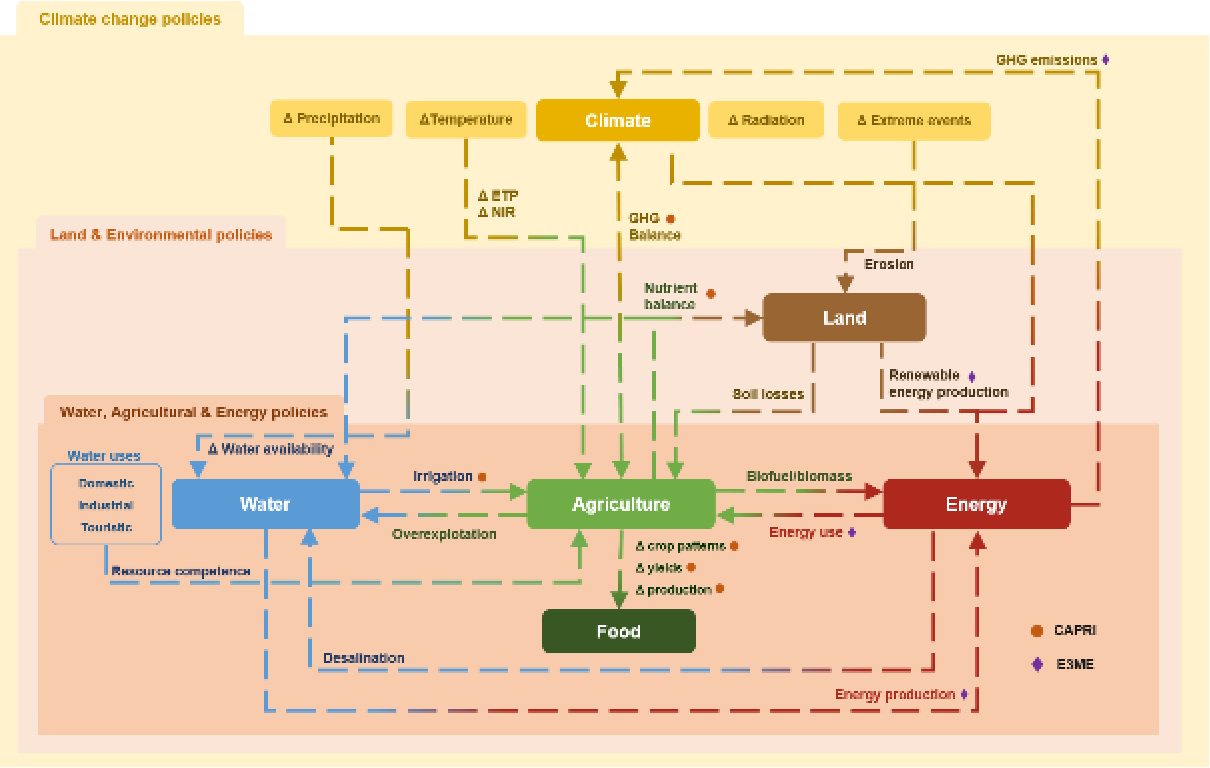

Figure 28: First draft of the conceptual model for all Nexus components

Source: Own elaboration

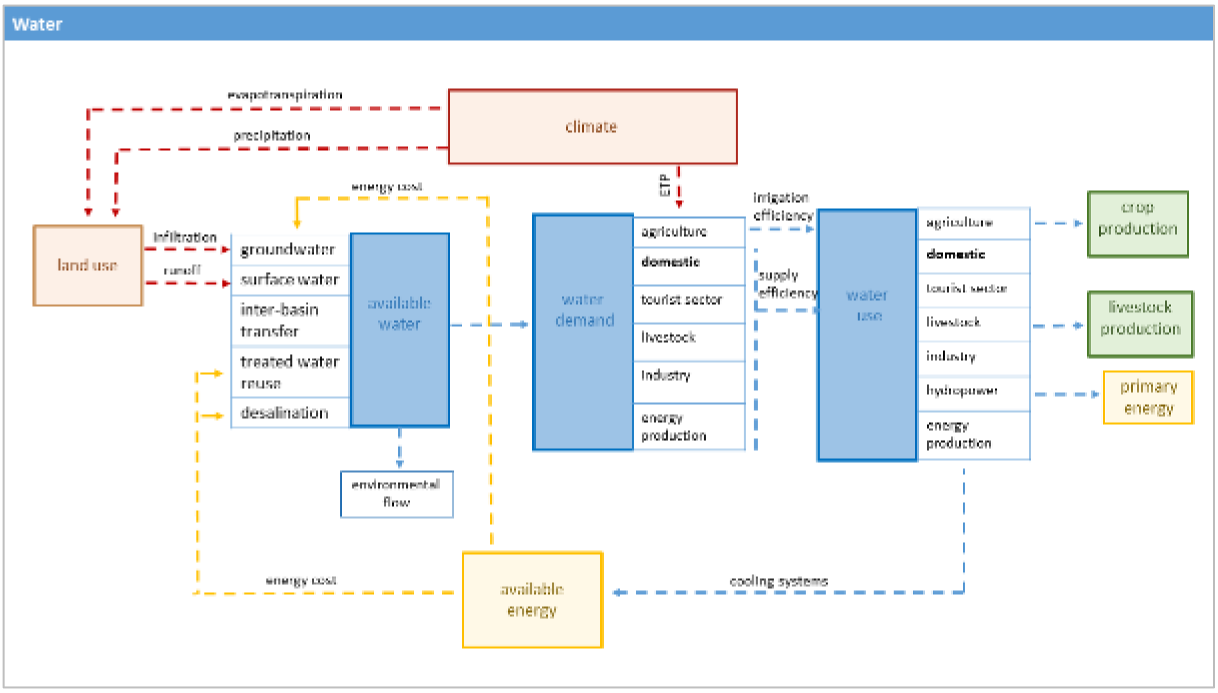

Figure 29: First draft of the conceptual model for water

Source: Own elaboration

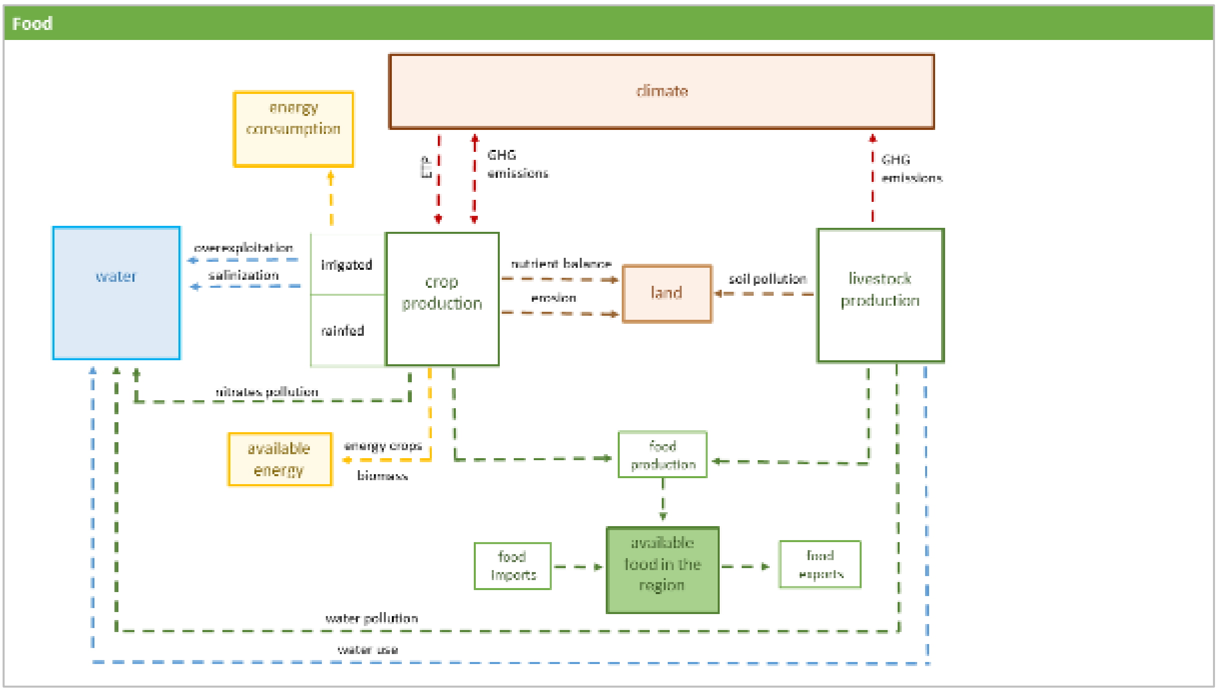

Figure 30: First draft of the conceptual model for food

Source: Own elaboration

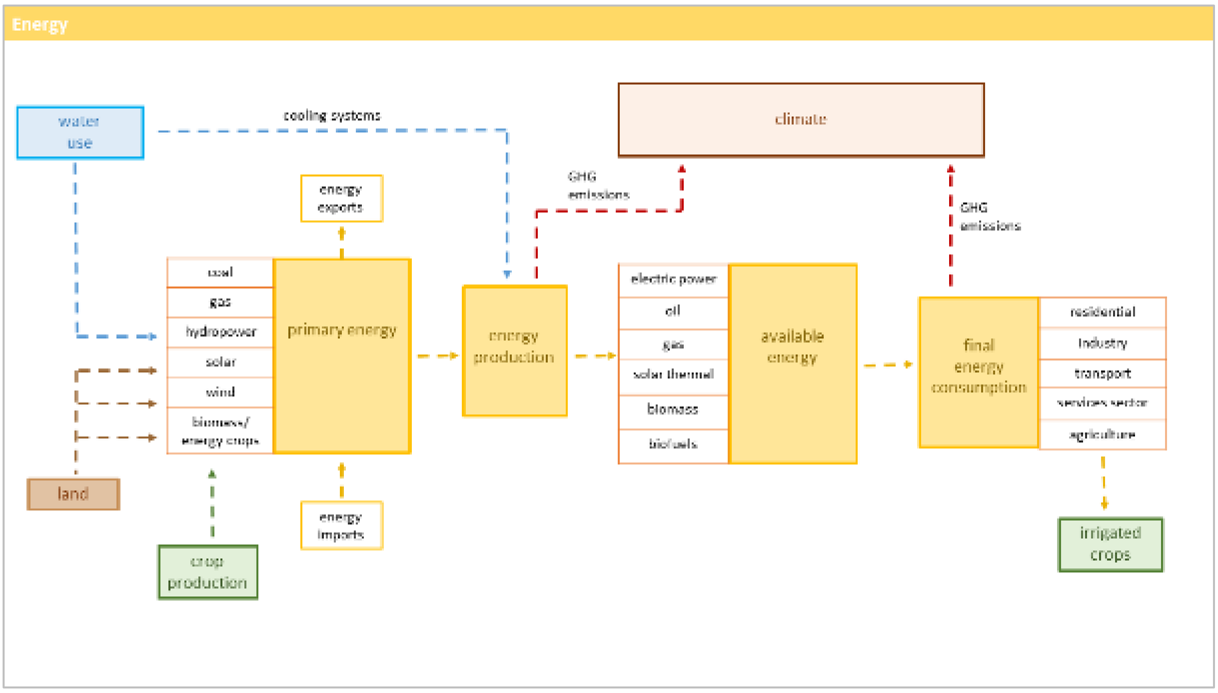

Figure 31: First draft of the conceptual model for energy

Source: Own elaboration

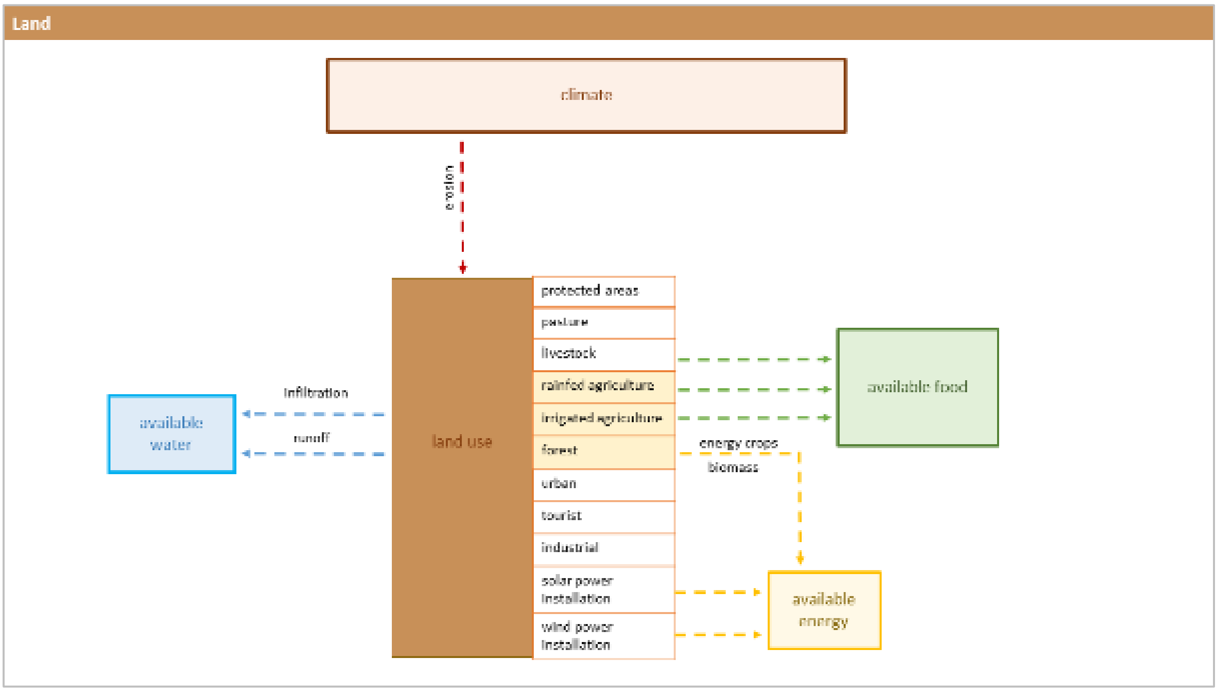

Figure 32: First draft of the conceptual model for land

Source: Own elaboration

7.2 SDM for Andalusia

The conceptual models and the outcomes of the CAPRI and EM3E models will be used to feed the SDM. Furthermore, data from different sources will also be incorporated in the SDM: EUROSTAT, INE, Andalusian Institute of Statistics and Cartography (IECA), Yearbook of Agricultural Statistics from the Regional Government of Agriculture, Andalusian Environmental Information Network (REDIAM), info-ENERGIA and River Basin Management Plans.

Figures 33 to 36 show first drafts of the SDMs for the water, food, energy and land sub systems, respectively.

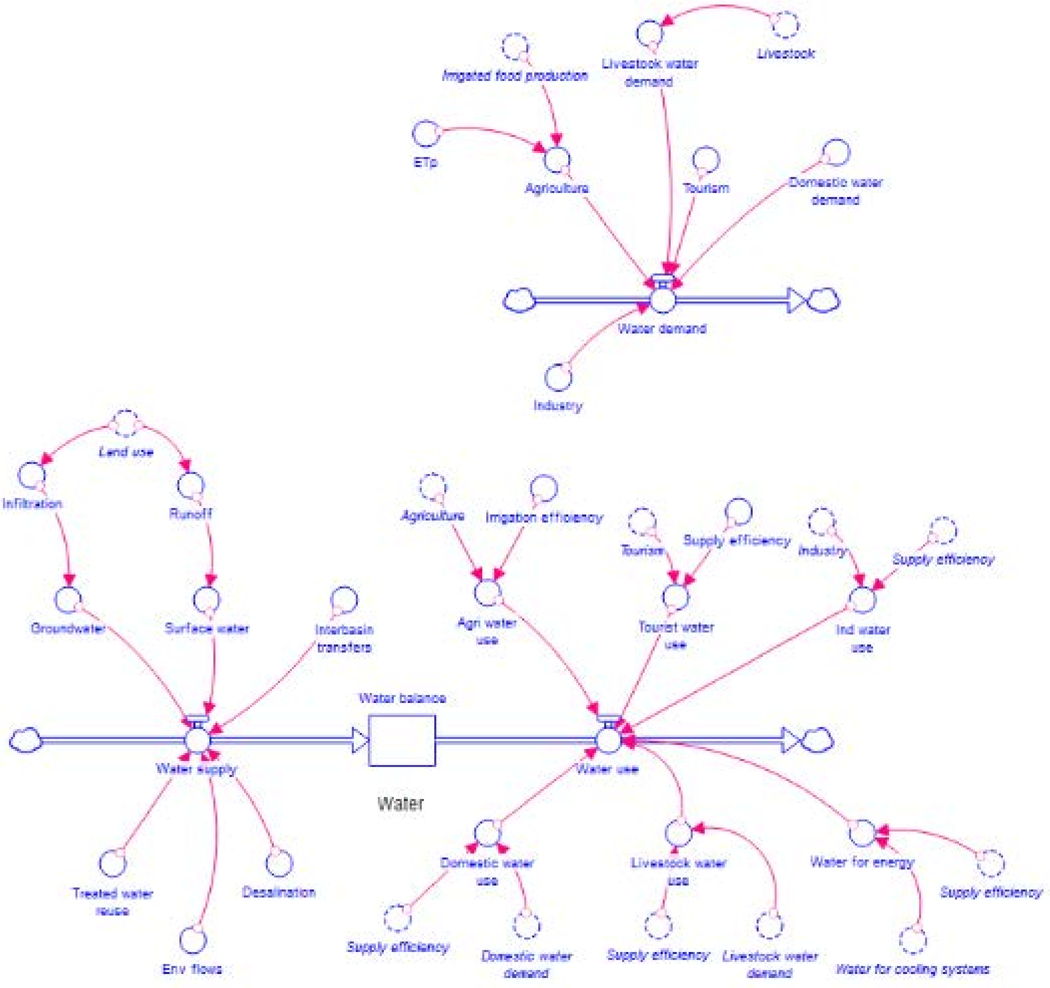

Figure 33: First draft of the SDM for the water sub system

Source: Own elaboration

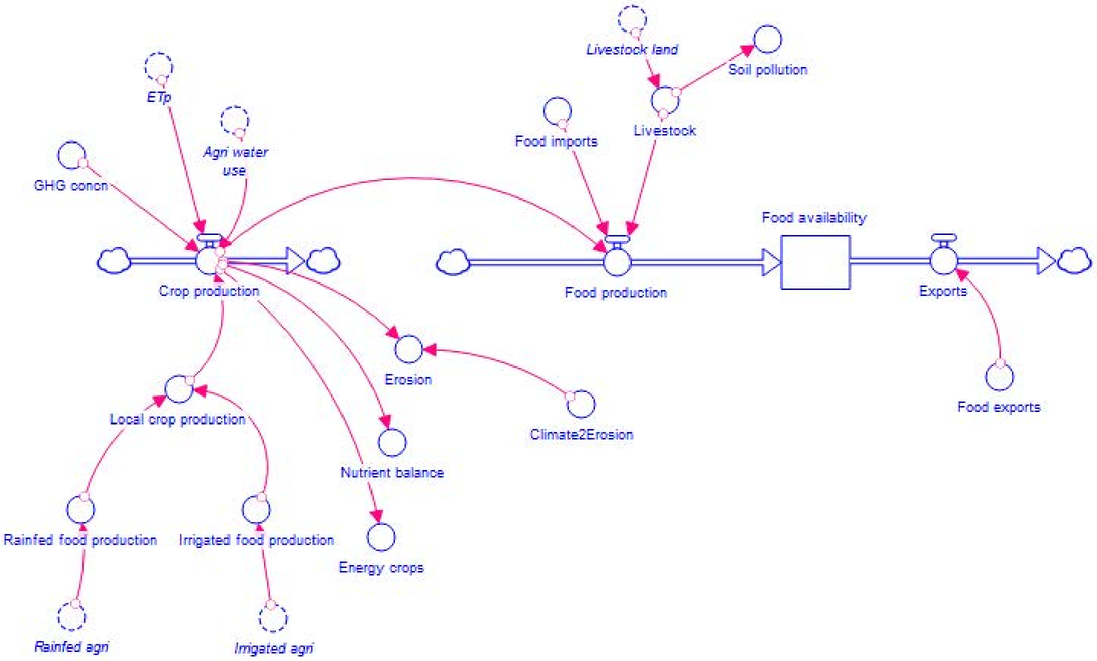

Figure 34: First draft of the SDM for the food sub system

Source: Own elaboration

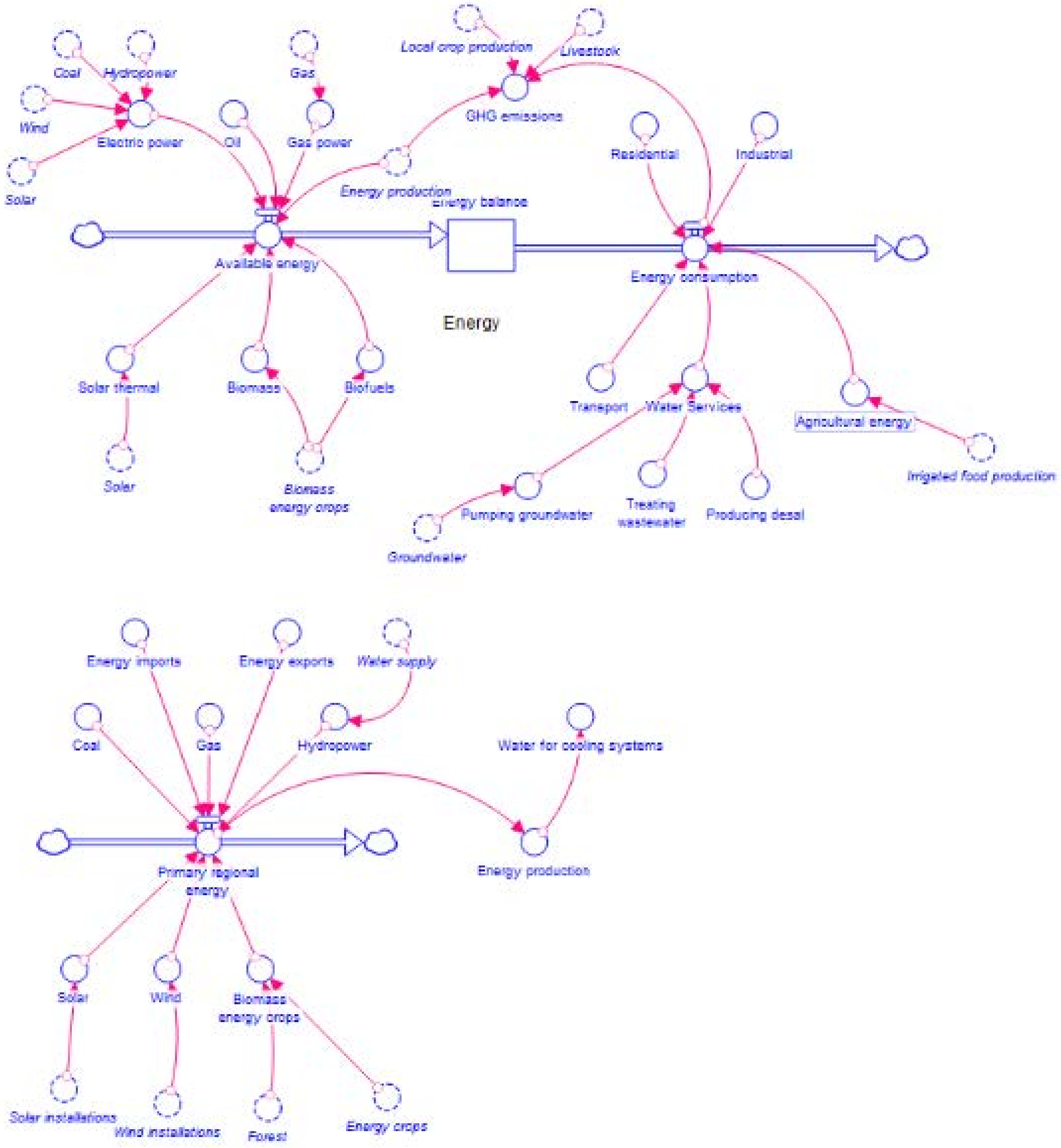

Figure 35: First draft of the SDM for the energy sub system

Source: Own elaboration

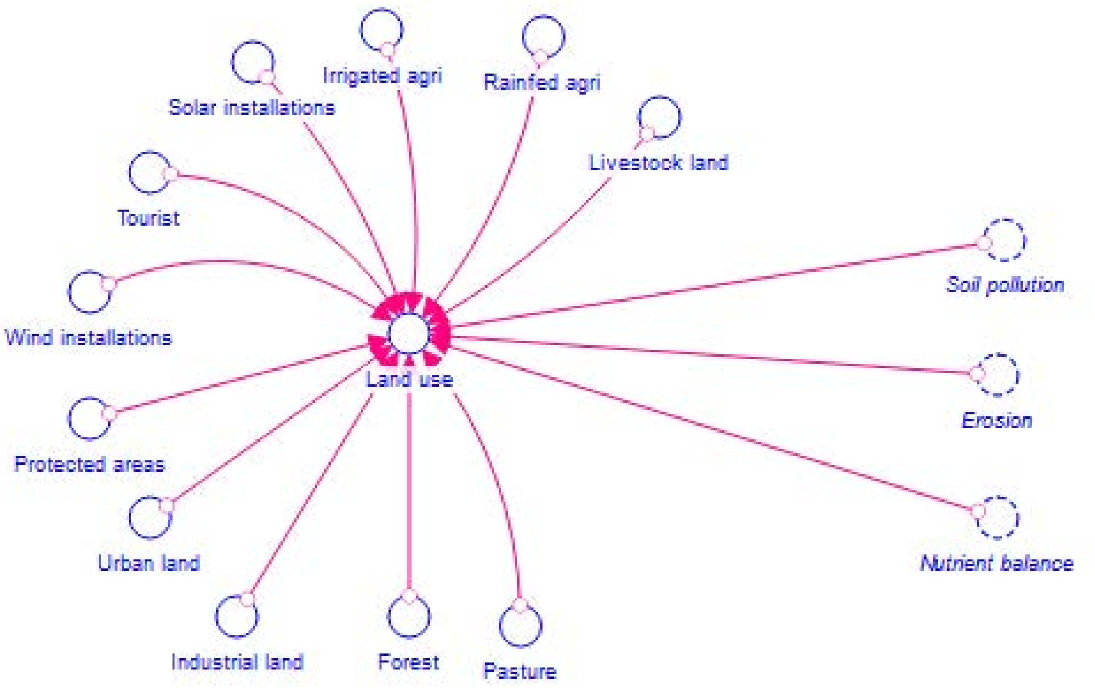

Figure 36: First draft of the SDM for the land sub system

Source: Own elaboration

8 Summary and next steps

This report describes the main achievements in the Andalusian case study. In particular, progress has been made by engaging the stakeholders in the research activities: 1) preliminary interviews were conducted, 2) the first workshop with stakeholders was held in October 2017 in Seville (Andalusia). With participatory methodologies (individual and group mappings, round-table discussions), the major nexus challenges in Andalusia were identified and policy scenarios were discussed.

The six major nexus challenges in Andalusia are: 1) Sustainable management of water resources, 2) Mitigation and adaptation to climate change, 3) Energy efficiency and promotion of renewable energies, 4) Fight against soil erosion and desertification, 5) Resource efficient food production, 6) Sustainable socioeconomic development.

Alongside these six major nexus challenges, three crucial policy scenarios were identified to meet the nexus challenges in Andalusia in the medium and long term: 1) Reduction of diffuse emissions of 18% in 2030, 2) Reduction of demand for irrigation water, and 3) Improvement of governance, transparency, and information.

It appears that CAPRI and E3ME include all crucial variables to analyse the nexus challenges and the first and second policy scenario; however, variables that are able to address an improvement in the governance, transparency, and information remain to be selected.

The next steps in the coming 6-12 months are to revise the conceptual model and the respective SDM on the basis of the individual and group maps. Additionally, the six challenges and three policy scenarios will be addressed with CAPRI or E3ME and will be fed into the SDM.

9 References

Confederación Hidrográfica del Guadalquivir (2015). Plan Hidrológico de la Demarcación del Guadalquivir. Segundo ciclo de planificación 2015-2020. Memoria.

European Commission (2015). Report on the implementation of the Water Framework Directive River Basin Management Plans. Member State: SPAIN. Accompanying the document, The Water Framework Directive and the Floods Directive: Actions towards the 'good status' of EU water and to reduce flood risks

European Parliament (2016). Research for Agri-Comitee – Agriculture in Andalusia. Directorate General for Internal Policies.

INE (National Institute of Statistics) (2015): Evolution of GVA in Andalusia and Spain.

Junta de Andalucía (2016). Informe de infraestructuras energéticas de Andalucía. Agencia Andaluza de la Energía, entidad adscrita a la Consejería de Empleo, Empresa y Comercio.

Junta de Andalucía (2015a). Informe de Medio Ambiente 2014

Junta de Andalucía (2015b). The agricultural and fisheries sector in Andalusia

Junta de Andalucia (2015c). Plan Hidrológico de la Demarcación Hidrográfica de las Cuencas Mediterráneas Andaluzas. Ciclo de planificación 2015-2021. Consejería de Medio Ambiente y Ordenación del Territorio.

Junta de Andalucia (2015d). Plan Hidrológico de la Demarcación Hidrográfica del Guadalete-Barbate. Ciclo de planificación 2015-2021. Consejería de Medio Ambiente y Ordenación del Territorio.

Junta de Andalucia (2015e). Plan Hidrológico de la Demarcación Hidrográfica del Tinto, Odiel y Piedras. Ciclo de planificación 2015-2021. Consejería de Medio Ambiente y Ordenación del Territorio.

Junta de Andalucía (2014a). Basic environmental data of Andalusia

Junta de Andalucía (2014b). Datos energéticos de Andalucía, 2014. Agencia Andaluza de la Energía, entidad adscrita a la Consejería de Empleo, Empresa y Comercio.

Junta de Andalucía (2011a). Agenda del Regadío Andaluz. Horizonte 2015. Consejería de Agricultura y Pesca.

Junta de Andalucía (2011b). Inventario De Regadíos 2008 Y Su Evolución En La Última Década. Consejería de Agricultura y Pesca.

MAGRAMA (2015). Encuesta sobre superficies y rendimientos de cultivos. Informe sobre regadíos en España. Ministerio de Agricultura, Alimentación y Medio Ambiente de España.

10 Appendix

Appendix 1: Questionnaire for preliminary interviews with stakeholders

Sustainable Integrated Management FOR the NEXUS of water-land-food-energy-climate for a resource-efficient Europe (SIM4NEXUS)

Caso de estudio: Andalucía

Encuesta sobre el nexo agua-agricultura-energía en un contexto de cambio climático

Organización:	**Fecha:**
Nombre y Apellidos:	**Email:**
Puesto:	**Tlf:**

1. ¿Cuál es el papel de su organización en el sector/es del agua/agricultura/energía en Andalucía? (eg..: usuario, gestor, toma de decisiones en materia de políticas, investigación, formación)

2. ¿De qué manera influye su organización en la toma de decisiones en materia de políticas agrarias o ambientales?

3. Principales foros/plataformas/congresos/seminarios en los que participa su organización

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-

4. Complete la matriz indicando las interrelaciones entre los distintos componentes clima, agua, alimentación, suelo y energía en Andalucía. Incluimos algunas interacciones a modo de ejemplo:
   - Un cambio en el clima puede afectar a la disponibilidad de recursos hídricos, al rendimiento de los cultivos y a la producción de energía renovable.
   - La disponibilidad de agua para regadío permite aumentar tanto la producción como la diversidad de cultivos pero lleva asociada una importante demanda de energía
   - Competencia por el uso de agua entre los distintos sectores (agricultura y turismo)
   - El sector agrícola es una importante fuente de gases de efecto invernadero (GEI) y, al mismo tiempo, es un sumidero de carbono. Por otra parte, la actividad agrícola contribuye a la sobreexplotación y contaminación de los recursos hídricos en la región

- El sector energético es un importante productor de GEI, influye de manera muy importante en los costes del regadío, y puede beneficiarse de la actividad agraria para la producción de biomasa.

	Clima	**Agua**	**Agricultura/ Alimentación**	**Uso del suelo**	**Energía**
Clima		Disponibilidad de recursos hídricos	Cambio en los rendimientos de cultivo		Producción de energía renovable
Agua			Producción agrícola		Demanda energía para regadío
Agricultura/ Alimentación	Emisiones de GEI	Sobreexplotación y contaminación de agua			
Uso del suelo		Competencia por el uso del agua entre distintos usos			
Energía	Emisiones de GEI	Costes del regadío	Producción de biomasa		

5. ¿Considera que las políticas existentes responden a los retos actuales en la gestión integral sostenible de los recursos? ¿Considera que tienen en cuenta el nexo agua-agricultura-energía?

6. ¿Cómo mejoraría estas políticas para promover el uso eficiente de los recursos?

7. ¿Conoce alguna iniciativa que se haya llevado a cabo anteriormente o en la actualidad para promover la gestión sostenible de los recursos en el territorio de Andalucía (proyectos de investigación, planes o estrategias locales, etc.)?

Compromiso de confidencialidad: Los datos personales recogidos en esta encuesta tienen como única finalidad proceder al tratamiento adecuado de la información y en ningún caso serán transmitidos a terceros sin consentimiento previo. Asimismo, el equipo investigador se compromete a respetar la confidencialidad de la información recogida en la encuesta, que se procesará y presentará de forma anónima.

Appendix 2: Description of stakeholders

Public sector

1) Regional Ministry of the Environment and Territory Planning (RMETP)

Consejería de Medio Ambiente y Ordenación del Territorio

This regional government has powers in the areas of environment, water and planning and land use management, in particular:

- Development, evaluation and monitoring of strategies, plans and programs in land, costal and urban planning.
- Promote, coordinate and develop the policies to take action on climate change
- Water policy and promotion of sustainable water use
- Hydrological planning in Andalusian river basins
- Coordination of water and environmental policies
- Biodiversity conservation and sustainable use of natural resources

2) Regional Ministry of the Agriculture, Fishing and Rural Development (RGAFRD)

Consejería de Agricultura, Pesca y Desarrollo Rural

This regional government has powers in the areas of agriculture, livestock, fishing, agri-food industry and rural development, in particular:

- Planning, reform and development of the agricultural and livestock producing sectors
- Organic production policy, as well as the promotion of the use of methods of agricultural production compatible with the requirements of protection of the environment and conservation of the natural environment
- Definition of the policy of support to the Andalusian agro-industry
- Elaboration and implementation of rural development strategies and plans
- Promotion and coordination of rural infrastructure plans and programs
- Management of the European Agricultural Funds

3) Environment and Water Agency of Andalusia (EWAA)

Agencia de Medio Ambiente y Agua

This agency is an autonomous organism that belongs to the Regional Ministry for the Environment. The general objective of this agency is the protection and improvement of the environment, the integral management of the water cycle and provision of services and the management and implementation of interventions entrusted by public or private entities in the territory in Andalusia. The functions of the Agency are:

- Evaluation and implementation of actions to cope with climate change
- Development of water policies in Andalusia (management and maintenance of hydraulic infrastructures, management of programs to face erosion, desertification and sustainable water use)
- Development of planning measures related to the natural and rural environment
- Promote the green economy and sustainable development of territory
- Enhance innovation and R&D in territory, environment and water
- Conservation of biodiversity and geodiversity of Andalusia

4) Andalusian Energy Agency (AEA)

Agencia Andaluza de la Energía

The Andalusian Energy Agency is a government-owned entity assigned to the Regional Ministry of Employment, Enterprise and Trade, increasing the use of indigenous renewable resources and actions of energy saving and efficiency and demand management. The main functions of the Agency are:

- Develop the policies of the Andalusian Regional Government aimed at optimising the energy supply in the region, from an economical and environmental point of view
- Support projects of interest for the transformation of the Andalusian energy system
- Develop programs and initiatives to promote savings, energy efficiency and the use of renewable resources.

5) Provincial Council (PC)

Diputación provincial

The Provincial Council is the administrative institution in charge of the province government. The main functions are:

- Provide assistance to municipalities in legal, economic, social services, urban planning and human resources issues.
- Waterworks and sanitation, energy, environment and urban waste management.
- Interventions in the agricultural, forest, rural development and agrifood sectors.

6) Guadalquivir River Basin Authority (GRBA)

Confederación Hidrográfica del Guadalquivir

The Guadalquivir River Basin Authority is a public corporation with legal personality and distinct from the state, assigned for administrative purposes to the Ministry of Environment and Rural and Marine Affairs. The main functions are:

- Development of the hydrological river basin plan, as well as its monitoring and review.
- Management and control of the hydraulic public domain.
- Administration and control of the water uses of general interest or those affecting more than one region.
- Project, construction and exploitation of the waterworks carried out by the agency's own funds, and those entrusted to them by the State.

Private sector

7) National Federation of Water Users Associations (FENACORE)

Federación Nacional de Comunidades de Regantes (FENACORE)

FENACORE is a non-profit association that comprises the irrigation water user associations (WUAs) throughout Spain. This organisation represents more than 700 000 irrigation users and encompasses 80% of national irrigated area. The objective of FENACORE is to harmonize the effort and work of all the parties involved in the Spanish irrigation and to collaborate closely with the different public administrations in the design of the country's water policy.

In this sense, FENACORE collaborated in the drafting of the Water Law and its Regulations, the preparation of the National Hydrological Plan (NHP), the preparation of the National Irrigation Plan (PNR) and the Water Law Reform Bill, the White Paper on Water Framework Directive or the Community Water Framework Directive. Recently, FENACORE has participated, among others, in hydrological planning or in the drafting of the new hydrological plans.

FENACORE works closely with the Ministry of Agriculture, Food and Environment. In addition, FENACORE is also a designated vocal of the National Water Council by Royal Decree and was at the time a founding member of the Environmental Advisory Council.

8) Andalusian Federation of Water User Associations (FERAGUA)

Asociación de Comunidades de Regantes de Andalucía (FERAGUA)

FERAGUA is an association that advises and the defends the rights of WUAs across Andalusia, covering 300 000 ha that represent 30% of the irrigated area in the region.

9) Farmer Organisation Coordinator (CAOAG)

Coordinadora de Organizaciones de Agricultores y Ganaderos (COAG)

COAG is a state-level agricultural organisation whose main objective is the defence of farmers' interests. This organisation assists more than 150 000 farmers through its 220 offices throughout the national territory and a permanent delegation in Brussels. It is recognized by the Ministry of Agriculture as the most representative agrarian organization and as such is part of the Agrarian Advisory Committee and member of the Economic and Social Council (ESC), COPA-COGECA and the European Coordinator Vía Campesina.

10) Andalusian Association of Promoters and Producers of Renewable Energy (APREAN)

Asociación Andaluza de Promotores y Productores de Energía Renovable (APREAN)

APREAN is a business association composed of a hundred regional, national and international renewable energy companies. The organisation coordinates the interests of wind power, solar photovoltaic, solar thermoelectric and biomass energy companies. Its main objective is to represent, coordinate and defend the common professional, economic and business interests of its members and to participate in the development of policies, especially energy and environmental policies.

NGOs

11) WWF

WWF is a global environmental conservation organisation with representations in more than 80 countries. The objective of WWF is conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable and promoting the reduction of pollution and wasteful consumption. WWF-Spain participate in advocacy and lobby actions to:

- Promote an energy transition law aimed at a 100% renewable, efficient and fair energy model by 2050
- Encourage sustainable water use management (adequate ecological flows and reduction of illegal wells)
- Boost sustainable food production (policy advocacy to change the CAP, promote high nature value agricultural systems)
- Avoid illegal agricultural activities and water overexploitation in Doñana Nature Park (Andalusia).

Research and education

12) Andalusian Institute of Agricultural and Fisheries Research and Training (IFAPA)

Instituto de Formación e Investigación Agraria y Pesquera (IFAPA)

IFAPA is an autonomous body with independent legal status assigned to the Andalusian Regional Ministry for Agriculture, Fisheries and Rural Development. The objectives of the institute are to contribute to the modernization of agriculture, fisheries and agri-food sectors, as well as to improve its competitiveness through research, development, technology transfer and training.

13) University of Cordoba (UCO)

Unversidad de Córdoba (UCO)

Research and education institution with an extensive experience in research on sustainable water use and irrigation energy efficiency.

14) University of Almeria (UAL)

Universidad de Almería (UAL)

Research and education institution with an extensive experience on sustainable water use and water policy.

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

D5.2: THE MAIN NEXUS CHALLENGES IN ‘SARDINIA’

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DATE: (24 – 12 –2017)

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Table of Contents

Glossary / Acronyms

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

TERM	EXPLANATION / MEANING
CF	COHESION FUND
EAFRD	EUROPEAN AGRICULTURAL FUND FOR RURAL DEVELOPMENT
ENAS	ENTE ACQUE DELLA SARDEGNA (SARDINIA WATER MANAGEMENT AUTHORITY)
ENEL	ENTE NAZIONALE PER L'ENERGIA ELETTRICA (ITALIAN ENERGY PRODUCTION COMPANY)
EMFF	EUROPEAN MARITIME AND FISHERIES FUND
ERDF	EUROPEAN REGIONAL DEVELOPMENT FUND
ESF	EUROPEAN SOCIAL FUND
GCM	GENERAL CIRCULATION MODEL
GDP	GROSS DOMESTIC PRODUCT
GHG	GREENHOUSE GASSES
GVA	GROSS VALUE ADDED
MEF	MINIMUM ENVIRONMENTAL FLOWS
RCP	REPRESENTATIVE CONCENTRATION PATHWAYS
SDM	SYSTEM DYNAMIC MODELLING
SSP	SOCIOECONOMIC PATHWAYS
TCI	TOURIST CLIMATIC INDEX
TOE	TONS OF OIL EQUIVALENT

1 Introduction

The Region of Sardinia is one among five Italian autonomous regions with special statute, granted by the Italian Constitution (Art. 116). This special statute grants the Region of Sardinia with a higher degree of legislative and financial autonomy. The political and legislative role of the Autonomous Region is strengthened by a governance system which established a direct relationship between the Regional Government and the European institutions, particularly for what concerns the Structural Funds (ERDF, ESF, CF, EAFRD, EMFF). The Charter of the Autonomous Region of Sardinia established that the Regional administration has legislative authority over public water rights, agriculture and forests, and tourism. Accordingly, the last Structural Fund Regional Programming (2014-2020) has identified among its areas of intervention: Tourism, Culture and the Environment, Intelligent Energy Efficient Networks and Agro-industry.

Discussions with experts and stakeholders of different sectors from the beginning of the project allowed to focus the main challenges that the region must face to reach a resource efficient and climate resilient society. In general, these discussions and an analysis of the regional policies highlighted a poor communication between sectors in the development of policies for each sector (silos thinking). In this sense, the main societal challenge can be seen as promoting coordination among nexus sectors to exploit the possible synergies and an overall need to substantially increase awareness. Besides this, most stakeholders agree on the central role played by the water sector with a shared objective of reaching a resilient system able to satisfy all demands. The second role is played by the energy sector which must reduce the costs of energy, while reducing CO2 emissions.

For the Sardinian Region, the most relevant Nexus sectors are Water, Food and Agriculture, Energy, Tourism and Climate. As in most Mediterranean climates, the ability to satisfy all water demands throughout the year is a factor limiting the economic growth and also has an impact on the environmental quality of the ecosystem downstream of the reservoirs. Water demands mainly come from irrigation needs, but also domestic (and tourist) demands, demands for energy production from hydropower, as well as minimum environmental flows. These are all important competitors for water resources. From another point of view, energy is required for water pumping and this energy is ultimately an economic cost that is only partially compensated by farmers. For these reasons, water covers a central role in the Nexus and undoubtedly an effort is needed to increase the operational resilience of the reservoir system without which sustainability goals cannot be reached. Agriculture is of high importance for the region in terms of its contribution to GDP, food security, employment and cultural heritage. It is also the most water demanding sector and holds a great potential for the reduction of CO2 emissions as well as contributing to important ecosystem services. The energy sector also has a key position for the economic growth of the region since the costs for energy are higher than national averages. This difference in price is mainly due to the absence of methane in the region. However, projects to bring methane on the island are in progress, as well as projects to increase the share of renewables.

The regional government has set a number of objectives and policies for the energy, water, and agriculture sectors. Shortly, these include the above mentioned use of methane, implementation of smart-grids that would allow to increase their loadings in the grid, incentives to increase irrigation efficiency, policies to guarantee minimum environmental flows, strategies to promote tourism during the low season. Although, these objectives, especially those for the energy sector, mention climate change mitigation strategies and are designed to reduce CO2 emissions in line with EU targets, as of today there is a lack of policies or plans directly addressing a climate change mitigation or adaptation strategy.

Sardinia is quite a large island with a large and consistent orography that define relevant gradients of climate conditions and natural resources availability across the north-south and west-east transects. Thus, it is expected to have different local responses for NEXUS sectors. Initially, Sardinia island-wide reservoir system was represented for simplicity as a unique aggregated system (i.e. geographically lumped), an overestimated efficiency of the supply system to capture and manage water was introduced, vastly overestimating and averaging resilience to changes in water supply and demand. It is important to articulate specifically the individual sources of supplies and demands, both spatially and temporally, to render the effective efficiency and resilience of water systems. Sardinia will be split into seven hydrographic basins to better capture hydrological dynamics across the island. Aggregation to the island scale will then take place *a-posteriori.* Thus better information and knowledge will be generated for policy and decision making, with results more accurately expressing on-the-ground situations and accounting for local level dynamics could be critical for modelling success and by extension for providing the end-user with robust policy-relevant messages. The responses to climate changes may vary spatially within the island and be subject to climate model variability. Thus to include uncertainties of climate projections, and their spatial variation, several downscaled GCMs projections are included in the analyses to define decadal (2010,2020,2030,2040,2050) time steps at 0.5 degrees to define rather short terms interval of climate impact on Sardinia Nexus.

1.1 Description of the Nexus challenges

Baseline trends of irrigated area in Sardinia show a relevant increase between 2010 and 2030, according to CAPRI model outcome. Such future expansion is consistent and quite similar for different development and emission pathways, as shown in table 1. The largest expansion of irrigated land by crop types is expected for vegetables, identifying several cash crops that can be promoted by high prices in the market. Furthermore, both rice and maize could encounter an expansion of their irrigated distribution, while the largest decreases in irrigated areas are foreseen for fruit trees and grapes.

Table 1. Trends of irrigated area (ha) between present (2010) and future (2030) conditions according to CAPRI projections for baseline and different emission pathways. The results are provided for total irrigated land, and by crop types.

CAPRI Irrigated land (ha)			
	2010	2030 baseline	2030 CC_RCP8.5
Maize	100	800	700
Rice	1600	1100	1600
Barley/oats/wheat	1600	1600	200
Potato	1300	400	500
Tomato	2300	3800	3800
Other vegetables	6500	17400	18300
Table Grapes	100	200	100
Wine	5800	3300	3400

Table Olives	100	200	200
Olives for oil	2600	2500	2500
Citrus Trees	1100	700	700
Apples Pears Peaches	400	200	200
Other Fruits	900	600	500
Total	24000	33200	32700

Baseline trends modelled with E3ME describe changes in both socio-economic metrics and a detailed projection for the energy sector for an annual time step up to 2030. In general, all economic sectors are projected to increase their GVA. Total employment shows a small increase of 5%, between 2013 and 2030. However, this increase is not homogeneous for all sectors and, notably, employment in the agriculture, forestry and fishery sector is projected to decrease by 32%. This would be in line with the present trend that shows the decline in number of farms but also an increase of the farm size.
For the energy sector, the baseline scenario of E3ME does not project any major change except for an increase in energy production from wind (256%) and a reduction from coal (-45%) for 2030, compared to 2013. Under this scenario, and in agreement with the simulations performed for the development of the Regional Energy Plan, reduction of CO2 emissions will not meet regional targets. However, further simulations are planned to include the ongoing regional actions and also to test alternative pathways.

Table 2. Trends of socio-economic indicators between present (2013) and future (2030) conditions according to E3ME projections. The economic values (prices in Euro) are standardized to base year (2005) to exclude price inflation.

		2013	2030
Sardinian GDP in millions of euros	GDP	33144	59833
Sardinian GVA at basic prices (2005 prices) in millions of euros	Agriculture, forestry and fishing	1431.1	2247.3
	Industry (except construction)	3262.7	4922.4
	Manufacturing	1674.5	3205.2
	Construction	6405.4	12793.3
	Wholesale and retail trade, transport, accommodation and food service activities	895.9	1376.2
	Information and communication	1055.8	1536.9
	Financial and insurance activities	3844.8	8004.2
	Real estate activities	2418.8	4847.8
	Administrative and support service activities	8845.4	14471.5

Sardinian Employment by Industry, thousands of people	Agriculture, forestry and fishing	40.8	28
	Industry (except construction)	56.8	52.3
	Manufacturing	42	39.7
	Construction	153.8	159.1
	Wholesale and retail trade, transport, accommodation and food service activities	9.7	7.5
	Information and communication	11.4	12.4
	Financial and insurance activities	3	3.7
	Real estate activities	59.5	69.6
	Administrative and support service activities	213.4	246.7
Sardinia electricity generation by technology in GWh	Coal	5.2	2.9
	Oil	5	0
	PV	0.9	0.9
	Wind	1.9	4.9
	Biomass	0.9	0.4
	Hydropower	0.6	0.5
Final demand for oil, middle dist, gas and Coal, thousands TOE	Industry	357.5	288.6
	Services	44.9	42.5
Final demand for biomass, thousands TOE	Industry	2.3	2.9
	Services	0	0

Discussion with stakeholders, local experts and knowledge collected in previous projects allowed to identify the main nexus interlinkages for Sardinia.

Climate to water: Climate influences basin run-off and thus the amount of water stored in reservoirs. It also has an influence on crop irrigation requirements and on evaporation from open bodies.

Climate to tourism: Climate influences the destination and season choices of tourist by affecting the climatic comfort.

Climate to energy: Climate influences the amount and timing of energy use for heating and cooling of buildings. Climate change will reduce energy requirements in winter and increase them in summer. Climate will also influence the productivity of solar and wind power plants.

Water to agriculture: The amount of water stored in reservoirs and the resilience of the reservoir system sets a limit to the expansion of the agricultural sector and at times of water scarcity it also determines a yield loss. Amount of water stored in reservoirs and its management determines yield production.

Water to energy: Some reservoirs are used for the production of energy from hydroelectric plants. As precipitations decrease with climate change and water demands from other sectors increase, the production of this clean energy can be preserved to some extent with an optimal water management scheme.

Water to Environment: Reservoirs reduce the natural run-off and this reduction has an impact of the health of downstream ecosystems. Minimum environmental flows (MEF) constitute at least 10% of the natural run-off but this MEF is not met under severe water scarcity. An optimized water management would allow for the conservation and health of the downstream ecosystems which are often areas used for fisheries and offer important ecosystems services as purification of water and conservation of biodiversity.

Energy to climate: The present emissions of CO2 for energy production must be reduced to meet EU targets to mitigate climate change.

Energy to water: water pumping to bring irrigation systems to pressure and to transfer water between reservoirs require high amounts of energy that ultimately determine the real price of water. Water saving and cheaper energy would allow to reduce the price of water.

Agriculture to water: Choice of crops, irrigation systems, and expansion of irrigated areas determine the demand of water for irrigation.

Tourism to water: tourist flows and infrastructures for tourists create a demand of water resources

Analysis of the nexus interlinkages and discussions with stakeholders allowed to identify a number of trade-offs in Sardinia. Irrigated areas show a constant and positive trend in the past 50 years and model projections suggest a further increase. At the same time, climate change scenarios are projecting a decrease of precipitations. In the past, the number of reservoirs has increased, many of them have been connected and the water management has improved thus increasing the resilience of the system. Nevertheless, after repeated consecutive years with low precipitations the reservoir system was not able to satisfy all demands, with water shortages not only for crops but also for domestic use and hydropower production. Policies insist on improving the drop for crop ratio, but these policies do not account for the fact that increased water efficiency in agriculture may actually have a positive effect on the expansion of irrigated areas thereby cancelling the purpose of the policy itself in the long term. However, an ideally perfect reservoir system would be able to satisfy all demands even under severe droughts and at least most of them under future water demands scenarios. The result of previous simulation for specific reservoirs, showed that irrigation demands could be satisfied under climate change scenarios at the expenses of energy production from hydropower plants (Mereu et al., 2016). It is likely that also at regional level the competition for resources will increase.

The region has approved to continue to use coal as fuel for energy production: while this allows to satisfy energy demands and contribute to control energy costs, it has a negative impact on the objective of reducing CO2 emissions.

The present urbanization plan has received many critics and is under discussion as it allows for the expansion of buildings also along the coast. This would have an uncertain effect on the tourist flows and the economy of the tourist sector. On one hand it might increase flows in the summer season and eventually increase revenues. On the other hand it is in contrast with the regional objective to increase tourist flows in spring and autumn. It also has a negative impact on the environment and may reduce the quality of the landscape, which is one of the main attractions for tourists in all seasons.

Despite the trade-offs, the Sardinian Nexus leaves space for some synergies that could be exploited to achieve a more efficient use of resources. Increase in water price in the past have reduced water demands for irrigation, however the price of water for farmers is still an order of magnitude lower than its real costs. The region plans to increase the renewable energy production potentials of the water management authority (ENAS) with the future aim for ENAS to become energy self-sufficient. Additionally ENAS may recover control of the hydropower plants given on free loan to the energy production company in the past. Such objectives would allow to reduce the costs of water and to fix a price for farmers equal or close to its real costs with consequent incentives for farmers to reduce their water consumption. Additionally, the production of energy from hydropower plants at present is not coordinated with the water management authority and their potential is not fully exploited. Management by the same authority would allow to optimize this energy production potentially reducing CO2 emissions.

The region also plans to increase the interconnections among reservoirs which would increase the resilience of the whole system allowing for an increase in food security and an increased capacity to satisfy MEF.

Climate change and policies oriented towards the promotion of tourism in spring and autumn are synergetic as the Tourist Climatic Index projects an increase in climatic comfort in these seasons and a slight reduction in the hottest month (August).

1.2 Description of the pathways

The conceptual framework for the Nexus in Sardinia is being transformed in an SDM model that considers the most important interlinkages among sectors. The model uses outputs of the thematic models as exogenous variables but also considers endogenous variables that allow to identify bio-physical and socio-economic interactions. In this initial version, the SDM uses outputs of the thematic models using SSP2 scenarios as the baseline, while the biophysical part of the model accepts RCP 4.5 and 8.5.

Discussion with stakeholders and analysis of the policies performed in WP2 allowed to identify the present management rules that govern the Sardinian Nexus. These include, for example, water management rules that are applied in case of water scarcity and rules for managing MEF. Discussion with stakeholders during a focus group and interviews allowed to also identify alternative policies to be applied to the NEXUS. Some of these alternative policies imply to run the thematic models with alternative pathways, while others can be implemented directly in the SDM. To distinguish these two alternatives, we have used the terms exogenous and endogenous policies respectively.

The Regional Energy Plan presents a set of actions that are being pursued with the general objectives of reducing CO2 emissions but also energy costs. The thematic model E3ME is being used to model how the implementation of these actions will affect the energy sector but also their effect on the expansion/contraction of other sectors.

Another important alternative policy we have been asked to explore involves water pricing. This exogenous policy will be addressed with CAPRI and possibly MAGNET/GTAP. The final list of exogenous policies still needs to be refined with stakeholders, however the discussion is focusing on the following ones:

1) Methane development

While the project of a methane pipe from Algeria has halted, the Sardinia Region and the National Government have reached an agreement to develop a methane distribution network in the island and methane will be shipped to the island. The project has started and will give access to methane for domestic and industrial purposes.

Goal: Reduce energy costs

For the purpose of the SDM, such scenario should be simulated from the socio-economic models and outputs on variation of GDP by sector could be used in the SDM to simulate its effects on other sectors, e.g. expansion/contraction of the tourist sector and relative tourist flows. This policy has also a relevant effect on CO2 emissions and this output could be included as an element of CO2 emission budget in the SDM.

2) Energy independence of the Regional Water Management Authority (ENAS)

ENAS has started to reduce its energy dependence on the private energy company (ENEL)

Goal: reduce the costs for water pumping from the present 20M euros per year

Policy: develop solar power station managed by ENAS and reacquisition of the hydropower plants presently managed by ENEL (Energy production company)

Effect of the policy: reduction of water prices for agriculture
Alternative policies:

1) ENAS remains dependent on ENEL for energy requirements and farmers continue to pay the present low price for water
2) ENAS reduces energy bill by 100%, thus the Region saves 20M euros per year and farmers continue to pay the present low price for water
3) ENAS reduces energy bill by 100%, thus the Region saves 20M euros per year, and asks farmers to pay for the real costs of water
4) ENAS reduces energy bill by 100%, thus the Region saves 20M euros per year, asks farmers to pay for the real costs of water and the income from water pricing is redistributed to farmers in the form of incentives in agriculture for efficient irrigation and Low Input Agriculture.

3) Renewable energies

The policy has an effect on CO2 emissions and thus global climate; it also has an effect on the energy sector potentially reducing the incomes for the energy production company (ENEL) and energy distribution company (Terna). This policy would have an effect on other sectors thereby affecting agricultural production and water demands from different sectors and would also alter the aggregated production from solar and wind (changing the harvesting capacity of energy farms) or hydroelectric (changing the distribution for hydropower plants) to reach policy targets of renewable energy.

Goal: increase the share of renewable energies and reduce CO2 emissions

Policy: Increase energy efficiency and self sufficiency

Alternative policies:
1) No increase in self-sufficiency (present use of renewables of 20%)
2) Increase the ratio between potential energy produced with renewables and consumed energy from renewables to 30% (investment of xxx M in incentives and infrastructures)
3) Increase the ratio between potential energy produced with renewables and consumed energy from renewables to 50% (investment of xxx M in incentives and infrastructures)

4) Sustainable Tourism development

Goal: increase tourist fluxes in shoulder months (spring and autumn)

Policy: Foster environmental quality by reducing peaks of tourist resource demands and further exploitation of land-use; decrease the seasonality of incomes from tourism; increase total annual tourist flows.

Measures: increase transport to the island in shoulder months; Taxes; urban development plans that regulate expansion of accommodation facilities in coastal and internal areas

The policy has an effect on the competition for water between the domestic sector and agriculture

1) Business as usual (increases fluxes at an annual rate of 1.3 m with the same seasonal distribution
2) Increase tourist fluxes only in the summer period at an annual rate of 1.4 m
3) Increase tourist flows only in shoulder months at an annual rate of 1.2 m

1.3 Develop a conceptual model

To articulate the conceptual framing of the Sardinia case for SIM4NEXUS, interactive processes with local experts and stakeholders were carried out to define the key nexus sectors to consider, identify sector drivers, relevant key policies, and crucially, how sectors and policies interact. Local experts and stakeholders included academics, public authorities, decision makers and unions. At the end of the process the modelling was expanded in terms of: i) nexus sectors, which include energy and food; ii) spatial scope, from district level to integrating sectorial interactions for the whole Sardinia region; and iii) increasing the detailed representation of nexus sectors in the model, including the policies that affect them. Figure 1 shows the conceptual system developed for Sardinia, on which further quantitative model development was based.

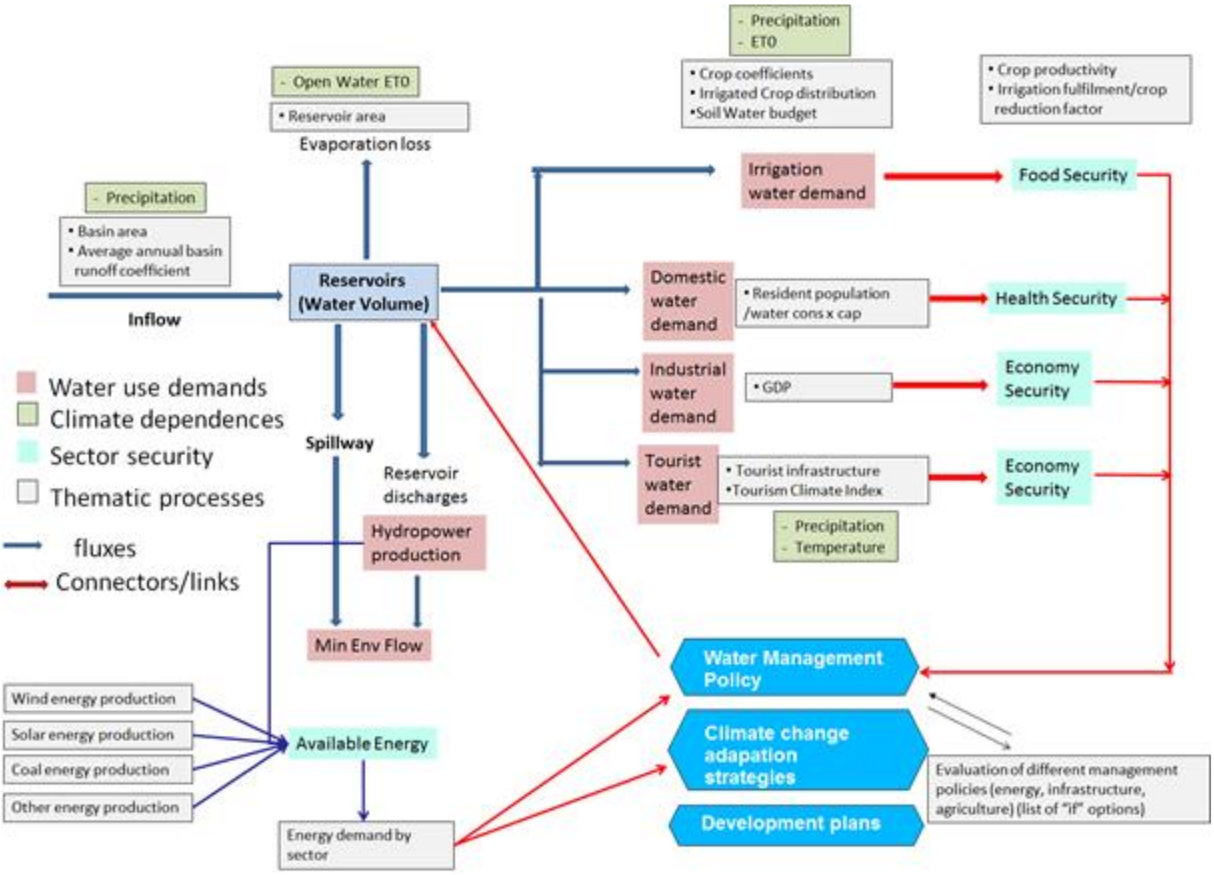

Figure 1: conceptual diagram describing the major nexus components relevant for the Sardinia case study.

Based on the above conceptualisation, it was then possible to identify the relevant 'thematic models' from within SIM4NEXUS from which data would be required. Here, data from CAPRI (Britz and Witzke, 2014), the GTAP project database (www.gtap.agecon.purdue.edu/), E3ME (Cambridge Econometrics, 2014), downscaled climate data from ISI-MIP (Hempel et al. 2013), as well as locally relevant data (e.g. for reservoir operating rules and environmental flow regulations), were acquired. Data from 2010 (the baseline) to 2050 under several RCP climate scenarios (van Vuuren et al. 2011) were included from the above-mentioned models and used for quantitative model development. It is likely that the conceptual framework will be further elaborated and improved during the SIM4NEXUS project, although the present framework already gives a sufficiently accurate representation of the nexus in Sardinia.

Based on the conceptual framework (Figure 1), and in constant collaboration with local case study leaders in Sardinia, the qualitative description was 'translated' into a quantitative nexus model built in STELLA Professional (www.iseesystems.com). The main focus of the model, based on Figure x, was the representation of the reservoir water balances for the island, accounting predominantly for water supply and for water demand related to agricultural, energy-related, and domestic/tourist consumption. On the water supply side, the model (Figure 2) accounts for inflows to the reservoirs based on precipitation partitioning to the runoff over the catchment areas upstream of the reservoirs. Initially, the water supply available for the 40 main reservoirs and multiple demands were aggregated at regional level. However, such aggregation has a number of flaws and stakeholders have asked for a disaggregation within regional districts. To meet this request, the final model will aim at a more articulated disaggregation within seven hydrological districts in Sardinia.

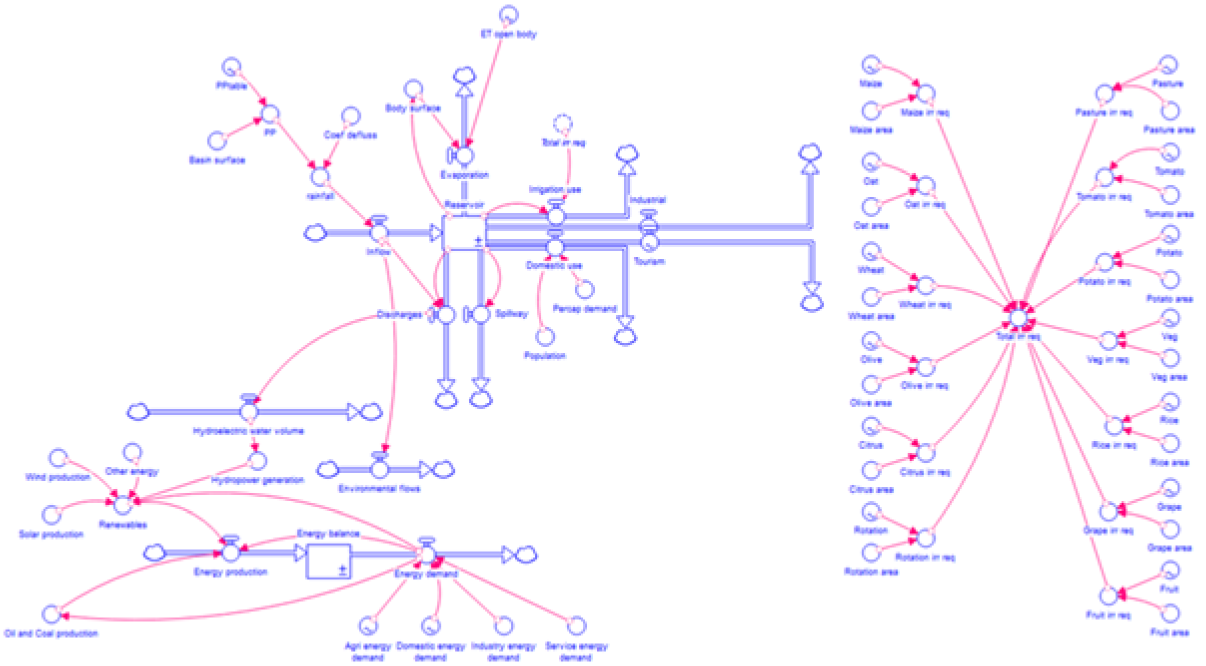

Figure2: the developed system dynamics model for the Sardinia fast track.

On the water demand side, the model considers: 1) open-water evaporation from the reservoir surfaces; 2) discharges for hydroelectric generation; 3) spillways in times of overflow; 4) irrigation requirements; 5) industrial demand; 6) domestic and tourist water requirements and; 7) minimum environmental flows. With irrigated agriculture being the largest water consumer, this sector was modelled in more detail regarding water requirements. In this instance, the crop water requirements per unit-area, and the area planted, were taken into consideration for 13 major crops on Sardinia as a function of changing climatic conditions.

Energy production in Sardinia is modelled from multiple sources including oil and gas, solar, wind and hydropower, while energy demand comes from the agricultural, domestic, industrial and service sectors. Touristic fluxes, and relative water demands, are modelled based on a Touristic Climate Index (Mieczkowski, 1985) and socio-economic scenarios. Climate change will have an impact on evaporation rates, crop water requirements, precipitation recharge to reservoirs, but also touristic fluxes. Data from thematic models provide projected changes of irrigated area by crop (CAPRI), energy production and demand by sector (E3ME), socio-economic factors (GTAP). The model will run simulations from 2010 to 2050 for several RCP scenarios. The model has a total of 73 variables accounting for each nexus sector and the interlinkages between the sectors. The modelling time-step is monthly, with all data scaled to this resolution.

Once the model structure was deemed representative for this case study, appropriate data were inputted into the model and the model outputs (in terms of the general trends of key variables such as the reservoir water balance over the year) were discussed with local case study experts to verify if the model was yielding sensible results.

1.4 Use of thematic models in understanding the Nexus

Data from thematic models provide projected changes of irrigated area by crop (CAPRI), energy production and demand by sector (E3ME), socio-economic factors (MAGNET/GTAP). We have been in contact with the responsible of the thematic models in the SIM4NEXUS project, and have acquired most baseline data, sufficient to test the interoperability of thematic model data within the elaborated conceptual NEXUS framework for Sardinia. The outcomes from thematic models have been archived to SIM4NEXUS fast-track dropbox, and subsequently downloaded for testing and validations. The thematic models data are available as following:

Climate data is available for the historical period (1961-2005) and future (2006-2099) for 5 different models (GFDL-ESM2M, HadGEM2-ES, IPSL-CMSA-LR, MIROC-ESM-CHEM and NorESM1-M) and 4 RCPs (2.6, 4.5 6 and 8.5), comprising an ensemble accounting for a total of 5 projections for historical period and 20 projections for future.

Data from the CAPRI model is available for Sardinia currently for periods/scenarios under consideration in the fast track, namely for 2010 (baseline) and 2030 (baseline and RCP8.5). Outcome from CAPRI for other target periods (2020, 2040 and 2050) and other scenarios is under request and should be acquired by the end of the year.

Data from E3ME is available on a yearly basis from 2013 till 2030 for Sardinia for SSP2. The request for remaining data for the period 2031-2050 is under way, and would be associated to alternative scenarios, in additions to SSP2.

Data from GTAP is under request, and could be used as socio-economic indicators in the Sardinia conceptual scheme as they become available to predict outcomes for future target periods/scenarios.

Soon (most likely in January 2018), we will be presenting in a workshop with regional stakeholders: 1) the outcomes of used Thematic Models for Sardinia, depicting base-line trends (2010, 2020, 2030, 2040, 2050) over the Nexus sectors water, land, food, energy and climate; 2) conceptual scheme of the Nexus and; 3) preliminary results and outcome from running the conceptual scheme in spatial distributed model, i.e. for specific hydrographic districts.

We do not believe there is further need of guidance, but rather a critical evaluation of defined trends in Sardinia that could arise from some model over-simplification or model biases. General biases from models is quite common and understandable, but should be verified and documented to clarify possible effects that these may have on results from system dynamic modelling of the Nexus.

Perhaps, water pricing is the most critical policy to implement in the model. There is a need to discuss how and if this can be addressed and the implications it would have on the different sectors. There may be a strong limitation in the representation of some crop types, and in particular Pasture, which has an extremely large relevance for irrigation in Sardinia and is not represented in CAPRI model.

Thematic models help integrate outcomes from different fields of expertise, and which represent drivers with strong interactions in the Nexus and whose integration is essential to define and understand development of optimal resource uses in the NEXUS.

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

At the beginning of the project, contacts were taken with three key stakeholders for two key Nexus sectors: water and energy. The SIM4NEXUS objectives were shared with the director of the Regional water management authority (ENAS) and with the author of the Regional Energy Plan now adopted by the Regional Government. These preliminary contacts together with knowledge gathered in previous projects for the food and agriculture and for the tourist sectors, allowed to identify a first version of the NEXUS framework in Sardinia.

1st Focus Group

The framework was further defined during a focus group held in Oristano on the 26th of May 2017. Eight stakeholders participated to the Focus Group covering the water and the food and agriculture sector and with different decisional power and interest including researchers, directors of the two main agricultural unions, director of the irrigation consortium, director of ENAS, and representatives of two regional agencies focusing on agriculture. During the focus group it was possible to reach a shared vision of the main nexus interlinkages to consider and their strength. In the few cases where there was disagreement on the strength of an interlinkage, a shared vision could be reached after a discussion. Participants were also asked to motivate the interlinkages thus allowing to further articulate the underlying mechanisms of the interactions among sectors. The results of this discussion were very important to clarify how sectors should be linked in the SDM model.

It must be noted that some effort was necessary to bring the participants to focus on interactions rather than on their sector of origin. Nevertheless, the Focus Group allowed to redefine the conceptual framework in such a way to meet the requests of stakeholders and to construct the SDM closer to reality. Specifically, after discussion, the framework includes water requirements for tourist infrastructures (e.g. irrigation for lawns) rather than only individual tourist water consumption. We were additionally asked to include the effect of touristic flows on the consumption of agricultural products as this is seen as a relevant interlinkage.

In general, the initial conceptual framework did not differ substantially from the view reached at the end of the focus group. Several interlinkages identified by the participants were actually a second order interlinkage as in the case of energy-agriculture that after the discussion was clearly meant the energy costs for pumping water needed for irrigation. It should be additionally stressed that often the mechanism of interaction implied socio-economic interactions which are difficult to simulate.

Finally, participants were asked to provide a list criticalities and possible actions for the different sectors and some effort to focus on those that could help exploit synergies among sectors. Given the limited time and that a sufficiently articulated SDM was not reached yet, this part of the discussion was not sufficient to finalize a list of possible alternative policies. However, the most frequent policies were:

1) Incentives to increase irrigation efficiency
2) Regional investments to increase the efficiency of the water conveyance system
3) Investments to decrease energy prices (Methanization of the island)
4) Policies for water pricing
5) Policies to promote internal consumption of agricultural products
6) Policies to promote the use of common databases for planning
7) A request for planning in the agriculture and water sectors accounting for climate change

After the focus group and completion of Block 1 of the policy analysis, 25 potential stakeholders were identified for individual interviews. As of 16th of December, nine interviews were undertaken.

The nine interviews do not yet allow for a robust policy coherence analysis, but it is noteworthy that some issues are common to all or most interviews. The first point in common is that the interviewed tend to fall back to a silos thinking and it requires some effort to bring them to consider the potential synergies or trade-offs between their sector and other sectors. While progressing with the interviews the focus on interactions between sectors was increasingly stressed in the attempt to collect more focused information for SIM4NEXUS. Despite this effort, the difficulty remains and perhaps additional or alternative methods should be considered during the interviews.

The second point in common to the interviews is a general criticism on the degree of awareness within citizens (low consensus) but also within institutions. This low level of awareness, pairs with a lack of coordination between objectives and measures and low investments in environmental education.

It is also important to note that several interviewed brought to our attention that inconsistencies often emerge at a very technical level. For example, the EU water directive, the Habitat Directive and the Birds directive all somehow have references to regulation of water bodies, however the boundary of the system that each directive regulates differs among directives. This lack of coherence creates strong difficulties where often it is not clear who is responsible for an area.

Another shared critic is not so much incoherencies between objectives or regulations but the lack of such regulations or laws that have not become in force because regulations were not outlined or reached final approval.

It is also a common perception that regional (but also national) laws are often farsighted and well thought of, but their conversion in specific regulations is often left to more administrative staff that often lacks the expertise to do so.

Finally, it appears that although there is some informal communication between decision makers, regional agencies and research institutions, the process of policy making is follows a top-down approach where agencies are poorly involved in the process and are rather responsible for there implementation.

As a version of the SDM able to deliver first results will be ready by the end of November and that interviews should be completed by then as well, the 1st workshop is planned in January 2018. During the workshop the first results of the simulation will be shown and the discussion will focus on eventual critics of the SIM4NEXUS approach as well as finalizing the alternative policies to test. During the workshop an effort will be necessary to tackle the general problems identified during the interviews.

2 Conclusions and follow-up

During the Sardinia fast track process, a number of important lessons were learned about the model development that will guide and influence future development in SIM4NEXUS. Perhaps the most important lesson is the criticality of close multi-stakeholder interaction. Different groups and individuals were involved at different stages in the process, and without close cooperation throughout, the process could easily stall or fail, or a poor/unrepresentative model could be developed, with consequences for the robustness and veracity of the messages being portrayed by the serious game. It could also mean limited uptake of the model, and therefore limited impact of the results. It is important to invest time and energy from the beginning to bring together individuals with different experience, to integrate their knowledge and focus the discussion around interactions between different sectors, rather than sectors alone. Large difficulties emerged during stakeholder interactions with respect to expanding the experience of individuals beyond their specific sectors (i.e. breaking 'silo thinking'). Only by including stakeholders in cooperative forums could these difficulties start to be addressed and compromises found. Academics with expertise in disparate fields, policy experts, programmers, database engineers and local experts in Sardinia familiar with the local context all contributed to the fast track.

Another important lesson was that since the Sardinia island-wide reservoir system was represented for simplicity in the fast track model as a unique aggregated system (i.e. geographically lumped), an overestimated efficiency of the supply system to capture and manage water was introduced, vastly overestimating resilience to changes in water supply and demand. By sticking with a lumped approach, model results would not be representative, and therefore confidence in the results and the implications for nexus sectors discovered would not be taken seriously. It is important to articulate specifically the individual sources of supplies and demands, both spatially and temporally, to render the effective efficiency and resilience of water systems.

In future developments, in the next 6 to 12 months, Nexus Platform development will be finalized for Sardinia and will represent spatial heterogeneity across seven hydrological basins to better capture different hydrological dynamics across the island (March-April 2018). Aggregation to the island scale will then take place *a-posteriori.* This lesson is important because better information and knowledge will be generated for policy and decision making, with results more accurately expressing on-the-ground situations. Platform simulations will also integrate further outputs from thematic models to evaluate impact and synergies for alternative policies (Summer 2018). Future results from platform simulations for Sardinia will be presented to stakeholders to identify further criticalities in the Nexus for Sardinia.

Stakeholders meetings are already planned to occur at the beginning of 2018, to present platform and evaluate choice of relevant policies in the Nexus. The Policy coherence activity is under way and will be further elaborated at next stakeholders meetings.

3 References

- Britz W, Witzke HP. (2014) CAPRI Model Documentation. Institute for Food and Resource Economics University of Bonn, Bonn.
- Cambridge Econometrics (2014) E3ME Technical Manual version 6. 136pp. Available at: www.camecon.com/how/e3me-model/
- Hempel S, Frieler K, Warszawski L, Schewe J, Piontek F. (2013) A trend preserving bias correction – the ISI-MIP approach. Earth System Dynamics. 4: 219-236. DOI: 10.5194/esd-4-219-2013
- Mieczkowski Z. (1985) The Tourism Climatic Index: A Method of Evaluating World Climates for Tourism. Canadian Geographer. 29(3). 220-233. DOI: 10.1111/j.1541-0064.1985.tb00365.x
- Van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt GC, Kram T, Krey V, Lamarque JF, Masui T, Meinshusen M, Nakicenovic N, Smith SJ, Rose SK. (2011) The representative concentration pathways: an overview. Climatic Change. 109: 5-31.

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

D5.2: THE MAIN NEXUS CHALLENGES IN THE SOUTH WEST UK

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Table of Contents

Glossary / Acronyms

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

AMP	Asset Management Period (depending on the use it can also be Asset Management Plan)
CAPEX	Capital expenditure
CAPRI	Common Agricultural Policy Regionalised Impact Modelling System
CFD	Contracts For Difference
DEFRA	Department for Environment, Food & Rural Affairs
DSR	Demand-Side Response
DWI	Drinking water Inspectorate
E3ME	a global, macro-econometric model
EA	Environment Agency
EU ETS	European Union emissions trading system
GTAP	Global Trade Analysis Project
HM Gov.	Her Majesty's Government
K	expected efficiency gain
ODI	Outcome Delivery Incentive
OFGEM	Office of Gas and Electricity Markets
OFWAT	Water Services Regulation Authority
OPEX	Operational expenditure
Pa	Per annum
PR	Price Review
RAB	Regulated Asset Base
RPI	Retail Price Index
SIM	Service incentive mechanism
SWW	South West Water
TOTEX	Total expenditure
UKWIR	United Kingdom Water Industry Research

1 Introduction

The key aim of the project is to better understand the complex interactions of the nexus components in the South West region, and to develop a decision support framework to facilitate integrated resource management in the context of policy and business planning. It is believed that an integrated approach will both enhance the protection of, and leverage the societal benefits from the natural capital within the south west region.

As the lead UK member of the SIM4NEXUS consortium, South West Water (SWW) is collaborating with academics from the University of Exeter to develop a detailed case study of the linkages between water, land, food, energy, and climate in the South West region. As the only UK water company involved with the project, SWW is able to provide the project a unique insight into the water industry and through the case study it develops, provide a unique application of the nexus approach.

The case study will address how legislation, policy and strategic planning can be aligned to;

1. Support sustainable agriculture and the provision of water and wastewater services in a region with significant environmental sensitivities and the UK's largest tourism region

2. Recognise the need for resilience in the face of climate change, population growth and an increasingly competitive market place.

Outputs from the SWW case study alongside the outputs from other consortium members will be used to create a unique "Serious Game" simulation of the Water, Energy & Food NEXUS. The Serious Game will facilitate detailed scenario based analysis and learning opportunities which will support both business planning and stakeholder engagement. Furthermore, SWW intend to use the project outputs to influence regulator policies and demonstrate a strategic approach to business planning that considers end to end resource management.

Project Aims:

- Demonstrate a long term (50 years) integrated approach to business planning, that considers:
    - End-to-end resource management (clean/waste, supply chain & beyond),
    - Resilience in the round,
    - Environmental protection and low carbon development,
- Support delivery of the Governments strategic priorities,
    - Securing long -term resilience,
    - Protecting customers,
- Enhance Stakeholder engagement at all levels,
- Develop robust understanding of the impacts of new and emerging legislation beyond the water sector,
- Develop educational tools for use with local educators,

Spatial scales:

The South West of England, as defined in this case study, includes the counties of Cornwall, Devon and parts of Somerset and Dorset - totalling an area of approximately 10,300 km2. There are 1.7 million residents across this region, with the majority of the population (45%) located in just 13 urban centres.

The case study will be conducted at 2 spatial scales;

Regional (South West Region within SWW's operational control) and,

Catchment (The Exe Catchment, via a parallel project entitled "Catchment Scale Intelligence").

Project partners:

South West Water (SWW) (http://www.southwestwater.co.uk/) is one of ten Water & Sewerage Companies (WASC's) operating in the UK. It is owned by Pennon Group Plc., an environmental utility infrastructure. SWW is the main SIM4NEXUS partner responsible for this Case Study.

The University of Exeter (UNEXE) participates and supports this Case Study with two Colleges and Research Groups:

The Centre for Water Systems (CWS) (www.ex.ac.uk/cws), which is part of the College of Engineering, Mathematics and Physical Sciences at the University of Exeter (UNEXE) in the UK based in Exeter, Devon.

The Energy Policy Group (EPG), (www.exeter.ac.uk/epg), which is part of the College of Life and Environmental Sciences at the University of Exeter, based at the Penryn Campus in Cornwall.

1.1 Description of the Nexus challenges

The nexus challenges are broadly outlined in the work package 2 Policy Analysis block 1 report, therefore the more specific challenges faced by the UK water sector are discussed in greater detail herein.

1.1.1 Major trends

The role of the water industry is to supply potable water, sanitation and drainage services to domestic and nondomestic consumers, drawing on resources from, and returning effluents to the natural environment of the UK. UK water utilities are major asset owners that have delivered investment totalling over £108bn since privatisation(OFWAT, 2016). Approximately 18 billion litres of water are abstracted, treated and supplied to consumers throughout the UK on a daily basis. Through the provision of these services the sector is a major consumer of energy and a source of greenhouse gas emissions contributing about 1.1% to total UK emissions (OFWAT, 2014, p. 24).

In 1989, privatisation of the water sector saw the 10 regional water authorities split into 34 licensed companies across England and Wales with the statutory duty of the provision of clean and waste water services. To prevent the newly formed companies acting as monopolies the Water Services Regulation Authority (OFWAT) was established to set appropriate service levels and ensure economic fairness for the consumer.

The water sector is regulated by 3 separate and independent bodies that work on behalf of Government, and is further advised that by several NGOs.

OFWAT (Economic)

The Water Services Regulation Authority is a non-ministerial government department which acts as the economic regulator for the water and sewerage sectors in England and Wales. Established following privatisation to ensure cost-effective delivery of service and protect consumer rights.

Environment Agency (Quality)

The Environment Agency (EA) established in 1996 is an executive non-departmental public body, sponsored by DEFRA to protect and improve the environment, and acts as environmental regulator to the water sector. Discharge to the environment from industrial activity is licenced by the EA through a permitting framework. The regulations enforced by the EA are typically implementations of EU directives. Newly introduced directives such as the Water Framework Directive place additional burden on waste water companies by tightening the discharge consent limits (European Parliament, 2000).

Drinking Water Inspectorate (Quality)

The Drinking Water Inspectorate (DWI) was established following privatisation to monitor and protect drinking water quality. Acting as the competent authority, the DWI's role is to ensure that the requirements of the EU Drinking Water Directive are met in England and Wales. Investment in the drinking water sector has been heavily influenced by a need to comply with DWI objectives, and HACCP standards (Hazard Analysis and Critical Control Points), in some cases (but not in SWW) leading to a bias toward investment in drinking water over waste water.

Lobbyist and Research - independent

Water UK

Water UK acts as an industry representative to lobby government to instigate and facilitate sustainable development of water policy.

UK Water Industry Research

UKWIR was established in 1993 to provide the water industry with a research platform to undertake work that would be of benefit to the whole sector.

1.1.1.1 Growing Need for integrated resource and asset management

Specifically in the water sector, the 2005 and 2014 Water Act's respectively added statutory obligations to OFWAT to contribute toward sustainable development and the "Primary duty to secure resilience" and "to further the resilience objective." (HM Gov., 2012) Clause 22 and 22,2(e). The resilience objective seeks to ensure that water companies secure long term resilience in their ability to supply primary services with regard to environmental pressures, population growth and changes in consumer behaviour.   Further clauses are included that state OFWAT should promote appropriate long term planning, investment, and sustainable management of water resources, with a view to increasing efficiency and delivering demand reductions.

Following the 2014 Water Act, OFWAT responded to the new primary duty by establishing the Resilience Task and Finish Group an independent body reporting to OFWAT, seeking to influence the sector more widely(OFWAT, 2015).

Resilience for the water sector as defined by the OFWAT Resilience Task and Finish Group(OFWAT, 2015):

> *"Resilience is the ability to cope with, and recover from, disruption, and anticipate trends and variability in order to maintain services for people and protect the natural environment now and in the future."*

In a broader scope this became mirrored in other utility sectors, the 2008 National Risk Register published by government in response to the National Security Strategy, highlighted weakness in the UK's ability to respond to perceived threats to national security. This lead to the development of Sector Resilience Plans (SRP) programme (The Cabinet Ofice HM.Gov, 2008). The SRP places an annual obligation on key sectors (including water and energy) to provide a response strategy to the identified risks. The 2010 Resilience Plans focused on the impacts and responses to flooding, however year on year the scope has increased to consider a more detailed view of asset base and range of risks.

In 2013 the Cabinet office established The National Resilience Capabilities Programme (Cabinet Office HM Gov., 2013) with the aim of increasing the UK's capacity to respond to, civil emergencies. Defra and the Environment Agency are charged with managing responses to the issues of severe flooding arising from river, ground water and coastal regions.

Research conducted by OFWAT shows that customer's number one priority for the water industry is safe, reliable supplies of water at a price they can afford (OFWAT, 2010). This is borne out in customer feedback from individual companies such as Southwest Water who conducted surveys in 2012 which showed customers consider safety of water, leakage control, prevention of pollution and resilience to be key priorities. (South West Water, 2012, p. 19)

From the above it is clear, although not explicitly stated, that resilience relies heavily upon the management of resources and assets to ensure controlled response to external stresses. Several of the recommendations of the resilience task and finish group are directly related to asset and resource management activities. Therefore a move toward improved resilience implicitly requires a move toward improved resource management.

To understand the challenges of the water sector as a whole it is important to consider the distinguishing characteristics of its major components.

Cross function similarities - Both drinking water and waste water activities can be characterised by:

- Climate of heavy regulation (although by slightly different regulators),
- A large number of assets spread over a large geographical region, (usually overlapped),
- Employ similar pumping, control and telemetry technologies,
- Serve the same or similar customer base,
- Significant data security issues,
- Tight financial margins,
- Low perceived value of product,
- Poorly understood by customer base,
- Complex organisational structures.

In general terms, wastewater services have the additional burden of:

- Increased process complexity, less process stability, influenced by a greater number of external variables,
- More complex environmental permitting regimes,
- Potential levels of historic underinvestment,
- Greater negative impact from customer behaviour,
- More frequent negative customer contact.

1.1.2 Price Review mechanism and incentivisation

To ensure fairness of pricing and economic performance, OFTWAT applies a price cap system to the Water Company's revenue. The price cap mechanism is expressed by the formula RPI + K, where RPI represents the Retail Price Index and K represents the expected efficiency gain the regulator believes the operator would have achieved in an unregulated competitive market. This model follows the recommendations of the Littlechild Report 1983.

OFWAT uses a modified formula to stimulate capital investment of RPI + K + U(OFWAT, 2015). In this case K= "price limit", and U= credit generated from previous economic periods. The addition of the U variable enables companies to make capital efficiencies in a given period and "roll-over" the benefit to the subsequent period. The first price review occurred in 1994 and was repeated following a 5 year cycle. The 5th price review (usually abbreviated to PR14) took place in 2014 to set prices for the period of 2015-20. These five year periods are described as the Asset Management Programme, i.e., AMP5.

The impact of the review cycle is complex and fundamentally influences the investment strategies of individual companies. A key finding of the UKWIR report into the impact of the regulatory cycle was that the most negative impacts are felt in the supply chain servicing the water industry, rather than within the water companies themselves(UKWIR , 2007). These impacts, amount to significant risk to the sustainability of the supply chain.

The final output of the Price Review are the individual companies' business plans, which set out how they will operate over the coming AMP period. This includes full disclosure of investment plans, service provision and recovery of revenue. Once agreed by OFWAT, the expectation is that each company operates according to the plan and is monitored against the agreed benchmarks.

The Regulated Asset Base (RAB) describes the net asset value of regulated assets (i.e. those assets directly associated with the provision of core service) which is used to determine; depreciation allowance and return on capital, two key variables of the bass tariff calculation. To leverage greatest value from the RAB water companies must look to asset optimisation and management practice.

The Service incentive mechanism (SIM) was introduced by OFWAT in 2010 as a means of stimulating an improvement in the provision of services to customers. The SIM is based on two metrics or Consumer Experience Measures which are combined to form a final SIM score:

- The 'quantitative measure' reflects the number of complaints and telephone contacts that the companies receive.
- The 'qualitative measure' reflects how satisfied consumers are with the quality of service they receive from their company.

The final SIM score is used by OFWAT to determine relative performance and apply either positive or negative price adjustment to the revenue stream companies can recover via customer bills.

PR14 and AMP5 saw the end of OFWAT's accounting division between OPEX and CAPEX budgeting objectives, and an introduction of a customer oriented approach to incentivisation. Total expenditure (TOTEX), combines capital (CAPEX) and operational (OPEX) expenditure into a single metric following the principle of "whole life costing". This metric marks a departure from the capital centric approach of previous price reviews. The key benefit of TOTEX is that it enables greater flexibility with investment and service delivery, and it emphasises the need to reduce whole cost of service provision.

Outcome Delivery Incentives (ODI), is a new incentive mechanism that requires companies to engage in a detailed customer consultation process, and set their own strategic targets/outcomes to reflect the priorities of their customers. To support delivery, the identified outcomes are incentivised via a rewards and penalties approach. The ODI's are grouped as follows:

- Penalty only
- Reward only
- Penalty & Reward
- Reputational, i.e., not directly financial

All incentives, financial or otherwise, form part of the regulatory contract (business plan) for the AMP against which OFWAT monitors performance.

1.1.2.1 Cost, environment and security of supply trilemma

As a privatised but regulated sector, water companies are exposed to market forces and motivated by shareholders to generate profit, whilst adhering to economic and environmental regulation. The result is that water companies are forced to consider carefully any activity that might risk regulatory compliance, profitability or incur costs that cannot legitimately be passed to consumers, leading to a culture historically focused on economic sustainability and risk aversion (UKWIR, 2006).

Summary of key water industry drivers:

1. To provide clean, safe and reliable drinking water;
2. To provide waste water collection and disposal;
3. To sustainably manage resources and minimise pollution;
4. Privatisation
    a. Provide dividend to shareholders (generate profit)
    b. Leverage greatest value from Regulated Asset Base (RAB)
    c. Address issues identified by the regulator: (OFWAT, 2015)
        - Chronic Underinvestment;
        - Requirement to improve drinking water quality;
        - Requirement to reduce environmental pollution;
        - Improvement in economic efficiency.
5. Industry regulation

The water industry is driven by three primary objectives; to maintain supply; to maintain the environment and to minimise cost. These objectives, while not entirely mutually exclusive are significantly conflicted. For example it is likely that to maintain supply, companies will need to expand capacity thus incurring construction costs, and causing more impact to the environment. Further environmentally sensitive practices are frequently less economically efficient and often don't enhance service to the customer. Historically, security of supply and environmental protection were relatively low priority, and emphasis was placed on cost efficiency by both the consumer and the regulator. This position is likely to change, with security of supply and environmental protection gaining prominence, meaning that cost efficiency will become increasingly more difficult to achieve.

WaterUK further suggest that the water industry is especially vulnerable to climate change as it is fundamentally dependant on the natural environment for its primary resources and will be directly affected by the main impacts of climate change (WaterUK, 2015):

- Temperature change;
- More intense rainfall;
- Drought/increased demand during hot weather;
- Sea level rises.

These impacts will be exaggerated further by socio-economic pressures as identified by DEFRA in the UK climate change risk assessment (DEFRA, 2012):

- Increased demand due to population rise;
- Resource depletion/rising energy cost;
- Increased urbanisation;
- Higher taxation.

In the Western world there is a general perception that access to clean drinking water and sanitation services is a basic human right, and in a region such as the South West UK there is an apparent abundance of available resource. Additionally the demand for drinking water and waste water services across the UK will inevitably increase. As temperatures rise and urbanisation increases, growing demand will become more energy intensive and difficult to service. This comes at a time when national and international policies are requiring industry to improve effluent quality, reduce energy consumption and manage carbon emissions. The result of this situation is such that drinking water and wastewater services do not have a high perceived economic value to the consumer. However such a view makes no provision for increased capacity, enhancement of service or resilience to factors such as climate change.

The water sector in the UK is essentially run by subcontracting companies operating under licence, to meet the business objectives of “UK plc” for the provision of service to UK population at large. As a fundamentally infrastructure and asset based industry, water companies attempt to leverage the value of their RAB to drive revenue, therefore asset and resource management are core activities. However the RAB mechanism has had the unforeseen effect that water companies have historically prioritised budgeting for capital investment rather than operational expenditure, leading to culture of “run to destruction” and an asset base with high operational cost. Furthermore, the uncertainties surrounding extreme weather and rising population apply additional unknown pressures, necessitating that a more risk based approach is adopted.

If the UK Government and by extension the UK populace require enhanced provision of water services then finance will be raised, but the question remains how can this be achieved with the least economic burden on consumers. This is a particularly challenging situation exaggerated by the financial priorities OFWAT and privatisation impose. Therefore the water industry is awkwardly placed in terms of regulatory climate and structural complexity, where both factors are towards the extreme end.

Many of the challenges of poor efficiency, reliability and below customer expectation service levels, i.e., leakage, are a legacy of plant dating back to the start of the 20th Century. There are numerous opportunities for improvement throughout the sector which range in complexity from the very simple, low cost – (changes in maintenance philosophy), to the highly complex major infrastructure projects – (separation of surface water).

The TOTEX model drives a more holistic view of budgeting and relies upon NPV accounting which can account for risk, thus leading to improved cost efficiency over the longer term. While the ODI mechanism adds a degree of complexity and diminishes performance transparency between companies, it also adds flexibility and a customer focused approach. If the water sector is to meet the challenges of the years ahead significant investment will be required, which in itself can only happen in conjunction with a fundamental readjustment to the value of water. Through activities such as the National Risk Register Government is beginning to understand the true value of utilities infrastructure and the need to support cost-effective resilience strategies. However the unit price of utility services is highly contentious and a balance must be made between competing stakeholder demands.

1.2 Description of the pathways

The scenarios developed for the case study are designed to facilitate a peer reviewed framework to challenge the long-term resilience of our services delivered in response, or in parallel to policy changes in other industries as illustrated by the linkages of the conceptual model.

SSP2 is used for the baseline data over five time steps: 2010 to 2050.

The following business priorities are explored:

1. Cost effective delivery of service, (CAPEX and OPEX)
2. Resilience of service delivery to the pressures of new legislation, climate change and population growth,
3. Sensitivity and resilience of service delivery to pressure placed on other nexus sectors,
4. Reduced uncertainty in long term (>50 years) strategic planning for integrated, end to end resource management.

Specific Optimisation objectives for the Nexus System Dynamic Model (SDM):

- Minimise total cost to meet demand (water, food, energy) in terms of Financial - Societal – Environmental.
- Efficient use of resources i.e. reducing internal loss.
- Resilience of service delivery to external pressure (climate change – population – new legislation).

1.2.1 Increased or decreased regulatory burden

Based on previous trends it is anticipated that future regulation and legislation will require higher quality standards for both drinking water and wastewater effluent. This fundamentally will require more intensive water treatment processes, which in turn leads to increasing energy use and higher operational greenhouse gas emissions. Notable examples of this can be seen in the implementation of EU directives into the UK regulatory framework, such as Urban Water Directive, Water Framework Directive, Bathing Water Directive and Drinking Water Directive.

With the pending departure from the EU, the UK regulatory environment is at a crossroads. It is possible that in an attempt to stabilise perceived economic decline the government will reduce regulatory burden and environmental standards, thus enabling companies to reduce operational costs. Conversely in an attempt to demonstrate a commitment to environmental protection an increased level of regulation of existing regulations may be attempted, thus driving up operational cost. Therefore a key variable in future scenario analysis must consider the level of regulatory burden applied to; the quality of drinking water, waste water effluent, sludge disposed to land and agricultural/industrial discharge.

1.2.2 Water trading - whole sale market separation

Following a similar model to the electricity sector, the UK water industry has recently undergone a significant structural change with the opening of the wholesale and retail water markets.

As of April 2017 it is possible for organisations to choose which company supplies their water retail services, in a change instigated by OFWAT to enhance competition in an otherwise monopolistic industry. This enables water retailers to purchase wholesale volume from incumbent water supply companies for resale to non-domestic consumers. Essentially creating a framework for a decoupled marketplace where consumers are able to purchase water services indirectly from the physical supply.

It is hoped that wholesale water trading between organisations can potentially lead to a more resilient business model and more competitive pricing. However, the extent to which this impacts resource management in reality is not fully understood and additional analysis may yield unforeseen benefits or shortcomings. Therefore, future scenarios will include wholesale market separation in addition to further disaggregation of the water sector.

1.2.3 Cost of energy

The cost of energy is regarded as a significant component of household expenditure in the UK and the ratio between income and energy expenditure is used as a poverty indicator. The government has placed increasing priority on reducing household bills and most recently announced potential for energy price capping. Within the water industry, energy is typically the second largest operational cost after Labour, and fluctuations in energy price have major implications for the unit cost of water and company profitability. Various government mechanisms can influence energy costs and it is important to consider this within any scenario analysis.

1.2.4 Utility tariff models

Various tariff models exist within both energy and water utilities and their misalignment can result in financial inefficiencies between the two sectors. Simple structures such as “flat rate” tariffs in which the unit rate is constant with time and volume are easy to manage but result in higher unit rate and total cost. “Seasonal time of day” tariffs see an increased unit rate for particular periods of the day or year coinciding with peaks or troughs in demand thus incentivising demand management. “Rising block” tariffs set a low unit rate for the first block of volume and an increasing unit rate for subsequent blocks of volume, thus incentivising demand reduction or efficiency. Application of different tariff models can act as both incentive and disincentive for demand management, efficiency and profitability. While the application of particular tariff models is down to the contractual arrangement between supplier and consumer, tariff structures will be examined within the model due to the potential financial benefits and support of wider objectives.

1.2.5 Capacity Market - Energy Market Reform

The 2013 Energy Act introduced a framework for electricity market reform which made significant alterations to the way energy is valued and traded. Notable elements of which are the introduction of ‘Contracts for Difference’ (CFD) as a mechanism for incentivising particular generation technologies and the opening of the Capacity Market. CFD’s replace the existing mechanisms of the Renewable Obligation and Feed-in-Tariff, and are not exclusively focused on renewable energy, but also include carbon capture and storage and nuclear. The primary advantage of the CFD is that it decouples generation from the highly volatile energy market, by ensuring a fixed unit rate for energy generated. This provides a significant degree of long-term certainty which enables developers to guarantee revenue streams before projects are built. The main challenge associated the CFD is faced during the negotiation stage where both the developer and the government have to take a view on the future value of energy.

The capacity market is intended to valorise activities which increase the headroom or spare generating capacity within the National Grid network as a commodity in its own right. Such activities focus on highly responsive generation of energy or reduction of demand, to attenuate peaks in the "unmanageable demand" on the network. Demand-side management is a catchall term to describe activities which shift or manipulate the energy demand profile of a consumer, such that peaks in tariff or other time variable charges are avoided. Such activities usually include some form of demand curtailment during an "event". The incentive to engage in demand-side management is usually one of cost avoidance rather than revenue generation, however with the advent of the Capacity Market, demand-side management services are now procured by National Grid under the umbrella term of Demand-Side Response (DSR) services. The intention is to offset the need to increase large-scale transmission or generation capacity which would have national cost repercussions. As confidence in the capacity market grows, water companies with their large operational asset base and high energy demand are likely to include DSR within their normal operational models.

1.2.6 Efficiency

Implementing efficiency measures which reduce the nominal demand for water and energy utilities provide a dual benefit. Firstly the benefit to the consumer is realised by reduced costs and secondly, the benefit to the supplier is realised by negating the need to invest in increasing capacity. Furthermore such measures have the effect of decoupling the linkages between the two sectors, aiding management. Efficiency and demand management activities are often relatively low capital cost, but frequently are rapidly limited by the laws of diminishing return, therefore cost benefit analysis must be considered within the model.

1.2.7 Low carbon energy/ decarbonisation

The UK government has binding legal commitments to reduce GHG emissions and has implemented a number of incentive mechanisms to stimulate the decarbonisation of industry. While progress has been made toward the targets, more work is required. The nexus approach is seen as a potential management strategy which may leveraged low carbon technologies for greatest benefit and will be included within our model.

1.2.8 Carbon trading

UK Carbon Reduction Commitment energy efficiency scheme was initially introduced as a trading mechanism similar to the EU ETS, but problems with the carbon floor price and inequality of market access led to the CRC digressing to a direct taxation mechanism. A trading mechanism is not inherently flawed and could still potentially lead to enhanced carbon efficiency within the UK marketplace. It is therefore hoped that when approached in a nexus framework, the viability of carbon trading can be demonstrated.

1.2.9 Disposal/Reuse of Bio solids

Following the economic regulators moves to separate wholesale and retail water markets to enhance efficiency and promote competition, water companies are being asked to prepare for a "bio resources" market which will further separate business functions and create new value chains. Bio solids are generated at several stages in the urban water cycle which can be used to generate valuable products including energy, fertiliser's and aggregates. Currently the majority of bio solids are disposed to land incurring both environmental impact and financial burden. Considering a circular economy approach, which examines how these products can be refined and utilised, is of growing interest to industry and will be examined by the nexus approach.

1.2.10 System Resilience

Infrastructure resilience is a key priority of the UK government and the nexus model offers an ideal opportunity to examine true systemic resilience between sectors. To date no major investigation has been undertaken into infrastructure resilience using a nexus model – thereby offering a unique research opportunity. Resilience within the south-west water case study will be examined at two spatial scales; initially at the highly granular catchment scale, where individual treatment plants will be considered; and secondly at a lower resolution (regional scale), where assets aggregation will facilitate a strategic level view.

1.2.11 Paid ecosystem services

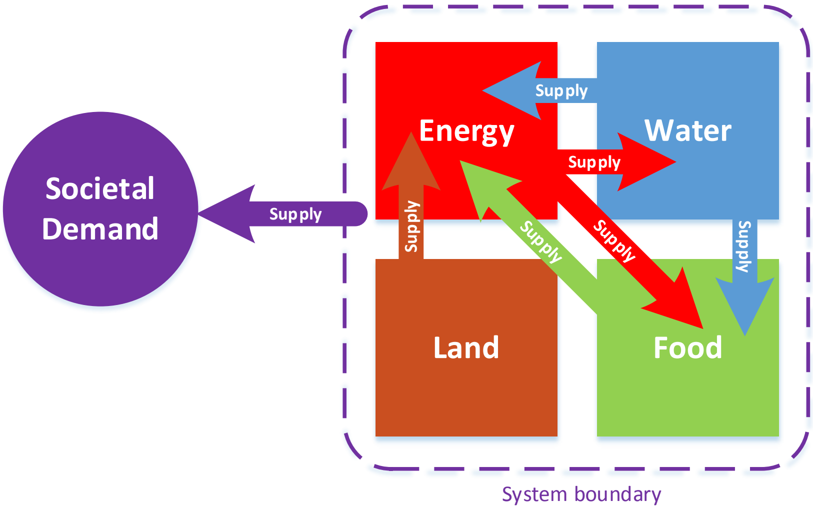
Currently in the UK paid ecosystem services exist within a voluntary framework supported by government endorsed guidance notes, with no obligatory or regulatory foundation. South West Water has engaged in a number of projects incorporating paid ecosystem services as a cost-effective means of flood mitigation and minimising raw water pollution. The agreements entered into are between 2 or more parties to monetise some aspect of the environment with regard to an amenity or service it can yield. Typically such agreements occur where a land owner is paid by a second party to alter an aspect of how they use the land under their management. The model will consider paid ecosystem services as a strategy for environmental protection and enhanced service delivery.

1.2.12 Embodied elements of service delivery

The embodied energy and embodied water components of a commodities value chain are highly complex and frequently difficult to calculate with certainty. This often leads to embodied resources being neglected from accounting activities. Due to the inclusive structure of the nexus model it is hoped that several of these elements might become more transparent and easily calculated to the first level of separation. While this will not provide a fully exhaustive analysis of embedded resource it will enhance understanding, and perhaps lead to further research.

1.3 Development of conceptual model

The conceptual model that we are developing incorporates societal demand as the primary driving force of the whole nexus system. In this view of the nexus internal supply lines between sectors become "losses" of the nexus system, and only supply lines that directly meet societal demand are considered outputs. Further internal supply lines can be viewed as embedded virtual components of the specific sectoral supply with one level of separation.



The demand society places on each sector can be expressed in very simple terms as a function of population multiplied by various coefficients to account for influencing factors:

- Water Demand Pa. (Mega Litres) = Pop. x climate coefficient x Life style coefficient
- Energy Demand Pa. (Giga Watt Hours) = Pop. x climate coefficient x Life style coefficient
- Food Demand Pa. (Tera calories) = Pop. x climate coefficient x Life style coefficient

This approach may not be sufficiently robust for reliable demand forecasting therefore extended functionality within the existing thematic models will be investigated. The preliminary data from GTAP and following discussions with the E3ME team, have revealed it is likely that these thematic models will provide suitable data to model societal demand.

Within the conceptual model the linkages of highest priority are:

Energy to water

The provision of water and wastewater services could not exist without the supply of energy. Further energy generation is the primary source of GHG emissions and the second largest operational cost associated with water/wastewater services.

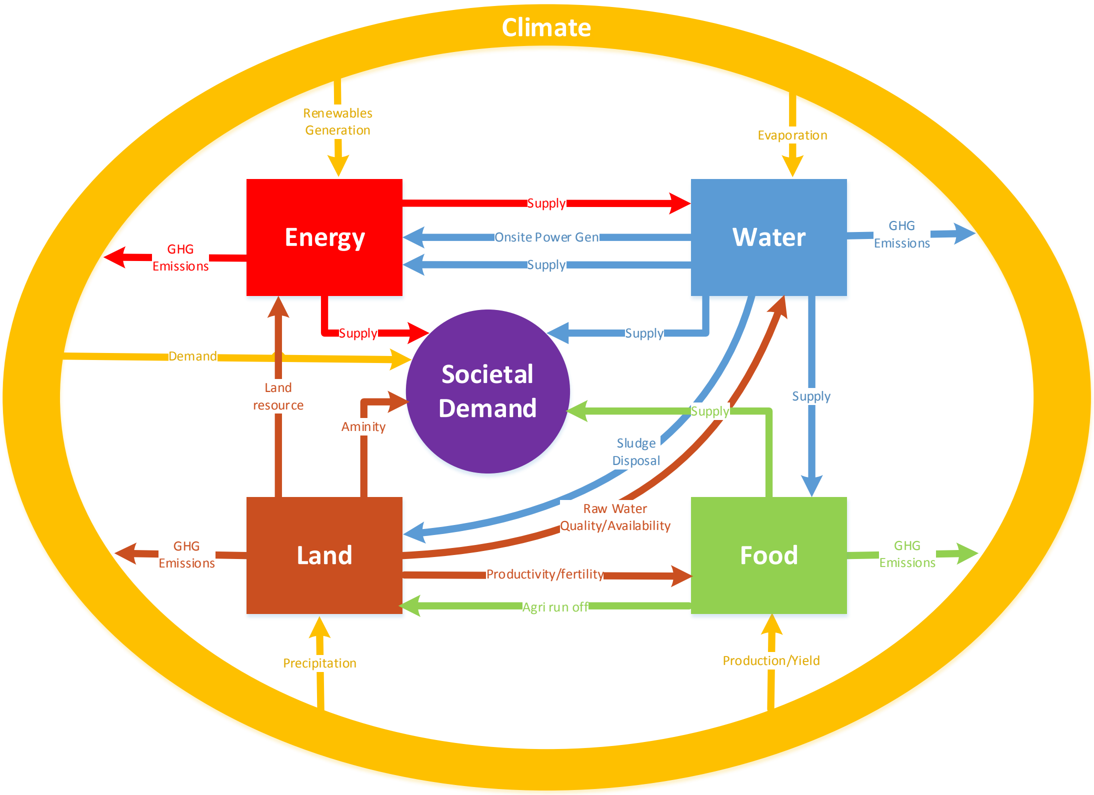
Water to land

Within the south-west region the primary means of sludge disposal is to agricultural land or land fill, and at present no alternative means are viable. Therefore it is of major importance to maintain this supply chain route and where possible reinforce it via better management practice. Beyond this, more sophisticated recycling technologies and circular economy options are to be investigated.

Land to water

Land is the main receptor of rainwater, and the use under which the land is placed influences the quality and availability of run-off to surface water, therefore integrated management is key. The south-west region is predominantly agricultural producing arable crops, meat and dairy products which are historically major contributors to poor groundwater quality. The application of ecosystem services is seen as one of the major routes for management in this area.

The initial conceptual model of whole nexus reflects the prioritisation outlined above while expanding the view to consider a broader range of linkages relevant to the water centric perspective.



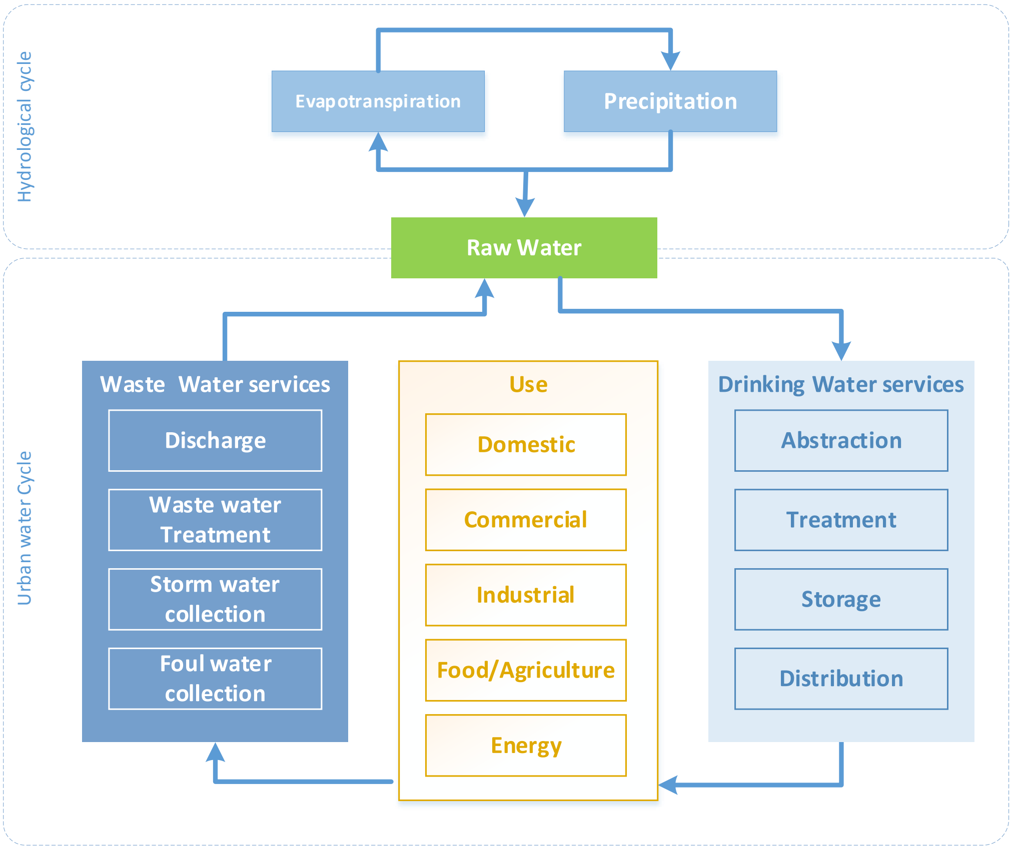
A first step in reducing the internal losses between sectors is likely to be achieved through decoupling of internal demand, by targeted efficiency measures within each sector. For example reducing the energy demand of water treatment by optimising pump efficiency or aeration. Similarly in the energy sector a move from conventional thermal plant towards renewable technologies such as wind and solar reduces operational water demand.

Note:

In the southwest region the only major generator of electricity using thermal based technology is Hinkley Point nuclear power station which sits just outside of SWW's operational region. The majority of energy generated in the southwest region is from renewable technologies. It is therefore unlikely that there is much scope for reducing water demand of energy generation in the southwest region, but the linkage remains of high priority for the water industry as a whole.

Following the creation of the initial conceptual model the next stage is to examine individual sectors in greater detail. The first sector to be examined in this way is the water sector where the greatest knowledge is held. Within the expanded view of the water sector two primary components can be seen; the natural hydrological cycle and the urban water cycle which interface via the raw water resource.

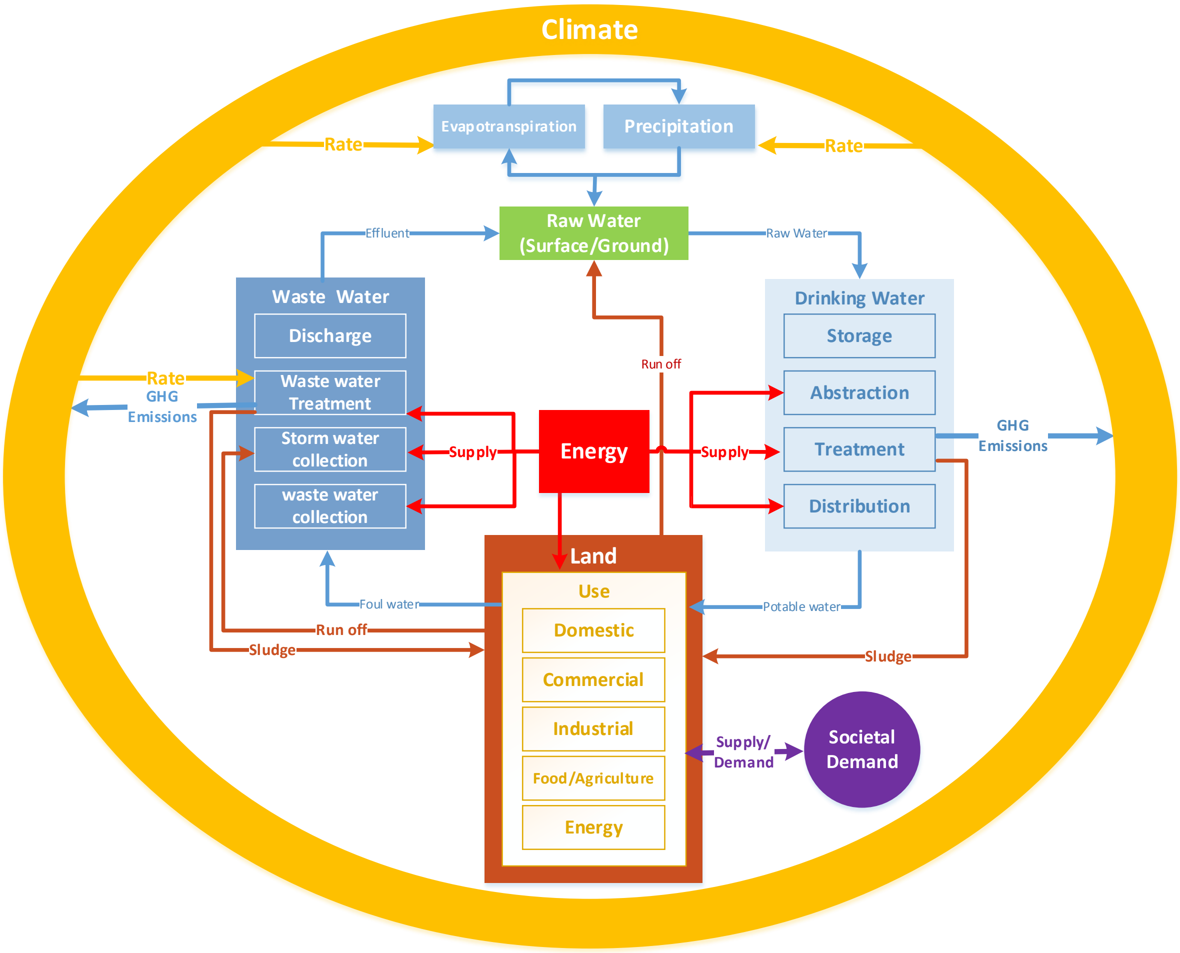
Expanding the "water sector" with a water centric view of the nexus:



The view here of the hydrological cycle is reduced to the two main components of evapotranspiration and precipitation. While numerous other elements exist within the hydrological cycle these two components are most instructive in modelling terms.

Within the urban water cycle three major events can be seen; Drinking Water Services, Wastewater Services and Use. Each of these components are in themselves systems of subsystems which can be further broken down. This is planned to occur during the SDM modelling phase.

By taking the expanded view of the water sector it becomes possible to reapply nexus linkages to better understand the relationships. In the below graphic these linkages are added but neglect the linkages between the additional sectors themselves.



Next steps in the development of the conceptual model is to expand the internal view of each sectoral component following the above methodology.

1.4 Use of thematic models in understanding the Nexus

The project teams for E3ME, GTAP CAPRI and PIK have been contacted to provide data. Further work is need to refine the policy questions before full understanding of how these models will feed the conceptual model is possible.

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

As the incumbent water and waste water supplier of the south west region, South West Water has a regulatory obligation to consult key stakeholders as part of the normal business planning process. By leveraging these well-established relationships it has been possible to rapidly open dialogue with suitable contacts within each organisation. This was achieved by first identifying likely individuals known to have interest in related fields and making contact to gage interest in the nexus approach. Initial meetings where arranged to describe and introduce the sim4nexus project and then invite delegates to attend workshop sessions.

Note: The first workshop is scheduled for 25th January 2018.

Due to the transparent structure of the UK regulatory system is was possible to perform preliminary mapping of the stakeholder relationships before workshop sessions. Clarification and nuance of these maps will be explored during the workshops. More detail of stake holder mapping is given in the work package 2 Policy Analysis block 1 report.

2 Conclusions and follow-up

Thus far the development of the conceptual model and policy analysis are the main achievements.

Work has begun on the system dynamics model, and the waste water treatment module is progressing well. The next stage is the drinking water module. We have established a basic excel model of the resource management element of this system and will begin implementing in the SDM framework in January.

The next major steps will be the stakeholder workshops and use of the thematic models. This will enable several sections of this report to be moved forward.

3 Bibliography

Cabinet Office. (2008). *National Risk Register.*

DEFRA. (2012). *UK Climate Change Risk Assessment .*

European Parliament. (2000). *Water Framework Directive - 2000/60/EC.*

HM Gov. (2012). *Water Act.*

OFWAT. (2010). *Delivering sustainable water – Ofwat's strategy, Water today, water tomorrow.*

OFWAT. (2014). *OFWAT Playing Our Part.*

OFWAT. (2015). history & privatisation accessed 2015.

OFWAT. (2015). *OFWAT Glossary of terms.*

OFWAT. (2015). *OFWAT Resilience Task and Finish Group final report.*

OFWAT. (2016). *Water sector overview.*

South West Water. (2012). *Water future, Our Vision.*

The Cabinet Ofice HM.Gov. (2008). *National Risk Register of Civil Emergencies.*

UKWIR . (2007). *The regulatory cycle and its impact on the efficiency of supply chain delivery Report Ref. No. 07/RG/10/4.*

UKWIR. (2006). *The UKWIR report Ref No: 06/RG/10/1 Barriers to Innovation in the UK Water Industry.*

WaterUK. (2015). *climate-change.*

Este, L. I. (2011). LA Lore Ipsiunm. Lorem Journal , 30-34.

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

D5.2: THE MAIN NEXUS CHALLENGES IN 'THE NETHERLANDS'

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Glossary / Acronyms

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

TERM	EXPLANATION / MEANING
BECC	BIO ENERGIE CENTRALE CUIJK
BTG	BIOMASS TECHNOLOGY GROUP BV
CAPRI	THE COMMON AGRICULTURAL POLICY REGIONAL IMPACT (CAPRI) MODEL
CBS	CENTRAAL BUREAU VOOR DE STATISTIEK/STATISTICS NETHERLANDS
CLM	
ECN	ENERGIEONDERZOEK CENTRUM NEDERLAND/ENERGY RESEARCH CENTRE OF THE NETHERLANDS
E3ME	E3 (ENERGY-ENVIRONMENT-ECONOMY) MACRO-ECONOMETRIC MODEL.
GW	GIGAWATT
HLPE	HIGH LEVEL PANEL OF EXPERTS ON FOOD SECURITY AND NUTRITION OF THE COMMITTEE ON WORLD FOOD SECURITY,
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
LULUCF	LAND USE, LAND-USE CHANGE AND FORESTRY
LTO	LAND- EN TUINBOUW ORGANISATIE)/THE DUTCH FEDERATION OF AGRICULTURE AND HORTICULTURE, AN ENTREPRENEURIAL AND EMPLOYERS’ ORGANISATION.
MAGNET	MODULAR APPLIED GENERAL EQUILIBRIUM TOOL, MAGNET IS A GLOBAL GENERAL EQUILIBRIUM MODEL
MTON	MEGATONNES
NGO	NON-GOVERNMENTAL ORGANISATION
NUTS2	NOMENCLATURE OF TERRITORIAL UNITS FOR STATISTICS, SECOND LEVEL
PBL	PLANBUREAU VOOR DE LEEFOMGEVING/NETHERLANDS ENVIRONMENTAL ASSESSMENT AGENCY
PJ	PETAJOULES
PROBOS	PROBOS IS AN INDEPENDENT NON-PROFIT INSTITUTE FOR FORESTRY, FOREST PRODUCTS AND SERVICES.
RCP	REPRESENTATIVE CONCENTRATION PATHWAYS
RVO	RIJKSDIENST VOOR ONDERNEMEND NEDERLAND/NETHERLANDS ENTERPRISE AGENCY
SDM	SYSTEM DYNAMICS MODEL
SER	SOCIAAL-ECONOMISCHE RAAD/THE SOCIAL AND ECONOMIC COUNCIL OF THE NETHERLANDS
SG	SERIOUS GAME
SIM4NEXUS-NL	THE NETHERLANDS CASE STUDY OF SIM4NEXUS
SSP	SHARED SOCIAL-ECONOMIC PATHWAY
STOWA	FOUNDATION FOR APPLIED WATER RESEARCH/STICHTING VOOR TOEGEPAST WATERONDERZOEK

TERM	EXPLANATION / MEANING
TOE	TONNES OF OIL EQUIVALENTS
UVW	UNIE VAN WATERSCHAPPERN/DUTCH WATER AUTHORITIES
WUR	WAGENINGEN UNIVERSITY AND RESEARCH
WWF	WORLD WILDLIFE FUND
WWR	WORLD WIDE RECYCLING GROUP

1 Introduction

1.1 Description of the Nexus challenges

1.1.1 Background

The Paris UNFCCC agreements and EU Energy and Climate goals and targets are leading, which means an 80-95% reduction of GHG emissions in 2050 compared to 1990. The CO_2-equivalent emissions in the Netherlands declined between 1995 and 2014 but in 2015 there was an increase mainly due to an increase of the coal and natural gas generated energy by the electricity producers, see Figure 1 (Statistics Netherlands 2015). The main GHG emitted was CO_2, which has been fairly stable since 1990. The other GHG emissions, such as CH_4 and N_2O-emissions, declined between 1990 and 2015. Agriculture is responsible for the majority of CH_4 and N_2O-emissions and for 12.5% of total Dutch GHG emissions (measured in CO_2 equivalents). Sources of agricultural emissions are animal production, the use of fertilizer, the use of fossil fuels for pumping, heating and tractor use, see agrimatie.nl.

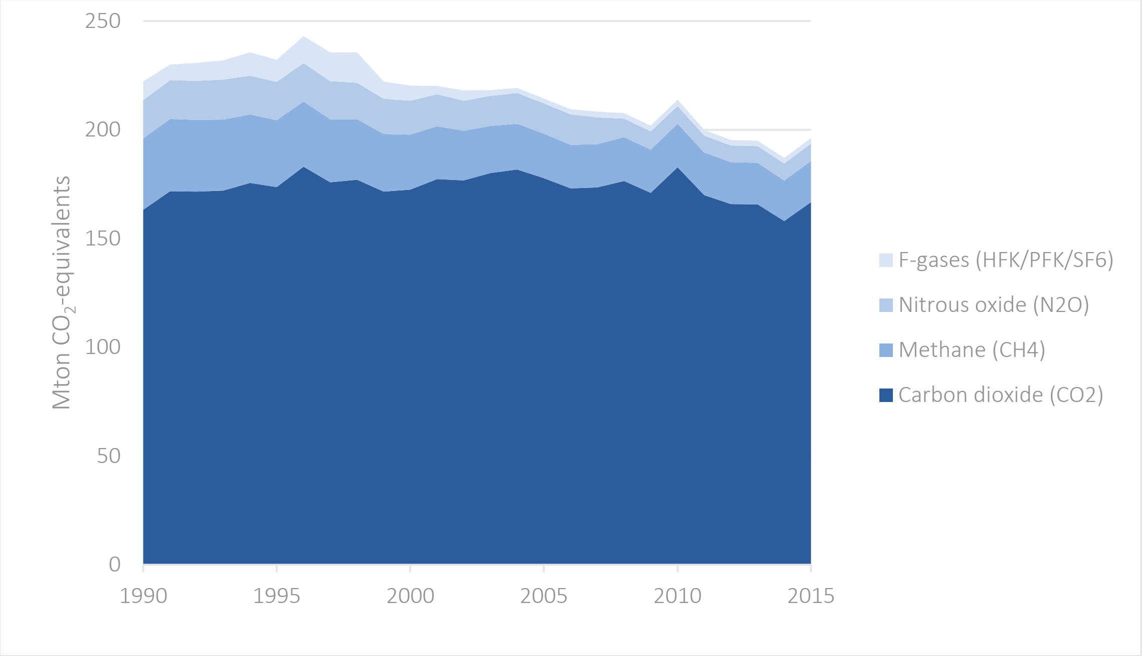

Figure 1: Greenhouse gas emissions (Mton-CO_2-eq.) in the Netherlands, 1990-2015. Source: statistics Netherland, www.clo.nl

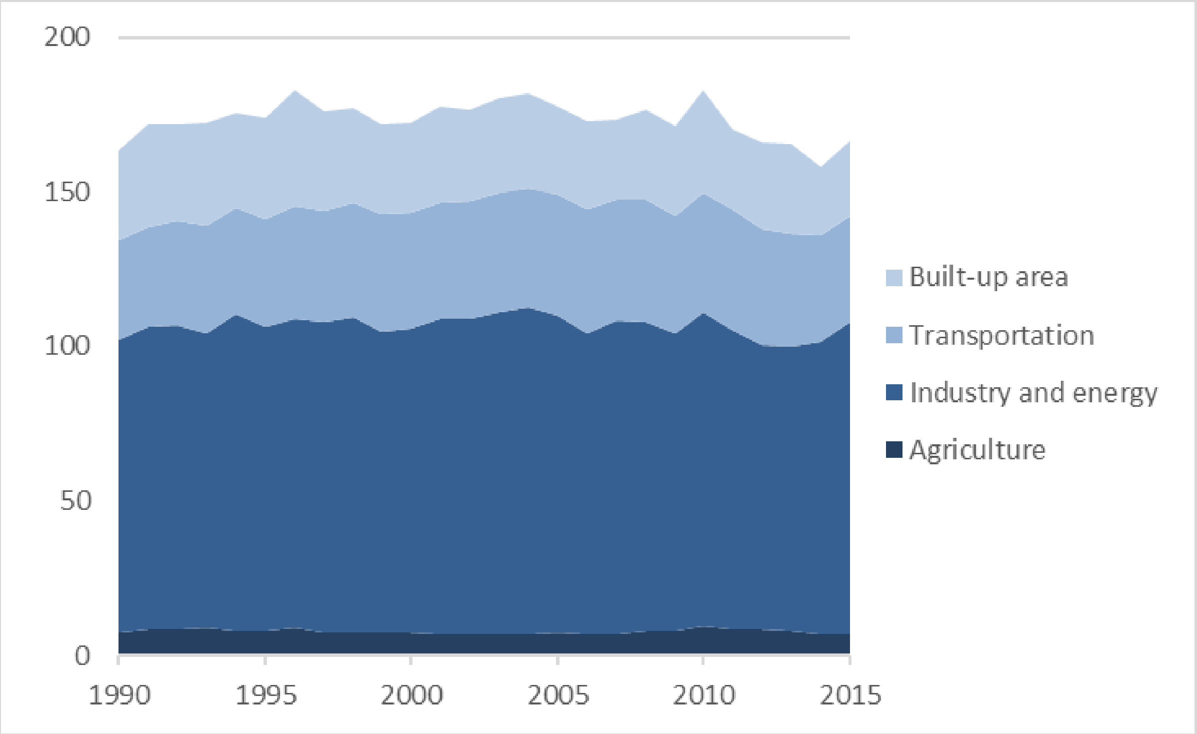

Figure 2: Carbon dioxide emissions (Mton-CO_2-eq.) per sector in the Netherlands, 1990-2015. Source: statistics Netherland, www.clo.nl

In 2015, the manufacturing and energy sectors were responsible for 60% of the carbon dioxide emissions in the Netherlands, see Figure 2. In addition, transportation counted for 21% of the carbon dioxide emissions, and the built-up area for almost 15%. Although agriculture was responsible for only a small share (4.4%) of the carbon dioxide emissions in the Netherlands, the carbon footprint of Dutch food consumption was substantial, as it included emissions from the whole value chain, e.g. the food processing industry and transport (Prins and Ros 2014).

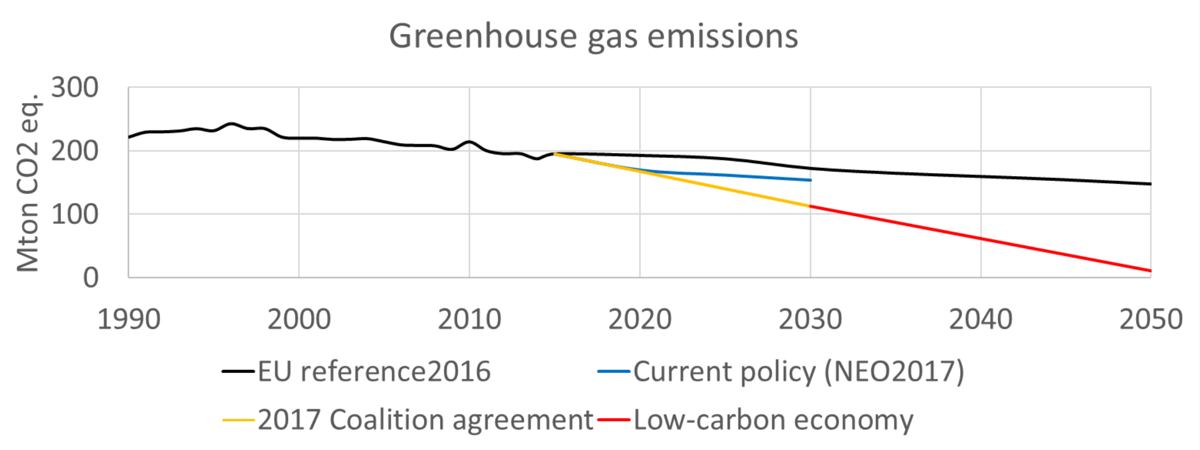

Figure 3: Ambitions for the reduction of greenhouse gas emissions (Mton-CO_2-eq.) according to different governmental documents. Sources: European Commission (2016), 2017 Coalition Agreement (VVD, CDA, D66 & ChristenUnie. 2017) and Schoots et al. (2017)

Figure 3 presents the projection of greenhouse gas emissions in the Netherlands and the ambitions of the Dutch government. According to the predictions of the European Commission in 2016, the GHG emissions (black line in Figure 3) will slightly decline towards 2050 with the largest decline after 2020 (European Commission 2016). This trend is mainly due to the implementation of energy saving technologies by producers and consumers. According to the National Energy Outlook 2017 (Schoots et al. 2017), which reflects the current and intended policy (blue line in Figure 3) until 2030, the GHG emissions will decline, but not sufficiently to be on the track to realise a low-carbon economy in 2050 (red line in Figure 3). The 2017 coalition agreement in the Netherlands formulated a target for GHG emission reduction between 49-55 percent in 2030 compared to the emission level in 1990. This is a target which is proportionate to a 95% reduction in 2050. The main contribution to the reduction will come from CCS. The low-carbon economy corresponds to a maximum emission level of 11 Mton CO_2-eq. in 2050. Note that GHG emissions from international shipping (8 Mton CO_2-eq. in 2013) and LULUCF (4 Mton CO_2-eq. in 2013) are excluded from the emission targets, see Tabel 2.1 in (Ros et al. 2016).

To reach a low-carbon economy in 2050, Ros et al. (2016) identified five categories of technological measures:

1. energy saving;
2. production of electricity without CO_2 emissions;
3. transition from oil/gas to electricity (electrification);
4. bio-energy, and
5. carbon capture and Storage (CCS).

Ros et al. (2016) argued that a mix of all these measures is necessary to reach a low-carbon economy in 2050. However, it is not clear yet how successful these measures can be implemented and what policy mix is required to change the economy in the Netherlands into the direction of a low-carbon economy. All these technological measures will have different consequences for GHG gases emissions, the production and use of energy and food, and the use of and consequences for water and land. These technological options will have socioeconomic consequences. Moreover, policies and socioeconomic interventions can contribute to the reduction of GHG emissions. These societal consequences or their cost-effectiveness have not yet been evaluated. For instance, energy saving can be realised with replacing energy-intensive technologies with less energy-intensive technologies or in some cases by non-energy requiring technologies.

1.1.2 Bio-energy

One of the options is the use of bio-energy. The advantage of bio-energy is that the reliance on fossil fuels declines and under sustainability conditions, it may contribute to the reduction of GHG emissions. Whether it does is one of the major subjects for discussion between supporters and opponents of the use of biomass for energy generation, and depends on the type of biomass, definitions and time horizon. Also, the change to higher production of bioenergy can have implications for water, land, and food (see Table 1) and the economy as a whole. Table 1 is based on the interlinkages identified and presented in SIM4NEXUS Deliverable 1.1 and only the interlinkages considered in the Dutch case are included. The cultivation of energy crops may compete with the production of food and fodder crops leading to increasing food and fodder prices. This can lead to indirect land use change which eventually can lead to even more emissions than fossil energy usage (PBL 2013; Popp et al. 2014). This ambiguous nature of biofuels has resulted in biofuel debates worldwide and actions in policy-making. The UN Committee on World Food Security (CFS) recommended in October 2011 a review of biofuels policies in relation to food security so that “they can be produced only where it is socially, economically, and environmentally feasible to do so” (HLPE 2014).

In 2015, The Netherlands produced 2,041 PJ energy, of which 5.6% was generated from renewable resources (Schoots et al. 2017). Nearly 2/3 of this renewable energy was generated from biomass. Biomass produced in The Netherlands is composed of 35% waste, 39% wood from various sources, 13% biogas from manure and sewage waste and the rest from other sources. There is potential to increase the production of biomass in The Netherlands from 80 PJ in 2015 (Schoots et al. 2017) to a maximum of 200 PJ (PBL 2013), which is insufficient to meet the 800-1,600 PJ energy required to meet the low-carbon economy targets. The rest needs to be imported from sources that meet sustainability criteria. These criteria are described in the EU Renewable Energy Directive II and currently under discussion. According to stakeholders, the market for biomass has an international dimension, especially if it will play a substantial role in the Dutch energy mix in the future. An international approach may connect the Dutch case to the European and global cases. It is worthwhile to investigate if the Dutch case could be imbedded in a European and global context.

Table 1. Interlinkages considered in the Dutch case study

	affected component				
changing component	climate	water	food	land	energy
climate		Availability of fresh water			
water				Shortage of fresh water limits the productivity of land	Water is a production factor for energy production (biomass)
food		Water footprints of food consumption in the NL		Land is production factor for food. Changes in diets (protein) and renewable energy preferences affect land use; land footprint	Energy used for food production; food crops for renewable energy.
land		Agriculture impact on water quality	Availability of land for food crops		Availability of land for food crops and fibre
energy	Impact of energy transition on climate (GHG emissions)	Water pollution (e.g. nutrients and pesticides in case of biomass, temperature rise by cooling water) and use for energy production. Energy for water management, water pumping and irrigation	Energy is a production factor for food. Competition between biomass and food production for available water, land, energy; impact on food prices and food security	Land use for energy production, ILUC	

One of the characteristics of biomass is that it is very diverse with respect to energy content, storage potential, production cost, cost-effectiveness, etc.. Also, for particular activities that rely on fossil fuels nowadays such as economic shipping, air transport and freight transport by road, bio-energy or bio-fuels are the only low-carbon alternative (Ros et al. 2016). Large-scale biomass production such as wood pellets is interesting for co-firing in coal power plants.

Table 2: Types of biomass for bioenergy production in the Netherlands in 2015 and their shares

TYPE OF BIOMASS	SHARE IN 2015 (%)
HOUSEHOLD WASTE AND INDUSTRIAL WASTE FOR COMBUSTION IN WASTE INCINERATION PLANTS	34.8
LOGS AND SCRAP WOOD (A-WOOD) FOR USAGE IN HEATERS AND BOILERS	17.8
PRUNED CUTTINGS	11.4
BIOGAS FROM FLUID MANURE	7.2
B-WOOD (PAINTED, LACQUERED, OR GLUED WOOD)	6.1
WOOD PELLETS	3.5
WET RESIDUES FROM FOOD PROCESSING INDUSTRY	3.2
ANIMAL FAT	3.2
BIOGAS FROM SOLID MANURE	3.0
BIOGAS FROM SEWAGE TREATMENT WASTE	2.7
BONE MEAL	2.6
RESIDUES FROM AGRICULTURE	0.1

Source: (Schoots and Hammingh 2015), p. 64

To illustrate the many various aspects of bio-energy, Table 2 shows the shares of types of biomass in the total energy production from biomass in 2015 in the Netherlands. Currently, more than one third of the biomass used for energy is waste from households and industries that is incinerated. The share of wood pellets is 3.5 percent, see Table 2. Projections for the future indicate a large increase of the share of wood pellets for bio-energy production in the Netherlands which ranges from 800-1,600 PJ in 2050, i.e. 42-84 percent of the current final energy consumption for 2050 (1,900 PJ). The maximum capacity of biomass production or collection in the Netherlands is estimated at 200 PJ, (PBL 2013). So, additional energy production from biomass would rely on imports of biomass (mainly wood pellets). Currently, the share of biomass primary wood pellets for electricity production amounts 3.5 percent.

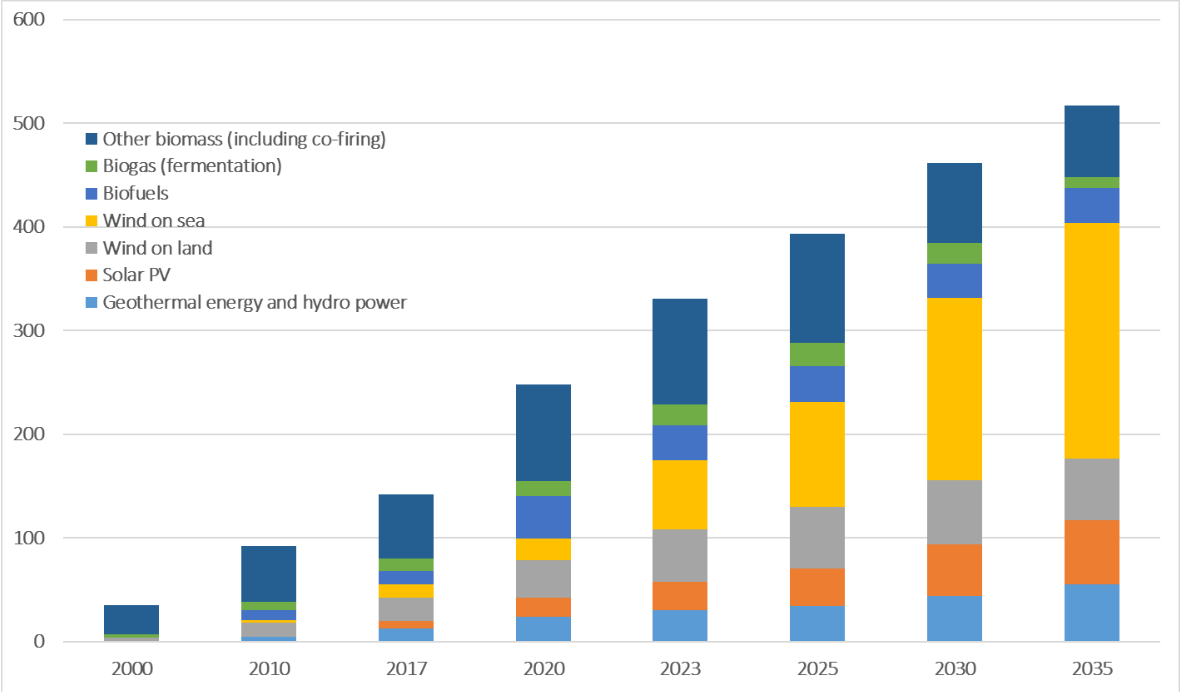

Figure 4: Development of the gross final renewable energy use in the Netherlands. Source: Schoots et al. (2017).

Given the current policies on the energy transition towards renewable energy, the share of renewable energy in total energy use is expected to be 16.7 percent in 2023 (Schoots et al. 2017), see Figure 4. The increase is 30 percent compared to 2020 and is due to large investments in large scale wind power projects at sea and solar energy projects. The energy derived from biomass will increase slightly between 2020 and 2023, because of the restrictions to physical capacity of co-firing and financial capacity in the renewable energy subsidies. The predictions for the share of renewable energy after 2023 largely depend on assumptions about the policy on renewable energy. (Schoots et al. 2017).

1.1.3 Objective and main challenges

The overall objective of the Dutch case study in SIM4NEXUS is to identify low-carbon and resource-efficient pathways for the water-land-food-energy nexus in 2050. In particular, what can be the role of biomass in the transition to a low-carbon economy in 2050 considering the interaction with water, land, energy, food and climate. Biomass will be needed to achieve the 95 percent GHG emission reduction to develop a low-carbon economy in 2050. However, the application of biomass needs to be sustainable and therefore has requirements and limitations. The main nexus challenges are:

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

1.2 Description of the pathways

1.2.1 Baseline scenario SSP2

For the future projections of the case study, the SSP2 scenario of the IPCC is taken as the baseline scenario. The IPCC is the intergovernmental panel on climate change which is a large group of scientist which have constructed five pathways for the future based on five different demographic and socioeconomic projections. The SSP2 scenario is described as the Middle of the Road scenario with medium challenges to mitigation and adaptation (Riahi et al. 2017). They state that:

> "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, Global and national institutions work toward but make slow progress in achieving sustainable development goals. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Global population growth is moderate and levels off in the second half of the century. Income inequality persists or improves only slowly and challenges to reducing vulnerability to societal and environmental changes remain."

The exact consequences for the Netherlands and the baseline development of its key indicators are not known yet. The results for the Netherlands of the SSP2 scenario from the thematic models (see section 2.4) are not yet analysed. Key indicators include the share of renewable energy, GHG emissions, energy produced out of (imported) biomass, amongst others.

1.2.2 Pathways

The pathways for the Dutch case study are still in progress. As mentioned in Deliverable D5.1, the Dutch case study will use RCPs indicated by the SIM4NEXUS project and other SIM4NEXUS case studies such as the European case study and the Latvian case study, which focus on the same nexus challenge "a low-carbon economy in 2050". In this way we can compare our case study results for the different pathways with the other case studies. The use of different types of biomass for energy production will have a key role in the pathways.

The new Dutch government presented her Coalition Agreement (VVD, CDA, D66 & Christen Unie, 2017) in October 2017 in which she presented ambitious reduction targets of 49-55 percent of GHG emissions for 2030. Perhaps, these ambitions coincide with one of the RCPs considered, otherwise it could be considered as a separate pathway. The goals in the Coalition Agreement will have to be realised with investments in renewable energy, energy saving and CCS.

In general, the SDM for the SIM4NEXUS case studies is likely to work with monthly time steps, although we prefer annual time steps. For the pathways and the policy instruments, we will use ten years intervals for adjustment of policies, i.e. 2020, 2030, 2040 and 2050, although we would prefer five years intervals for policy changes in the SDM and in the SG.

1.2.3 Policy instruments or measures to be considered

The exact policy instruments are not yet set but will be subject of the second workshop. The list of measures and instruments considered in the Dutch case include:

- Stimulate investments in renewable energy (wind, solar, biomass);
- Stimulate investments in energy saving;
- CCS at seas;
- Financial instruments like levies on fossil fuels (on top of the CO_2 emission trading price), subsidies on the investments on renewable energy, energy saving and CCS, import tariffs on carbon intensive products, for instance;
- Framework: adjustment of regulation so that it becomes easier to apply biomass for energy application (as in the case of manure for instance);
- A scientific-based dialogue on biomass with pros and cons;
- Enforcement of current legislation related to biomass;
- Create a level playing field for biomass at European level, and create a level playing field between different resources (environmental costs of fossil fuel use are not internalised in the fossil fuel prices);
- Collective agreements with the economic sector such as biomass sector, agriculture etc. on GHG emissions reduction.

1.3 Develop a conceptual model

Based on the challenges formulated in section 2.1, we will focus on the role of biomass in the transition towards a low-carbon (and fossil fuel poor) economy with sustainable use of water and land. In our case study, the interplay between food production, water, energy, climate and land is central, see Figure 5. Next to the technological options, we also pay attention to behavioural aspects of economic actors and the possible policies to be implemented. Note that we define policies in close collaboration with all relevant stakeholders to reflect a participatory approach of policy making. The conceptual model for the Dutch case starts from the NEXUS framework as given in Figure 5. The components distinguished in Figure 5 are included in our conceptual framework: climate, energy, water, food and land. In addition, the socio-economic frame is added as containing driving forces for developing a low carbon economy.

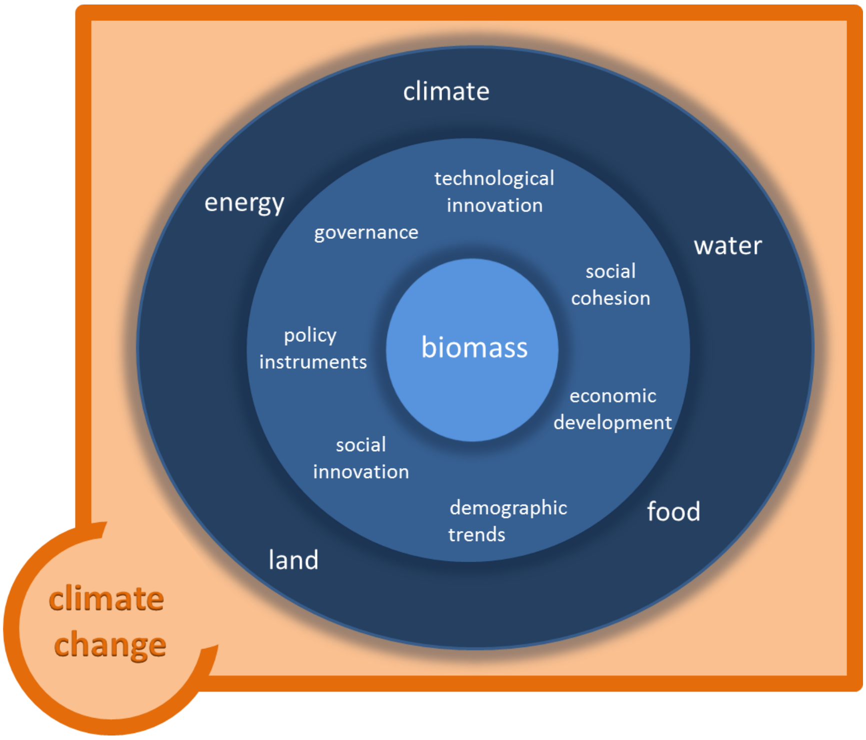

Figure 5: The water-food-energy-land-climate nexus

Figure 6 presents the conceptual framework of the system elements (boxes) and interlinkages (arrows) of the nexus challenges of the Dutch case-study. The system elements include the nexus elements in the outer circle of Figure 5 as well as the socioeconomic system, and agriculture. The system elements reflect the different subsystems considered. The systems consists of 7 sub-systems: energy/biomass, climate, land, water, food, socio-economic and agriculture. The links between the different sub-systems are illustrated in Figure 6, and will be described below. Note that the conceptual model in Figure 6 is under development. The subsystems will be elaborated on.

In particular, the energy subsystem is divided into energy from biomass and energy from other sources of energy (fossil fuels and other renewables). The socio-economic system consists of drivers such as

demographic trends, economic development and innovation. Agriculture includes arable farming, animal husbandry and forestry.
The arrows in Figure 6 reflect the different connections (flows) between the different system elements.

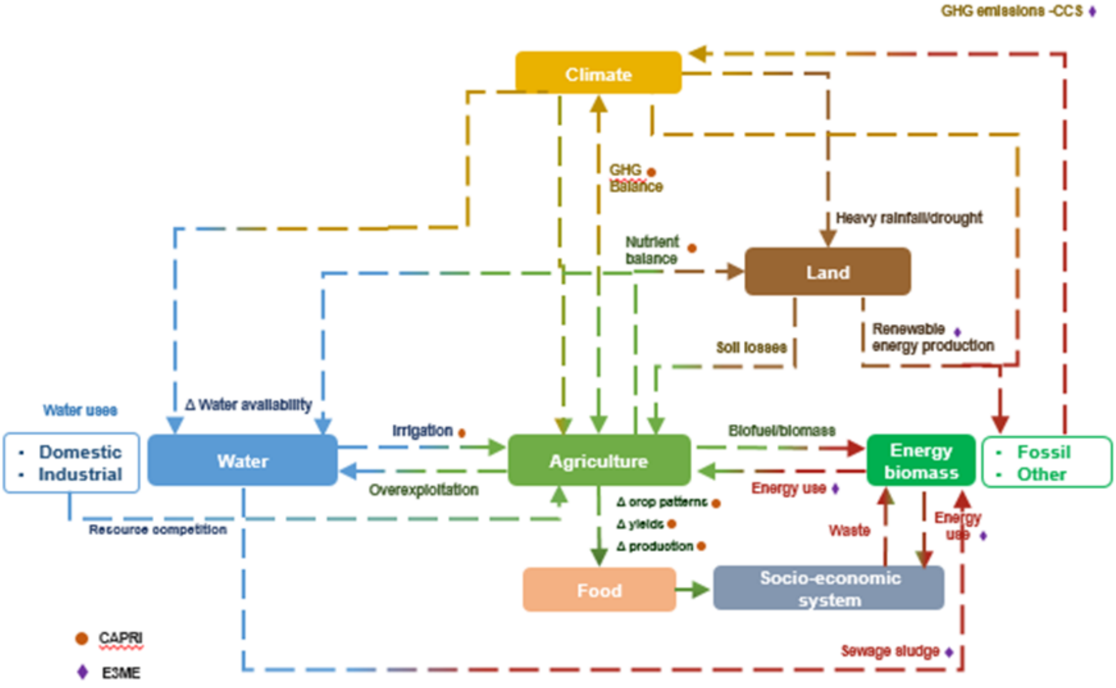

Figure 6: Conceptual framework (December 2017) for the role of biomass in a low-carbon economy in the Netherlands with sustainable use of water and land.

Energy including biomass

The energy system consists of two subsystems, The energy from biomass system affect agriculture (energy use such as biogas) and the socioeconomic system (transport). It is affected by agriculture (biomass/bioenergy), water (biogas from sewage sludge) and the socioeconomic system (waste from households and industrial waste for incineration). The energy from fossil fuels and other renewable energy types are affected by the available land for solar and wind and the socioeconomic system (drivers of total energy demand/consumption including duel for transportation). It affects climate through GHG emissions from energy production from fossil fuels, agriculture and (supply of energy).

Climate

Changes in climate affect the availability of water, crop growing conditions for agriculture and most likely increase biomass production and extreme weather conditions (heavy rainfall/droughts). Climate is affected by the GHG emissions from energy production and agricultural production. Part of the GHG emissions will not contribute to climate change because of carbon capture and Storage (CCS).

Land

The land subsystem affects agriculture by the availability of land, water through the run-off of nutrient emissions to water and the land use for renewable energy production (wind, and solar). Land is affected by the nutrients from agriculture and the extreme weather events (heavy rainfall/droughts).

Water

The water subsystem affects fossil energy production (cooling water), agricultural production (irrigation) and energy from biomass production (biogas from sewage sludge). It is affected by climate (water availability), agriculture (overexploitation of fresh water resources) and land (nutrient emissions from runoff).

Food

The food is affected by agriculture (supply of food commodities) and food availability affects the socioeconomic system i.e. the consumption of food.

Socioeconomic system

The socio-economic system consists of drivers such as demographic trends, economic development and innovation. It affects the energy sector in several ways. The drivers affect the energy consumption, and food consumption. It also effects energy from biomass through the household waste and waste from industries used as in waste incineration plants to produce energy.

Agriculture

Agriculture includes arable farming, animal husbandry and forestry. Agricultural land-use marks the landscape and affects soil, water and air, including the emissions of GHGs. In our framework. Agriculture affects land (emissions of nutrients), water (overexploitation of fresh water), energy from biomass (biogas from manure, and agricultural residues and biofuels from bioenergy crops), and climate (GHG emissions). In addition, agriculture affects food with supply of several food commodities. Agriculture is affected by climate (better crop growing conditions, worse crop growing conditions due to extreme weather events), water (irrigation), energy (energy use), land (availability of land for agriculture).
Climate change also has an indirect effect on agriculture via land. Extreme weather can lead to soil losses and reduced agricultural and biomass production. Agriculture produces food and fibre and is therewith linked to the rest of the socio-economic system. Within agriculture, both growing crops and keeping livestock are important. Livestock is dependent on land for fodder production. Manure from livestock can be used for energy production.

Biomass

Biomass and its application for energy production are the central elements in the case study for the Netherlands. It relates to all nexus elements and therefore all nexus subsystems (water, land, agriculture, food, energy.. In particular, the following subsystems “produce” biomass intentionally or unintentionally:

- Agriculture: first and second-generation biofuels and other bio-energy,
    a. Energy crops
    b. Biogas from manure
    c. Energy from crop residues
    d. Carbon sequestration, ‘negative production’.
- Socio-economic: waste (biodegradable and non-biodegradable)
- Water: sewage sludge, algae

For convenience, imports and export of energy and biomass are not explicitly included in the conceptual model in Figure 6. They are however very important for the Dutch case because it is not expected that the Netherlands can produce the biomass needed within the borders of the country.

1.4 Use of thematic models in understanding the Nexus

In SIM4NEXUS deliverable 4.1, we have indicated that we will use three thematic models in the case study of the Netherlands: MAGNET, CAPRI and E3ME. This section describes in detail the list of indicators that will be derived from the different thematic models. A number of indicators in the Dutch case study can be obtained from more than one thematic model, such as the fodder imports, see tables 3 and 4. We will request for indicators from both models to check for consistency across the results of the thematic models. For a number of indicators, we also have "backup" sources (databases from Statistic Netherlands or results from alternative models such as DRAM, i.e. the agricultural economic model for the Netherlands) in the case that the indicators of the thematic models are different than expected. The next sections present the lists of variables resulted from MAGNET (section 2.4.1), CAPRI (section 2.4.2) and E3ME (section 2.4.3). For a small number of indicators, we will use alternative sources, see section 2.4.4.

Note that we will only use the data for the Netherlands in the case of the global model MAGNET and we will use the NUTS2 level data in the case of CAPRI and E3ME, so that we are able to distinguish different regional divisions in the Netherlands up to the individual provinces (NUTS2 areas in the Netherlands).

1.4.1 MAGNET

From MAGNET we will use variables relevant for the socio-economic system, see Table 3. These variables are important drivers for the demand for biomass in the Dutch economy. The data will be complemented with national statistics from different sources. For Dutch scenario's we will use results of the National Scenario Studies (WLO, http://www.wlo2015.nl/). Statistics Netherlands will be used for supplemental data on population.

Table 3: Concept list of variables from MAGNET

Variable	Unit	Alternative (from other thematic model)	Categories of indicator
Dutch population	number		
GDP	€ bln		
Urban land use	m^2, ha or km^2		
Demand for food	€ bln		
Demand for energy	€ bln and PJ		
Food import	€ bln		
Food export	€ (or ton) per year	CAPRI	
Fodder import	€ (or ton) per year	CAPRI	

1.4.2 CAPRI

CAPRI is an agricultural-economic model for the EU at the level of NUTS2. It projects scenarios of land use based on policy instruments and autonomic changes. For the Dutch case study, there are many variables with respect to land use mainly with agricultural activities, see Table 4. The Netherlands and its provinces (NUTS2 level) are distinguished by CAPRI as well as many crop, fodder and livestock production types.

Table 4: Concept list of variables from CAPRI

Variable	Unit	Alternative (from other thematic model)	Categories of indicator
Agricultural and forestry land use	m^2, ha or km^2		
Energy crop land area	Ha		
Food crop land area	Ha		
Fodder crop area	Ha		
Grass land area	Ha		
Food products	€ (or tonnes) per year		All categories distinguished
Food crop residues	PJ (or tonnes) per yeare	E3ME	
Fodder crop products	€ (or tonnes) per year		All categories distinguished
Livestock	€ (or tonnes) per year		All categories distinguished
Manure	PJ (or tonnes) per year	E3ME	All categories distinguished
Food export	€ (or tonnes) per year	MAGNET	All categories distinguished
Agricultural and forestry land use	m^2, ha or km^2		
Fodder import	€ (or tonnes) per year	MAGNET	All categories distinguished
Emissions (N and P) from agriculture	Tonnes per year	DRAM	

1.4.3 E3ME

The data listed in Table 5 will be used from E3ME. E3ME produces data on electricity generation by technology (GWh/y) for the period 2010-2050. The focus is however not on production but on demand. For power generation a number of energy technologies on electricity capacity (GW) and generation (GWh/y) will be used:

1. solid biomass;
2. solid biomass CCS ;
3. biomass integrated combined cycle gasification (BIGCC);
4. BIGCC plus CCS ;
5. Biogas ; and
6. Biogas + CCS.

For final demand (in toe) we will use information on combustible waste and biomass for different users. It is not possible to distinguish between types of biomass. For example, it will be possible to say how much biomass the road transport uses, but not what type of biomass. E3ME will provide data on CO_2 emissions by sector, employment (thousands of people) and value of production (€ bln).

Table 5: Concept list of variables from E3ME

Variable	Unit	Alternative (from other thematic model)	Categories of indicator
Solar power production	PJ		
Wind power production	PJ		
Biomass production	PJ		
Manure	PJ (or ton) per year	CAPRI (or DRAM)	All categories distinguished
Bio-waste NL	PJ		All categories distinguished
Wood	PJ (or ton) per year		?
Food crop residues	PJ (or ton) per year	CAPRI (or DRAM)	All categories distinguished
Non-renewable power production	PJ		Solar, wind, hydro
Energy imports	PJ		All categories distinguished
Energy export	PJ		All categories distinguished
Biomass imports	PJ		All categories distinguished
Energy supply to socio-economic system	PJ		All categories distinguished
Energy supply to agriculture and forestry	PJ		All categories distinguished

1.4.4 Other sources

Table 6: List of variables from other sources

Variable	Unit	Source	Categories of indicator
Bio-energy sources and uses (e.g. 1st and 2nd generation)	PJ	National supplementary statistics	All 1st and 2nd generation types
Wood land area	Ha	WLO	

1.5 Engaging stakeholders in the case study

Based on the central issue of the case 'the role of biomass in reaching a low-carbon economy', we have identified organisations which are involved in this field and which would be potential users of the results of this case-study and the SG. Many public-private covenants have been concluded such as the Dutch Energy Agreement for Sustainable Growth (SER 2013, 2015). Within these covenants public and private parties collaborate on sustainable growth, including a low-carbon economy. Stakeholders include

- Companies such as
  - the energy sector including bio-energy producers;
  - manufacturing sectors with high carbon footprints and with clear nexus trade-offs (chemical sector);
  - agriculture and forestry sector; and
  - other sectors;
- National government such as
  - the ministry of Infrastructure and Water - formerly ministry of Infrastructure and the Environment - for policies on water, spatial planning, waste, the environment, and;
  - ministry of Economic Affairs and Climate for policies on energy, biomass and circular economy and climate adaptation policies, nature and forestry;
  - ministry of Agriculture, Nature and Food Quality for policies on agriculture, nature and food;
  - RVO;
- Regional governments – provinces, Dutch Water Authorities (UvW/STOWA) and the individual water boards, and municipalities;
- Public Agency on Nature conservation and forestry – Staatsbosbeheer;
- NGOs on nature conservation and environment, renewable energy;
- Research – ECN, PBL, WUR, CLM, Universities of Utrecht and Groningen.

1.5.1 The stakeholders' process

First, relevant stakeholders involved with biomass were selected, advised by colleagues with expertise in biomass. The first round of stakeholder consultation was done by conducting 15 interviews from various sectors. One of the questions in the interview was who else is relevant for the issue of biomass in The Netherlands and should be involved in the case. In this way the group of relevant stakeholders was built out. Then the project team analysed the type and number of stakeholders involved in interviews, and added missing persons and organizations with an Internet search. Table 7 presents the organisations of stakeholders that have been interviewed for the case study so far.

Table 7: Type of organisations approached to be involved

TYPE OF ORGANISATION	NUMBER OF INTERVIEWS	ORGANISATIONS
NATIONAL GOVERNMENT	2	MINISTRY OF INFRASTRUCTURE AND ENVIRONMENT, RVO

REGIONAL GOVERNMENT	I	OVERIJSSEL
PUBLIC AGENCY	1	STAATSBOSBEHEER
BUSINESS SECTOR (OR REPRESPENTATIVES)	5	LTO, LTO-NOORD, WWR, BECC,
RESEARCH	3	PBL, WUR, ECN
CONSULTANCY	2	BTG, PROBOS
NGO	1	PLATFORM BIO-ENERGIE

Eventually, 55 representatives were invited for the workshop, mainly through email. For those who did not reply to the email, we approached them personally by phone. Then we started the process of briefing the participants with the objective and agenda of the workshop, and a policy brief on the policy analysis for the EU. Eventually, 14 stakeholders (not involved in the research project) participated in the workshop on October 26, 2017.

The main lesson from this process was that a personal, individual invitation often is needed to persuade people to join a workshop. But it takes much time and resources and it must the carefully orchestrated by the team. It is also of great importance to be clear on the main aim of the day, as part of expectation management.

1.5.2 Workshop 1: process

During the workshop the aim of the Dutch case was explained, which is to explore the role of biomass in the transition process towards a low-carbon economy in the Netherlands. In two presentations the problems at stake and the interactions with water, land, energy use, food production and climate were explained. Emphasis was put on the interaction with land and land use in and outside the Netherlands. The options and challenges for the use of biomass for a low-carbon economy were then explored with the stakeholders, which came from national and regional governments, business companies, NGOs and knowledge institutes.

Also, the role of the SG was explained. The project team emphasized that the results of the workshop would be brought into the Serious Game, in order to approach biomass issues from various angles and viewpoints. Only three participants of the workshop had experience with a SG. An important aspect of biomass is the tension between applying biomass for energy generation versus using less natural resources in a resource efficient and circular economy. It was made clear that the advantage of a SG is that the players will experience the effects of their decisions.
During the workshop the stakeholders discussed the barriers and opportunities for increasing biomass production and use for energy generation, and also the solutions that they saw were at hand.

We asked the workshop participants to fill out a questionnaire on the evaluation of the workshop as well as on the involvement the participants in the project prefer. We made minutes and took photos. The main results from the questionnaire were the following:

- The participants concluded that the NGOs from the field of nature were missing, such as Natuur & Milieu, Greenpeace, and/or WWF. In addition, they missed the agricultural sector although they were invited. This was already mentioned during the workshop;
- 10 of the 14 participants filled out the questionnaire on evaluation of the workshop and involvement in the project;
- The workshop was evaluated from partly positive (7) to positive (3);
- Negative feedback: no results, final result is uncertain, biodiversity not included;

- Positive feedback: the consensus approach involved: an instrument with potential to influence policy, the networking character of the workshop (meet new stakeholders and not only the regular ones);
- What is the expected outcome of the project for the stakeholders: influence on the project/Serious Game (8), Knowledge (6), Network (6). Policy (2);
- Which results of the project have your interest? Serious game (8), Analysis of policy and policy coherence (8), Knowledge and information (6), Databases (2), and Models (1);
- Nine out of ten stakeholders would like to stay involved;
- Preferred involvement: Stay informed on the progress and the results (8), Participate in the next workshop (8), Test person for the SG (6), Advisor for the project/SG (3), End-user of the SG (3), Host or co-organizer of project events (1) (related to other H2020 project TRANSLINK).

After the workshop, the project team evaluated the workshop and planned how to communicate the results. We decided to report about the workshop in Dutch, the workshop language. We made an English summary for wider usage. Then we sent a final report on the workshop to the stakeholders. In first instance, we sent a draft to the participants, which they could comment on. Then we sent a final report from the workshop to all those invited. The English summary of the workshop is included in section 2.5.3 and will be included in SIM4NEXUS deliverable 2.2.

The next steps derive from the workshop evaluation questionnaire and its inventory of roles. It has been agreed that we keep the stakeholders posted on the development and that they will be invited for the second workshop. Optionally, we will organise a session for stakeholders to reflect on the conceptual model before the second workshop. In the second workshop the project team will present the first results of the policy coherence analysis. During the second workshop the Serious Game will be enriched with insights from the stakeholders. The project team will also invite missing stakeholders to this workshop and interview some of them.

1.5.3 Workshop 1: summary

Image is imperative to biomass. Today, the image is negative, and this is hampering initiatives due to a lack of trust, uncertainties of the sustainability of biomass and a polarized discussion. This was one of the main findings from the workshop where it was emphasized that biomass is also a broad concept covering consumer waste, agricultural production and residues, wood and other resources. Also, biomass can be used for various purposes, as in new products from various industries or making energy. By discussing it as one single subject, the discussion is blurred. It is important to the view that vested interests in agriculture tend to oppose the road to more sustainability. Not that farmers themselves are against sustainability, but the conditions for working and investing, established by the vested interests, are not supportive for a transition towards a sustainable development.

The policy framework is important to this picture; it is seen as fragmented, subject of frequent change, lacking economic incentives, it is not coherent and many decisions are simply postponed. As dialogue also is scarce, progress in applying biomass in energy production is slow. The consequences for the biodiversity and the ecosystems are severe. The solution is to be found in a systemic approach that appreciates the scope and scale of the issue, which embraces a cascade approach and allows an integration of a multifunctional usage covering the whole value chain. Policy should then support this in a coherent way, based on an enhanced knowledge base. In this way, biomass could be a part of a well-functioning market based on a level playing field with for instance also the indirect effects of fossil fuel and equal international rules of play. This is necessary as the biomass market is an international market, where the role of the Netherlands is limited. The transition should in first instance be an European transition. More collaboration and coherence is then needed, with joint interventions between sectors, regions and countries. Major differences in interests and cultures makes this hard without an enduring dialogue.

For the Serious Game the advice is to develop the SIM4NEXUS-NL emphatically from the aim of the project. The value added must come from the ability for the players to deal with wicked, persistent, problems and make hard choices in a context that reflects the complexity of the reality. These were among the most prominent findings of the workshop where 15 stakeholders from the business sector, NGOs and the government discussed the low-carbon economy in the Netherlands. We emphasize that these findings are not necessarily shared by all participants, they merely represent the issues brought forward during the workshop. We will follow up on these issues in the continuation of the project. See for more in section 3.2.

2 Conclusions and follow-ups

2.1 Main Achievements

2.1.1 Definition of the case: biomass as central issue

Based on Ros et al. (2016), and after discussions with experts in the field of Dutch energy and climate policy, it was decided to focus on the role of biomass in the energy transition to a low-carbon economy in 2050. Reasons for this choice were the connections between biomass, land, water, energy, food and climate, and the scarcity of land and high importance of agriculture in The Netherlands. Ros and Daniëls (2017) concluded that a 95 percent reduction of GHG emissions in 2050 compared to 1990 will only be feasible in The Netherlands if biomass and CCS will be applied. But the supply of sustainably produced biomass is limited and there are numerous demands for biomass. EU and Dutch biomass policy developed the cascade principle that sets out the priority for high-quality use of biomass and puts biomass for energy generation at the lowest cascade level.

The main research question is:

'What can be the role of biomass in the Dutch transition to a low-carbon economy by 2050, considering the interaction with water, land, energy, food and climate?'

With the underlying questions:

- To what extent is the intensification of biomass production for energy in The Netherlands feasible from a biophysical, socioeconomic and policy perspective?
- How much sustainably produced biomass will be available in 2050 for energy generation in The Netherlands, produced in the Netherlands or abroad and imported? Depending on definitions and the point of views on sustainability, this will be a range and not a fixed amount.
- Which users will share the available biomass in The Netherlands in 2050, and who will get priority? Priority will be flexible and depend on point of view.
- What will be the impact on water, land, agriculture, food and GHG emissions of biomass production and use in The Netherlands in 2050?

The impact on water, land, agriculture and food in The Netherlands will be investigated, as well as the global land footprint and GHG emissions. GHG emissions from biomass are disputed and depend on definitions and considered time horizon of the regrowth of the wood. So here too, there will be ranges rather than fixed numbers.

2.1.2 Renewable energy share should grow sharply in The Netherlands

The Dutch coalition agreement sets a target of a 49-55 percent reduction of GHG emission in 2030 in The Netherlands as compared to 1990 and aims for a maximum temperature rise below 2 degrees Celsius , according to the Paris agreement (VVD, CDA, D66 & Christen Unie, 2017). However, there are no targets for the share of renewable energy in the energy mix, reduction in energy use and increase of energy efficiency in 2030 or 2050, nor is there a distribution of the reduction targets among the different economic sectors. This means that there is a large degree of freedom in choosing different pathways to reach a low-carbon economy in 2050, although Ros et al. (2016) state that all available options to reduce GHG emissions need to be used to reach a 95 percent reduction of GHG emissions in 2050.

2.1.3 Numerous nexus sectors and policy areas involved

According to the first phase of the policy analysis, the following sectors and policy areas are relevant for the Dutch case: water, land, energy - especially biomass, agriculture and food, environment - especially nature, biodiversity, forestry and waste, climate mitigation and adaptation and (circular) economy. Policy documents that are relevant for these policy areas at national scale were gathered and analysed (Task 2.2: Block 1 of policy analysis, according to common Guidance). Policy goals for most of these policy areas are coherent 'on paper'.

2.1.4 A serious game as an intermediating tool

At the first workshop, stakeholders pointed out the bad image of biomass for energy use in Dutch politics and public opinion as the main challenge for increasing the share of biomass in the energy mix. Biomass is heavily disputed in The Netherlands, because the reduction of GHG emissions reached by using biomass as compared to fossil energy depends on definitions and time horizon, and because biomass production has potentially negative effects on water, land and food. The discussion is highly polarised, and a serious game may become an intermediation tool to facilitate the discussion, if assumptions and methods used in the game are accepted and if the game is considered as 'neutral'. This means that outcomes of the game may be ambiguous and presented as ranges, depending on definitions and visions. This is the consequence of using disputed knowledge. The serious game could also have an educational function, as the bad image of biomass is partly based on incorrect information.

2.1.5 Conceptual framework and complexity modelling

A first draft of a conceptual model was designed, based on the conceptual models for the SIM4NEXUS pilot case studies Sardinia and Andalucía, see section 2.3. The model contains the subsystems water, land, agriculture, food, energy, climate and socio-economic system, and the interconnections between these subsystem, for example material and energy flows, climate change effects and other and influences.
The thematic models CAPRI, MAGNET and E3ME have been deployed in the complexity model.
SSP2 was chosen as the baseline scenario and needs to be translated into the Dutch situation.

2.2 Next steps until November 2018

2.2.1 Development of conceptual framework, complexity model and serious game

The functional requirements for the conceptual framework, complexity model and serious game will be formulated, in cooperation with the stakeholders. Within the limits of feasibility, these requirements will be translated into the model and game. As biomass is the central element in the Dutch case study and not water scarcity as in the pilots, this draft conceptual model needs some adjustments, based on the functional requirements of the Dutch case and on the input from the stakeholders. Biomass is part of the nexus elements (subsystems) water, land, agriculture, food and energy, as well as part of flows

between these elements. The tension between biomass production for energy generation on the one hand and the pursuit of resource efficiency and circular economy on the other hand should be included, as well as the competition between several users for sustainable biomass as a scarce resource.
Biomass is a catch-all term, according to the stakeholders. It is wise to divide the diverse types of biomass by origin, source and uses in the conceptual model and serious game. Also, the ambiguity of model outcomes, depending on definitions and viewpoints, needs to be integrated in the model and game.

2.2.2 Involve a wider scope of stakeholders

The waste, agriculture and nature sector were missing at workshop 1, as well as opponents of the use of biomass for energy generation. They will be interviewed and approached for the next workshops. There are three other workshops planned for the case study. Figure 7 presents the planning of the workshops and involvement of stakeholders of the Dutch case study. Also, we indicated what stakeholders can expect (green boxes) from the project team during the workshops and what the team expects from the stakeholders (blue/gray boxes). Workshop 2 is planned in April/May 2018 and workshop 3 by the end of 2018. Subjects to be discussed in workshop 2 will be policy coherence, the conceptual framework and functionality requests for the modelling. Workshop 3 will show a prototype of the serious game and focus on improving the game options, as indicated by the stakeholders. The stakeholders who participated in workshop 1 declared that they wanted to stay closely involved in the further development of the conceptual framework, model and serious game.

Workshop 1 Oct.'17	Workshop 2 Apr./May.'18	Workshop 3 end'18/begin'19	Workshop 4 end'19
• Explanation of SIM4NEXUS and SG	• Preliminary results policy coherence	• Improved options with your suggestions	• Play the SG and learn from results
• Opportunities and challenges biomass	• Improvement model with your suggestions	• Play with prototype SG	• Policy recommend-dations

Figure 7: Involvement of stakeholders during the SIM4NEXUS case study in the Netherlands

2.2.3 Analyse policy coherence in practice

In 2018, the coherence of the Dutch policies for the water-land-energy-food-climate nexus wil be further analysed, as far as it is relevant for biomass. For this purpose additional interviews with stakeholders from all sectors will be held. It will be explored how policy synergies and conflicts are dealt with in implementation practice and lessons will be drawn, including key success factors. Policy pathways will be developed to feed the models.

3 References

European Commission. 2016. “EU Reference Scenario 2016 Energy, Transport and GHG Emissions: Trends to 2050.” Report. Brussels: European Commission.

HLPE. 2014. “Food Losses and Waste in the Context of Sustainable Food Systems.” Rome: FAO. www.fao.org/cfs/cfs-hlpe.

PBL. 2013. “Biomassa: Wensen En Grenzen.” Den Haag: Planbureau voor de Leefomgeving.

Popp, J., Z. Lakner, M. Harangi-Rákos, and M. Fári. 2014. “The Effect of Bioenergy Expansion: Food, Energy, and Environment.” *Renewable and Sustainable Energy Reviews* 32 (April):559–78. https://doi.org/10.1016/j.rser.2014.01.056.

Prins, Anne Gerdien, and Jan Ros. 2014. “Bio-energieteelt: een onuitputtelijke bron? Het potentieel van bioenergieteelt nader bekeken.” PBL-publicatienummer 1369. The Hague: Planbureau voor de Leefomgeving (PBL). http://www.pbl.nl/publicaties/bio-energieteelt-een-onuitputtelijke-bron.

Riahi, Keywan, Detlef P. van Vuuren, Elmar Kriegler, Jae Edmonds, Brian C. O’Neill, Shinichiro Fujimori, Nico Bauer, et al. 2017. “The Shared Socioeconomic Pathways and Their Energy, Land Use, and Greenhouse Gas Emissions Implications: An Overview.” *Global Environmental Change* 42 (January):153–68. https://doi.org/10.1016/j.gloenvcha.2016.05.009.

Ros, Jan, and Bert Daniëls. 2017. “Verkenning van klimaatdoelen: Van lange termijn beelden naar korte termijn actie.” 2966. Den Haag: PBL.

Ros, J.P.M., K.M. Schure, J. Matthijsen, C.R. Vringer, H.E. Elzenga, J. Notenboom, R. Koelemeijer, et al. 2016. “Opties voor energie- en klimaatbeleid.” 2393. Den Haag: Planbureau voor de Leefomgeving. http://www.pbl.nl/publicaties/opties-voor-energie-en-klimaatbeleid.

Schoots, Koen, and Pieter Hammingh. 2015. “Nationale Energieverkenning 2015.” ECN-O--15-033. Amsterdam/Petten: Energieonderzoek Centrum Nederland (ECN) Amsterdam/Petten.

Schoots, Koen, Michiel Hekkenberg, and Pieter Hammingh. 2017. “Nationale Energieverkenning 2017.” ECN-O--17-018. Amsterdam/Petten: ECN.

SER. 2013. “Energy Agreement for Sustainable Growth.” The Hague: SER. https://www.ser.nl/~/media/files/internet/talen/engels/2013/energy-agreement-sustainable-growth-summary.ashx.

———. 2015. “The Agreement on Energy for Sustainable Growth: A Policy in Practice.” The Hague: SER. https://www.ser.nl/en/publications/publications/2015/agreement-energy-sustainable-growth.aspx.

Statistics Netherlands. 2015. “CO2 uitstoot groeit veel harder dan economie.” Statistics Netherlands. https://www.cbs.nl/nl-nl/nieuws/2015/46/co2-uitstoot-groeit-veel-harder-dan-economie.

VVD, CDA, D66, and ChristenUnie. 2017. “Vertrouwen in de toekomst Regeerakkoord 2017 – 2021 VVD, CDA, D66 en ChristenUnie.” Coalition Agreement. Den Haag. https://www.kabinetsformatie2017.nl/documenten/publicaties/2017/10/10/regeerakkoord-vertrouwen-in-de-toekomst.

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

D5.2: THE MAIN NEXUS CHALLENGES IN 'SWEDEN'

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OTHER AUTHORS: -

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Table of Contents

Glossary / Acronyms

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

RCP	REPRESENTATIVE CONCENTRATION PATHWAYS
GDP	GROSS DOMESTIC PRODUCT
SDM	SYSTEM DYNAMICS MODELING

1 Introduction

Sweden is a country in northern Europe (Figure 1) bordered by Norway in the west, the North Sea in the southwest, the Baltic Sea in the east and Finland in the northeast.

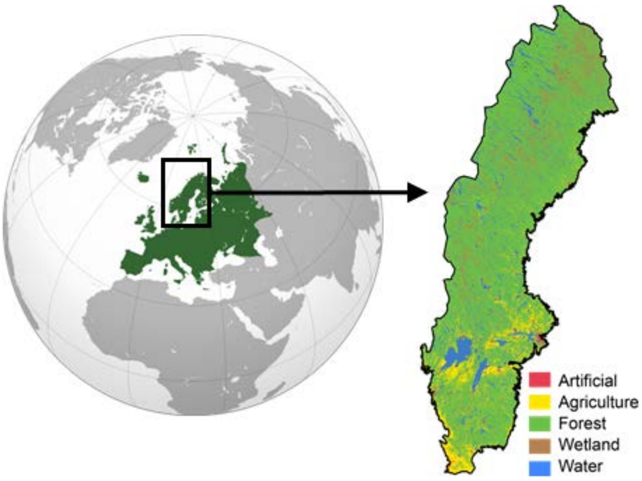

Figure 1: Sweden's geographic location and different landcover types.

Sweden is well known for being a heavily forested country with uncounted lakes and rivers. It is perhaps not surprising that forestry and forest products are of great importance to the national economy. In addition, more than half of Sweden's electricity is generated from renewable sources such as hydropower and forest biofuels. However, changing climate conditions are expected to heavily affect both water resources, forest ecosystems and their interlinkages. Forests depend on water, but have, at the same time, the potential to regulate water availability and quality. On top of that, both forest and water resources directly control the available potential to generate electricity from forest biofuels or hydropower. These interactions of forest, water, climate change, and bioenergy (Figure 2) as an overarching issue promise to be of crucial importance in future years.

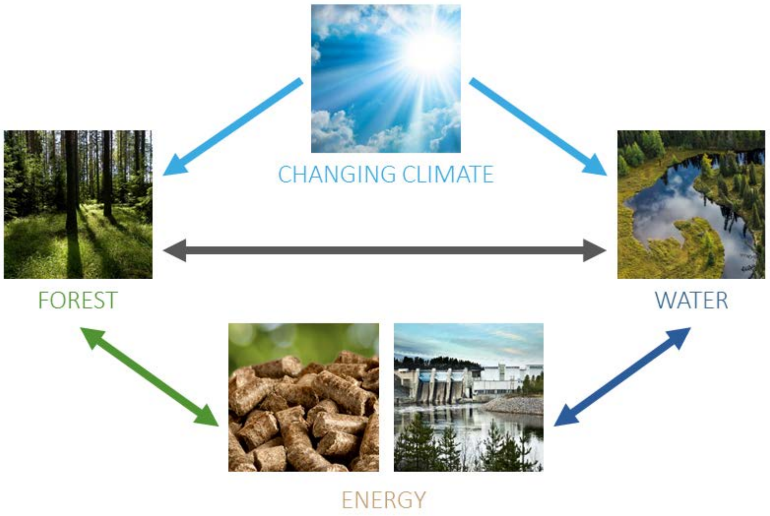

Figure 2: Overview of the forest-water-energy interconnections under changing climate conditions in the Swedish case study.

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Sweden currently has two major initiatives of interest to these nexus sectors: (1) ***The Generation Goal*** and (2) ***The Environmental Objectives*** (Swedish Environmental Protection Agency, 2017).

The ***generational goal*** – the overall goal of Swedish environmental policy – defines the direction of the changes in society that need to occur within one generation if the country's environmental quality objectives are to be achieved. One of its targets is to increase the share of renewable energy and use energy efficiently with minimal impact on the environment. This goal is already achieved (Swedish Environmental Protection Agency, 2017), because Sweden managed to reach its goal of a 50 per cent renewable energy share several years ahead of the Swedish government's 2020 schedule, in 2012. Swedish bioenergy use has grown from 40 TWh/year in the 1970s to around 140 TWh in 2012 (Andersson, 2012). Bioenergy was the leading factor in Sweden's 9 percent decrease in greenhouse gases between 1990 and 2010, while gross national product increased by 50 percent. According to Andersson (2012), bioenergy's success also rests on the long-standing tradition of using natural forest resources while also protecting and developing them. Sweden's total forest stock has increased each year despite the rapid expansion in biomass use for energy.

The sixteen ***environmental quality objectives*** describe the state of the Swedish environment which environmental action is to result in. These objectives are to be met within one generation, i.e. by 2020 (2050 in the case of the climate objective). Objectives related to the forest and water sectors include:

- Reduced Climate Impacts (to be met by 2050)
- Flourishing Lakes and Streams (to be met by 2020)
- Good-Quality Groundwater (to be met by 2020)
- Sustainable Forests (to be met by 2020)

According to present forecasts (Swedish Environmental Protection Agency, 2017), these environmental objectives will not be met in time. In fact, the objectives of reducing climate impacts even shows a negative trend in the state of the environment, because greenhouse gas emissions are still rising. This clearly shows that the current environmental initiatives are not sufficient to achieve society's agreed environmental objectives for water and forests. For example, about three quarters of the largest river systems are affected by fragmentation from water regulation causing negative ecological consequences. In addition, the growing demand for bioenergy has led to an intensification of the forest industry through extensions of managed forest land, introduction of fast-growing tree species, increasing use of fertilization and increasing felling rates. The effects of such new management strategies for increased biomass production on forest species, soil resources and water quality at landscape scales are, however, not well understood and not addressed adequately. In addition, Sweden is at the time of writing facing recurring problems of declining groundwater levels causing an increased risks for forest fires, drinking water shortages and low water levels. This has triggered a new debate on the forest cover - water yield relationship (i.e., on whether trees 'use' or 'supply' water), which is attracting increasing attention in Swedish media.

These issues will be addressed by the Swedish national case study focusing on a time frame until 2050. Together with stakeholders, the question as to whether the goal of becoming a fossil-free nation interferes with some of the national environmental objectives will be discussed.

1.1 Description of the Nexus challenges

1.1.1 Climate Sector

Temperature and precipitation are projected to increase more in high-latitude regions such as Sweden than in the rest of Europe (IPCC, 2014; Jacob et al., 2014). Based on the two Representative Concentration Pathways RCP4.5 and RCP8.5 (representing intermediate and high emissions, respectively), the annual average temperature is projected to be 2-6°C higher by the end of this century than for the period 1961-1990, while the average annual precipitation is projected to increase by 10-40% (Sjökvist et al., 2015). Extreme short-term precipitation events (in particular short torrential showers) are projected to become more intensive (Sjökvist et al., 2015). Due to the fact that high-latitude ecosystems have adapted to low natural energy flows, they are relatively more sensitive to a given shift in climate, physical and biogeochemical conditions, which could intensify regional and seasonal environmental responses (Roots, 1989).

To enhance the preparedness and capacity to respond to such climate change impacts, the EU Adaptation Strategy (European Commission, 2013) aims to make Europe more climate resilient. The strategy stresses that many economic sectors, including forestry, are directly dependent on climatic conditions and are already facing the consequences of a changing climate. Challenges are related to both physical climate impacts and mutual dependencies across environmental systems, as well as to policy failures and knowledge gaps. Adaptation strategies are seen as the most effective instrument when assessing impacts, vulnerability and adaptation options and thus to face the projected impacts of climate change across sectors.

1.1.2 Landuse Sector (Forests)

Within the boreal region, Fennoscandia represents an extreme in terms of the degree and extent to which landscape dynamics are influenced by land management (Gauthier et al., 2015). For example, more than two thirds of Sweden are currently covered by forests, of which the majority is subject to forestry (SLU, 2015). The country has a long history of using its natural forest resources, while also protecting and developing them (Andersson, 2012). Total forest industry output was approximately 23 billion Euros in 2011 (Skogsstyrelsen, 2014), while the export value of forestry and the forest products industry was 13 billion Euros. The total number of employees in large-scale forestry has declined significantly in recent years, while, at the same time, the role of forest entrepreneurs (and their employees) has become increasingly important (Skogsstyrelsen, 2014).

Forests play an important role in terms of diverse and multifunctional benefits to people in Sweden. In addition to the economic output that is generated by the forestry sector, forests also deliver social and environmental functions. For instance, forests support biodiversity, provide opportunities for recreational activities (‘freedom to roam’, which is a general public right codified in law), allow for mushroom and berry picking, sequester atmospheric carbon, improve air quality, and regulate water quantity and quality.

Forestry in Sweden is currently regulated by the 1993 Forestry Act (Swedish Government, 1993), which states that “the forest is a national resource”, which “shall be managed in such a way as to provide a valuable yield and at the same time preserve biodiversity”.

The forestry sector is subject to alterations in the light of developments in energy, governance and landuse systems, climate politics, and taking account of an increasing competition between economic, environmental and recreational functions (Sandström et al., 2011). The growing demand for bioenergy has led to an intensification of the forest industry (Helmisaari et al., 2014), in particular through extensions of managed forest land, introduction of fast-growing tree species and increasing use of fertilization (Rytter et al., 2013). In the future, more intense forestry practises require technological and logistical improvements to render an economically sustainable production and to reduce the negative effects on our environment (de Jong et al., 2014). In addition, the extended growing season that arises from warmer temperatures in the future, in particular in the North, means that some areas will become increasingly available and attractive to forestry. This warming might also imply a shift in vegetation types and a shortening of the presently rather long rotation periods of typical boreal forests. Consequently, one of the key questions is whether the extraction of forest biomass can be further increased in the future without negative consequences for other forest functions and for water availability/quality. Typical forestry practices have an impact on soil, water, climate and biodiversity (de Jong et al., 2014) and, thus, a main challenge is to manage trade-offs between economic, environmental and recreational functions (Sandström et al., 2011).

1.1.3 Water Sector

Swedish hydrological regimes (Figure 3) are generally characterized by rather low winter streamflow with a dominating snowmelt-driven spring flood peak (mainly in central and northern Sweden), followed by low summer flows and/or a somewhat lower precipitation-induced flood peak in the fall (mainly in southern Sweden). In a future climate, however, streamflow is projected to change to a more even regime with dominating large winter streamflow and no spring flood peak at all (Arheimer and Lindström, 2015; Donnelly et al., 2013; Teutschbein et al., 2011, 2015). Annual water availability in general is expected to increase as a result of increasing precipitation. There are, however, large seasonal variations: especially during summer months, water availability is likely to decline as a results of increasing evaporation rates in large parts of the country (Eklund et al., 2015). In southern Sweden, water shortages during summer increasingly affect the drinking water supply, both in terms of quality and quantity.

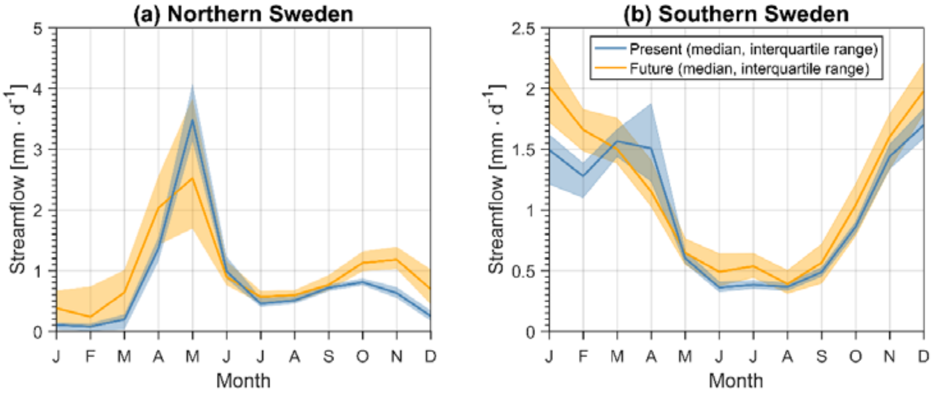

Figure 3: Projected changes in hydrologic regimes representative for (a) northern Sweden and (b) southern Sweden.

To achieve good quantitative status of surface water bodies including streams, the Water Framework Directive (European Parliament and Council of the European Communities, 2000) established a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater.

Hydrological extreme events, which are defined by the departure of surface and subsurface water supplies from average conditions at various points in time (WMO, 2006), can cause severe habitat damage, problems for agriculture, forestry, industry, building infrastructure, energy production and water supply (Swedish Commission on Climate and Vulnerability, 2007). In Sweden, past changes in climate and land cover have had a major impact on streamflow patterns (Destouni et al., 2013). In a changing climate, shifts in meteorological conditions are expected to even further perturb regional hydrology, and thereby also the occurrence, frequency and duration of both floods and droughts. In fact, climate models project that extreme floods are expected to occur less often in northern inland Sweden and the northern coastal areas, while most the rest of the country is likely to suffer from more common extreme floods in a future climate (Eklund et al., 2015). Concurrently, more days with low river flows (i.e., hydrological droughts) are expected in southern and central Sweden.

Although Sweden has historically been a region abound with water, it is not exempt of droughts: the 2003 summer drought severely impacted the European continent, including Scandinavia (NVO, 2011). There was, however, large spatial variability in hydro-climatic patterns across the country, which indicates the complex interplay of meteorological and topographic features and the resulting hydrological impacts at the catchment scale. Events such as the European-wide 2003 drought could become more frequent in coming decades, and, thus, the early recognition of critical drought conditions is essential for drought risk management with large economic and social benefits. Yet, most available hydrological climate change impact studies concerning Sweden neglect hydrological droughts. To make matters even more concerning, interviews among Swedish municipalities and drinking water producers revealed that only 12% specifically considered potential effects of droughts on drinking water in their risk assessment (Norén et al., in preparation). Thus, there is now an urgent need to estimate water availability in a changing climate and a developing society.

Mitigating the effects of floods and droughts are addressed both in the Water Framework Directive (European Parliament and Council of the European Communities, 2000) and the Floods Directive (European Parliament and Council of the European Union, 2007).

Multiple ongoing global changes have reshaped the pools and fluxes of biogeochemical elements in terrestrial and aquatic ecosystems. Of these, dramatic increases in the loading of bioreactive nitrogen (N) and phosphorus (P) to terrestrial ecosystems during the 20th century have drawn particular attention (Galloway et al., 2008) and are linked to multiple environmental problems, ranging from declines in species diversity to stratospheric ozone loss (Gruber and Galloway, 2008). Large quantities of anthropogenically mobilized N and P are also flushed from land to water (Seitzinger et al., 2005), contributing to freshwater and marine eutrophication (Bouwman et al., 2013; Conley et al., 2009), and connecting mounting water quality concerns to hydrological patterns that are themselves sensitive to climate drivers (IPCC, 2014). Concurrent to these global changes, warming temperatures, longer growing seasons, and rising atmospheric CO_2 concentrations may lead to increased plant growth (Richardson et al., 2010), greater nutrient uptake and accumulation in terrestrial ecosystems (Luo et al., 2004), and reduced nutrient losses to surface waters in some cases (Lucas et al., 2016).

The Water Framework Directive (European Parliament and Council of the European Communities, 2000) aims at enhancing the status of aquatic ecosystems and reducing discharges/emissions/losses of priority substances. Surface water and groundwater bodies are further protected from pollution by the Nitrates Directive (Council of the European Communities, 1991a), the Urban Waste Water Directive (Council of the European Communities, 1991b) and the Groundwater Directive (European Parliament and Council of the European Union, 2006).

In southern Sweden, water shortages during summer increasingly affect the drinking water supply, both in terms of quality and quantity. Increasing temperatures, shifts in seasonality and more streamflow (especially during winter) are likely to cause higher nutrient loads in Swedish boreal (Teutschbein et al., 2017). In addition, a continued intensification of the forest industry (Helmisaari et al., 2014), in particular extensions of managed forest land and increasing use of fertilization (Rytter et al., 2013), may increase the risk of nutrients leaching from watersheds (Sponseller et al., 2016). Consequently, key research questions in the water sector relate to how future climate change, streamflow shifts and changing forestry practices might affect (drinking) water availability and quality.

1.1.4 Energy Sector

Sweden’s total energy supply in 2015 was 557 GWh. The most important energy sources (Figure 4) are nuclear fuel (33 %), crude oil and petroleum products (24%), biofuels (23%) and hydropower (12%). For the past decades, Sweden has invested heavily in alternative energy sources and is now in the front line of renewable energy use. The interaction between abundant natural resources, high oil prices, public concern for the environment, broad policy support, and strong incentives led to a transformation of Sweden’s oil-dependent energy system (Andersson, 2012). Despite a large per capita energy consumption, Sweden’s economy is today one of the least dependent on fossil fuels and has one of the lowest carbon emission rates. Thus, Sweden has set a model in terms of a resource-efficient and low-carbon economy that much of the world could emulate.

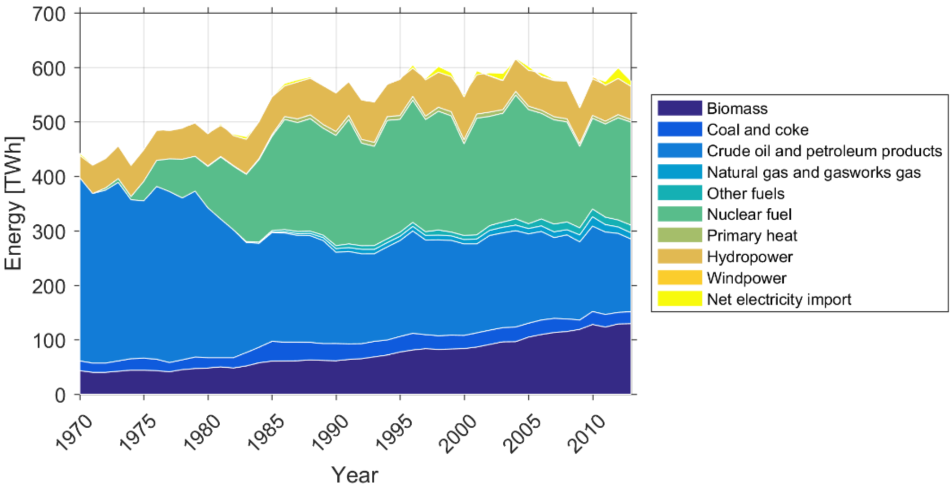

Figure 4: Total energy supply by energy commodity 1970-2013 based on data provided by Statistics Sweden.

Biofuels play a major role in industry, district heating, and to an increasing degree also in electricity production and transport (Figure 5). Biofuel is a collective term for several different types of fuels, including densified and undensified wood fuels, black liquor, biofuels from agriculture, combustible waster, bioethanol, biodiesel and biogas. The biofuel market in Sweden is presently growing at a rate of 3 TWh per year, which equals 1.5x10^{6} m3 of wood (de Jong et al., 2014). At present, the two leading biofuel sources are undensified wood (41%) and black liquor (33%), followed by densified wood (8%) and municipal waste-bio (7%). The increasing use of biofuels for electricity and heat production has caused a rising demand for wood fuels (Energimyndigheten, 2016), which has been satisfied through increased extraction of forest biofuels (de Jong et al., 2014). The market is expected to grow further in the near future (Energimyndigheten, 2013) and the supply of forest biomass for energy could potentially increase by 70% (Andersson, 2012). As the market for biofuels further grows, the question arises as to whether the supply of forest biomass for energy can further be increased. The competition between forests, water and energy resources is further intensified by changing climate conditions. Knowledge gaps and considerable uncertainties on how environmental systems will change and on their impacts are major challenges.

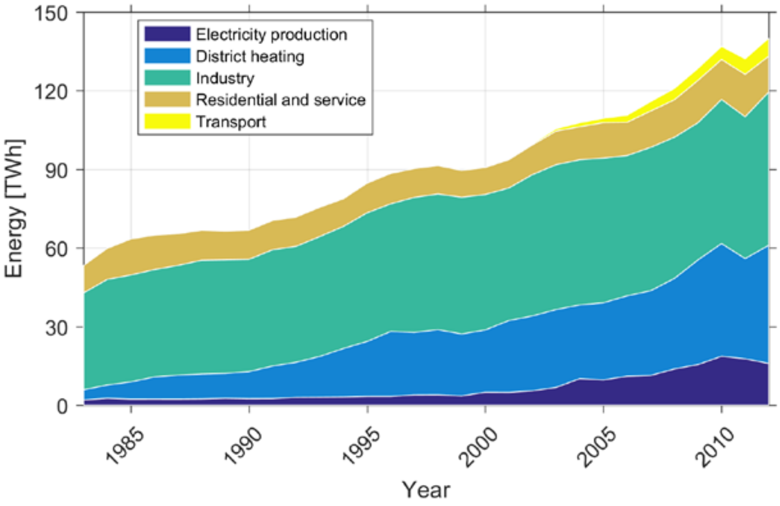

Figure 5: Use of biofuels, waste and peat by sector 1983–2012

Sweden is the largest hydropower producer in the EU and the tenth biggest in the world, generating on average 67 TWh of electricity per year. Most hydropower is produced in northern Sweden. The annual hydropower output varies depending on seasonal precipitation: during the past 15 years, hydroelectric output varied from 53 TWh in 2003 (European summer drought) to 79 TWh in 2000 (particularly wet year). Swedish hydropower provides a valuable source of renewable energy and is able to balance the national electricity grid (Rudberg, 2013). However, about three quarters of the largest river systems are affected by fragmentation from water regulation (Rudberg, 2013), causing negative ecological consequences. Swedish law prohibits hydropower constructions in four of the biggest streams and a number of smaller rivers, and, thus, limits further expansion of hydropower. Large uncertainties remain in terms of the effect of future seasonal shifts in water availability (e.g., more streamflow during winter, but expected longer drought period during summer) on hydropower, which highlights the need for further research.

1.2 Description of the pathways

1.2.1 Climate

The Swedish case study will focus on the RCP4.5 and RCP8.5 greenhouse gas concentrations trajectories, which represent intermediate respective high emissions. However, both the Europe 2020 strategy (European Commission, 2010), the Swedish 2020 Climate and Energy Goals (Swedish Government, 2006), and the most recent Climate Act (Swedish Government, 2017) set out targets for reducing greenhouse gas emissions (Table 1).

Table 1: Overview of European and Swedish climate targets

	Sweden 2020	Sweden 2045	Europe 2020	Europe 2030
Reductions in Greenhouse Gas Emissions	40%	85% (zero emissions)	20%	40%

1.2.2 Water

Sweden aims at enhanced climate adaptation, sustainable use of water resources, and effective governance in the aquatic environment area (Swedish Government, 2014). The Swedish Government has been discussing (1) interim targets for good status for Sweden's waters and long-term sustainable management of surface runoff in built environments and nature, (2) measures to deal with direct emissions of hazardous substances to aquatic environments and (3) better conditions for restoration of freshwater environments (Swedish Government, 2014). More specific pathways for the water sector will be discussed with the stakeholders at the first workshop in April 2018.

1.2.3 Forest

The goals of the Swedish Government are (1) to ensure a reliable yield of timber (Swedish Government, 1993, 1979), (2) a long-term sustainable development and management of forest resources (Swedish Government, 2013, 1998), and (3) to create conditions for reduced emissions of greenhouse gases from forestry (Swedish Government, 2014).

According to the latest forest statistics report (SLU, 2016), total standing volume is projected to increase from 3.5 billion cubic meters in 2016 to roughly 5 billion by 2110. This, however, assumes that forestry continues to be managed as it is today and that observed historical trends continue. The expected changes are driven by increasing growth, which is expected to rise from 120 million m^3 per year to over 160 million m^3 per year by the year 2110 (SLU, 2016). Felling rates are projected to increase from today's 80 million m^3 per year to 115 million m^3 per year by the year 2110 (SLU, 2016). At the same time, consumption of all wood products in Europe is projected to increase (Jonsson, 2011). This is in line with the baseline projections for the forestry sector provided by the MAGNET model for the European countries (Figure 7). More specific forestry pathways will be discussed with the stakeholders at the first workshop in April 2018.

1.2.4 Energy

Both the Europe 2020 strategy (European Commission, 2010) and the Swedish 2020 Climate and Energy Goals (Swedish Government, 2006) set out targets for increasing shares of renewable energy and improving energy efficiency (Table 2).

Table 2: Overview of European and Swedish energy targets

	Sweden 2020	Sweden 2030	Sweden 2040	Europe 2020	Europe 2030
Share of Renewable Energy	50%		100%	20%	27%
Improvements in Energy Efficiency	20%	50%		20%	27%

1.3 Develop a conceptual model

Work on the conceptual model has been progressed over the last months. However, the model has not yet been discussed/finalized with the System Dynamics Modeling (SDM) team and coordinators of WP3/WP4. In addition, it requires more discussion during the first stakeholder workshop in April 2018. The first draft of the conceptual model (Figure 6) covers four nexus sectors relevant for the Swedish case study: climate, water, landuse (i.e., forest) and energy. Some aspects like social/technological innovation, demographic trends or economic development are not yet included in this first draft.

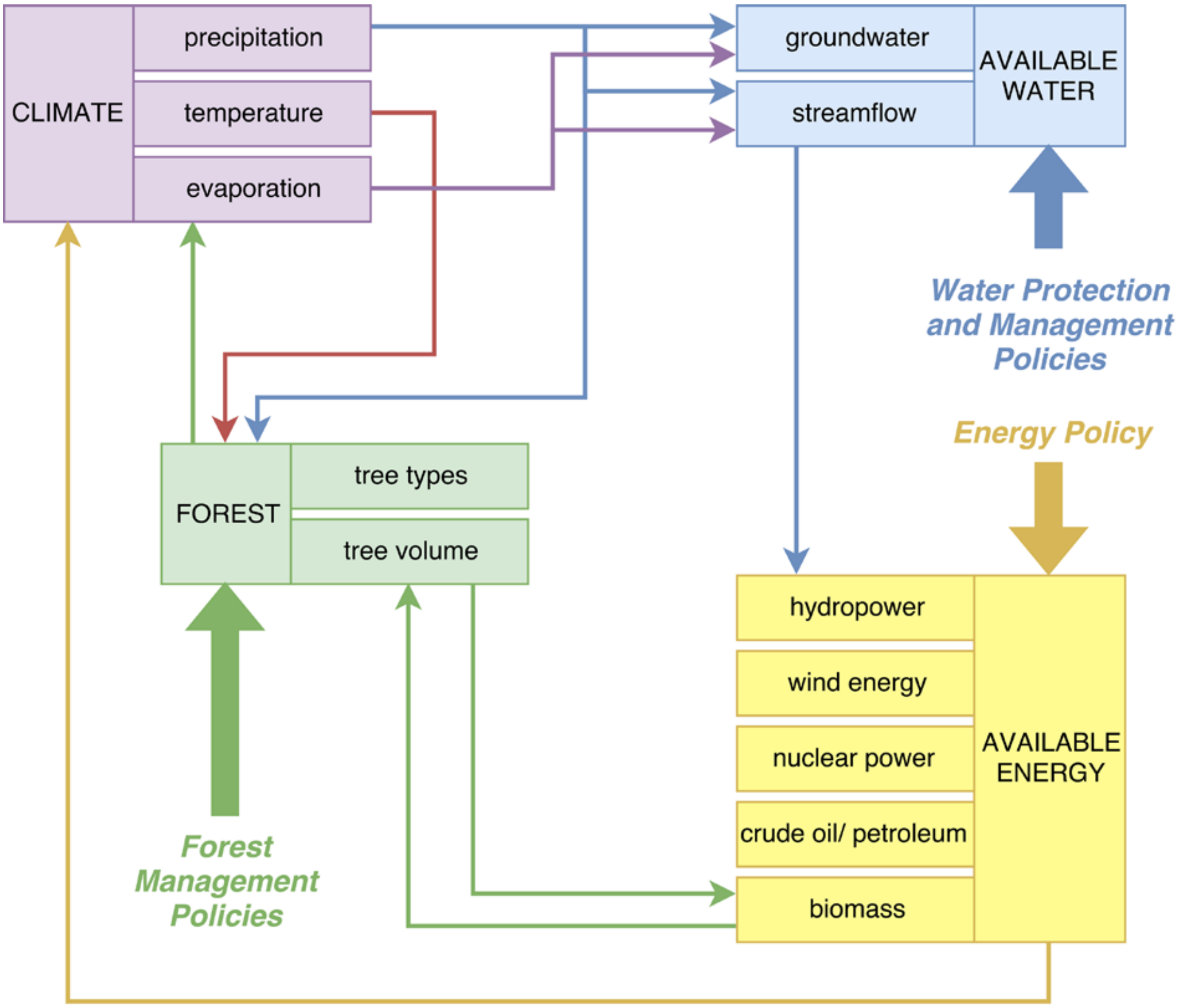

Figure 6: First draft of a conceptual model covering the nexus sectors climate, water, landuse (forest) and energy in the Swedish case study.

1.4 Use of thematic models in understanding the Nexus

The Swedish case study will use output from the models E3ME, MAGNET and GLOBIO to address the nexus challenges in Sweden.

1.4.1 E3ME

1.4.1.1 Summary

E3ME simulates interactions between the economy and the energy system. Its two-way feedback mechanisms allow 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. Final energy consumption is modeled 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.

1.4.1.2 Application in the Swedish case study

For the Swedish case study, E3ME will help to address the link between climate and energy sector, more specifically energy production from biomass and hydropower, by providing estimates on energy supply and consumption, emissions, GDP and population. Summarized model outcomes will be presented in the upcoming stakeholder workshop in April 2018.

1.4.1.3 Status Baseline Scenarios

Baseline scenarios are already available at the global scale. For the national scale, baseline scenarios are not available yet. The case study leader has contacted the modelers (Dec 7 2017) with a request to provide the model outcomes needed to address the nexus challenges identified in the case study.

1.4.1.4 Constraints in the capabilities

As an economy-energy model, E3MW does not account for physical changes in nature (for example caused by a changing climate). As such, climate change impacts on water availability for hydropower production and forest growth are not considered. There might also be environmental/physical limitation on how much biomass can be extracted from forests for energy production. Further, 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.

1.4.2 MAGNET

1.4.2.1 Summary

The MAGNET model 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 bio-economy. 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.

1.4.2.2 Application in the Swedish case study

The advantage of MAGNET for the Swedish case study is that it covers the forestry sector and accounts for electricity and fuel production from forest biomass. MAGNET will help to address the link between climate, land (i.e. forest) and energy sector, and it will contribute to examine the interplay between deforestation and biofuel production. It further accounts for the fertilizer sector (in agriculture), which can be used to separately assess future river water quality and the impacts of nitrogen (N) and phosphorus (P) leaching on the Baltic Sea (e.g., eutrophication). Summarized model outcomes will be presented in the upcoming stakeholder workshop in April 2018.

1.4.2.3 Status Baseline Scenarios

Baseline scenarios are already available at the global and continental (European) scale. Baseline projections for the forestry sector over Europe (Figure 7) indicate increasing production, domestic use and exports. Imports, on the other hand, are projected to decrease slightly until 2020/2030 and possibly increase thereafter2050.

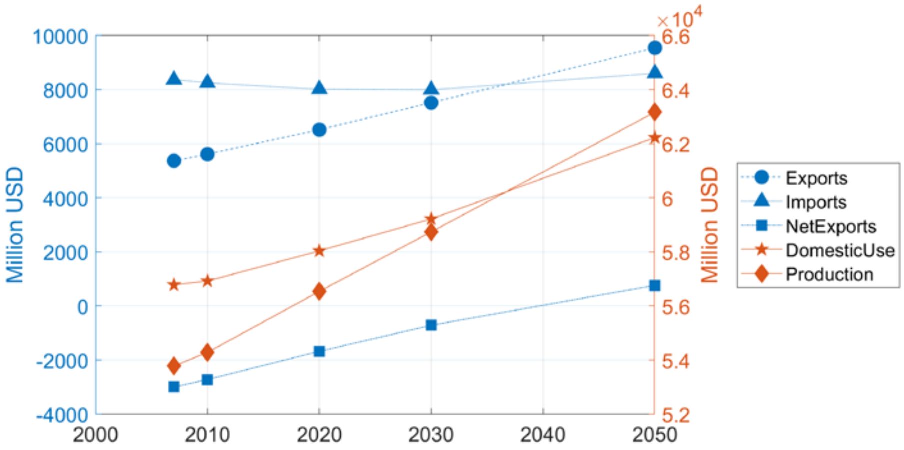

Figure 7: Projected changes in the European forest sector as projected by MAGNET for the SSP2 baseline

For the national scale, baseline scenarios are not available yet. The case study leader has contacted the modelers (Dec 7 2017) with a request to provide the model outcomes needed to address the nexus challenges identified in the case study.

1.4.2.4 Constraints in the capabilities

In general, MAGNET is an economic model, which does not account for physical changes in nature (for example caused by a changing climate). As such, climate change impacts on water availability for hydropower production and forest growth are not considered. There might also be environmental/physical limitation on how much biomass can be extracted from forests for energy production. In addition, MAGNET does not specifically account for the water sector.

1.4.3 GLOBIO

1.4.3.1 Summary

GLOBIO 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. It can be used to assess the consequences of environmental change on biodiversity (terrestrial and aquatic), and ecosystem services.

1.4.3.2 Application in the Swedish case study

GLOBIO will contribute to understand the environmental and biodiversity aspects of the forest and water sectors in the Swedish case study. Summarized model outcomes will be presented in the upcoming stakeholder workshop in April 2018.

1.4.3.3 Status Baseline Scenarios

Baseline scenarios are expected to be available end of December 2017.

1.4.3.4 Constraints in the capabilities

GLOBIO simulation results primarily cover biodiversity in terrestrial and aquatic ecosystems. GLOBIO itself does not simulate vegetation or streamflow dynamics and it does not consider the energy sector. Furthermore, GLOBIO is based on statistical cause-effect relationships based on the scientific literature, which might lead to large deviations in some specific cases, especially in a changing climate.

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

1.5.1 Stakeholder process

A list of organizations relevant for the sectors under consideration in the Swedish case study was created (see T2.2) based on expert judgement. To identify the most relevant stakeholders and their influence in the policy process, they were clustered into actor groups (i.e., types of organizations) that have similar roles in the policy arrangement: (1) businesses, (2) common interest associations, (3) local federations, (4) local governmental organizations, (5) regional governmental organizations, (6), national governmental organizations, (7) non-governmental organizations (NGOs), (8) research organizations and (9) trade associations. We identified eighteen ***businesses***, comprising a number of different hydropower, biofuel and forest-owing companies as well as one ***common interest association***, i.e., a group of individuals who voluntarily formed an organization to promote agroforestry. The list further included two ***local federations*** formed by municipalities to manage local drinking water concerns, 290 municipalities belonging in the group of ***local governmental organizations***, five ***regional governmental organizations*** coordinating the work within the Swedish water districts, and nine ***national governmental organizations*** mainly consisting of Swedish government agencies that act independently to carry out policies. Furthermore, six ***NGOs*** dealing with forest issues and nature conservation, five ***research organizations*** in the forest, water and energy sectors, as well as nine ***trade associations*** were identified. The division of resources between these actors naturally leads to differences in power and influence. As a starting point for looking at the relative position of the stakeholder and their power relations, actor groups were mapped to visualize their sizes, influence, roles and relationships (Figure 8). In addition, a power-interest grid per sector was generated (Figure 9) to visualize which stakeholders are key players that should preferably be fully engaged and which stakeholders only play a minor role.

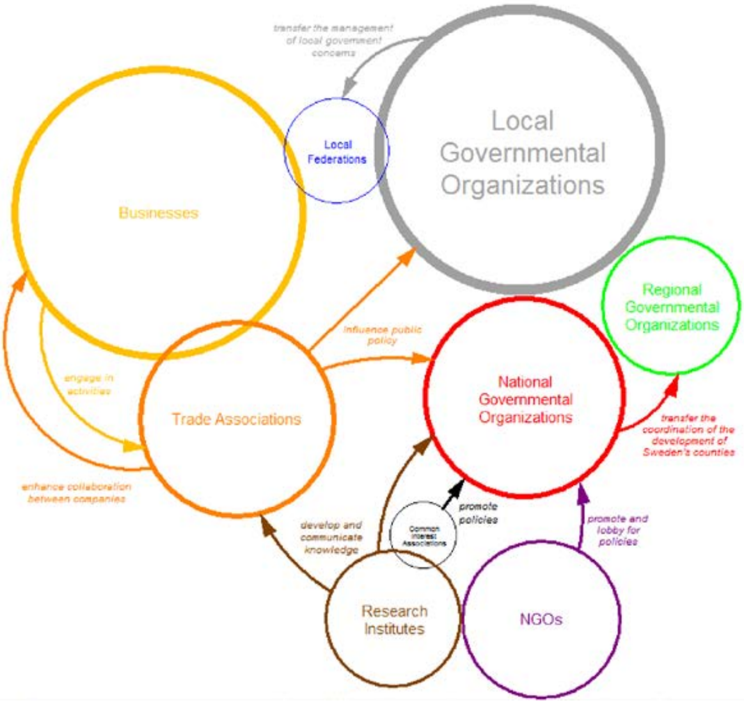

Figure 8: Map of relevant stakeholder groups and their relations. The size of the circles indicates the size of stakeholder groups, different colors represent different groups, the distance/overlap between circles indicates the relationship between the groups. Arrows indicate the main direction of the relationship.

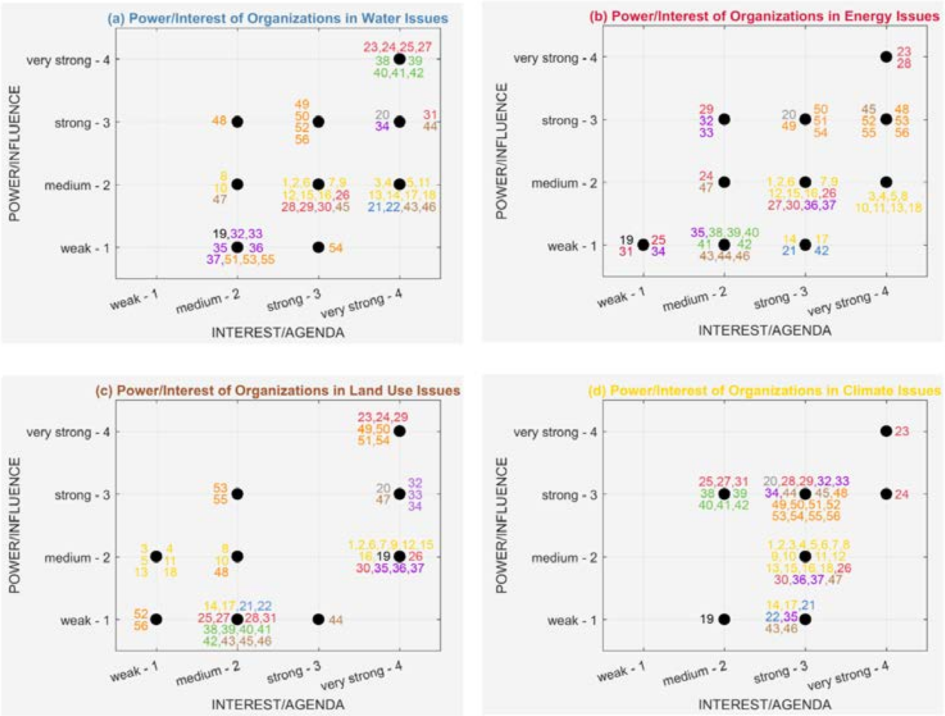

Figure 9: Power-interest grid of potential stakeholders in (a) the water sector, (b) the energy sector, (c) the land use sector, and (d) the climate sector.

Key stakeholders with high power (strong to very strong) and high interest (strong to very strong) were identified for each sector separately based on the power-interest grid (Figure 9). Ten stakeholders, which play a major role in more than two sectors, emerged (Table 3).

Table 3: Key stakeholders with high power and interest in more than 2 sectors (F = forest/land use, W = water, E = energy, C = climate)

ID	ORGANIZATION	F	W	E	C
Key actors in all 4 sectors					
20	Sweden's 290 municipalities	x	x	x	x
23	Ministry of the Environment and Energy	x	x	x	x
24	Swedish Environmental Protection Agency (Naturvårdsverket)	x	x	x	x
49	Mellanskog	x	x	x	x
50	Norrskog	x	x	x	x
Key actors in 3 sectors					
34	Swedish Society for Nature Conservation	x	x		x
51	Swedish Forest Industries Federation (Skogsindustrierna)	x		x	x
52	Swedish Hydropower Association (Svensk Vattenkraftförening)		x	x	x
54	The Federation of Swedish Family Forest Owners (LRF Skogsägarna)	x		x	x
56	Water Regulation Enterprises (Vattenregleringsföretagen)		x	x	x

The identified potential stakeholders were already contacted by e-mail, informing them about SIM4NEXUS and inviting them to participate in an online survey. The online survey aimed at collecting general information about the contact person's background and expertise, which nexus sector they mainly belong to, their perspective and understanding of climate change, and if they would be interested in participating in the SIM4NEXUS project. Reply statistics can be seen in Figure 10.

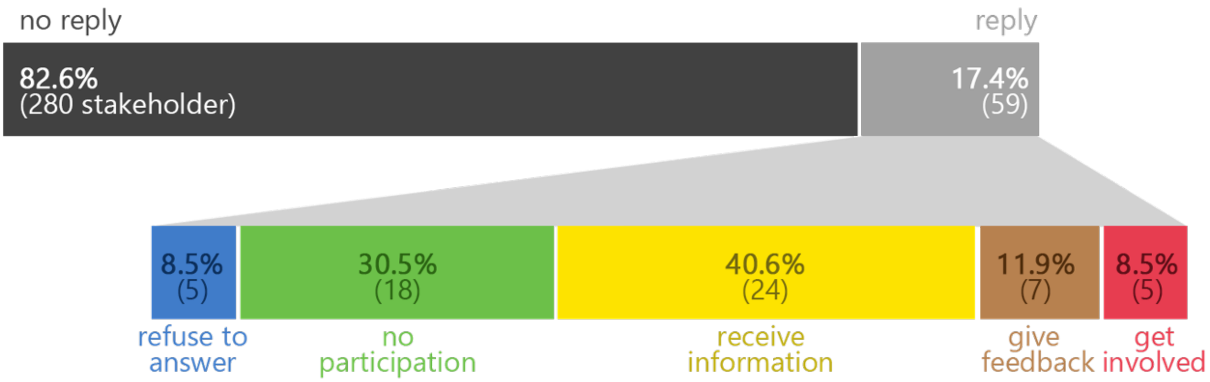

Figure 10: Reply statistics of the online survey sorted by the degree of willingness to engage in SIM4NEXUS

1.5.2 First Workshop

Workshop 1 is planned for April 2018.

1.5.3 Next steps

At present, a new assistant is being recruited to join the Swedish team and help with the stakeholder engagement process. Once the assistant is officially employed (mid- to late January 2018), (s)he will start to plan and implement the stakeholder mobilization. More online surveys and telephone interviews are planned.

2 Conclusions and follow-up

Given the importance of forestry and forest products to Sweden's economy, the large number of lakes and rivers in the country, and Sweden's ambitious goals to have zero emissions and to rely entirely on renewable energy sources, the interactions of ***forest, water, climate change, and bioenergy*** have been identified as ***main nexus sectors*** of interest. In the coming years, Sweden's government aims at

- having zero net emissions by 2045
- enhancing climate adaptation
- sustainable use of water resources
- effective governance in the aquatic environment area
- ensuring a reliable yield of timber
- long-term sustainable development and management of forest resources

However, the question arises as to whether the goal of becoming a fossil-free nation interferes with some of the national environmental objectives such as sustainable development of water and forest resources.

At the time of writing, a first draft of the conceptual model covering the sectors of interest has been developed. Further work is needed in collaboration with stakeholders, the System Dynamics Modeling (SDM) team and coordinators of WP3/WP4 to further develop the model.

Three thematic models have been chosen to provide simulations for the Swedish case study: E3ME, MAGNET and GLOBIO. Output of the models is not yet available, but expected during the December 2017 or shortly thereafter.

The underlying work for starting the stakeholder process is accomplished. The first block of the policy analysis as well as identification of NEXUS interlinkages and challenges are completed. Due to a shortage in staff and a prolonged recruitment process, work with the stakeholders and especially the first workshop will be delayed. The first workshop is currently planned to take place in April 2018.

3 References

- Andersson, K., 2012. Bioenergy, the Swedish experience: how bioenergy became the largest energy source in Sweden.
- Arheimer, B., Lindström, G., 2015. Climate impact on floods: changes in high flows in Sweden in the past and the future (1911–2100). Hydrol Earth Syst Sci 19, 771–784. https://doi.org/10.5194/hess-19-771-2015
- Bouwman, L., Goldewijk, K.K., Van Der Hoek, K.W., Beusen, A.H.W., Van Vuuren, D.P., Willems, J., Rufino, M.C., Stehfest, E., 2013. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period. P Natl Acad Sci USA 110, 20882–20887. https://doi.org/10.1073/pnas.1012878108
- Conley, D.J., Paerl, H.W., Howarth, R.W., Boesch, D.F., Seitzinger, S.P., Karl, E., Lancelot, C., Gene, E., 2009. Controlling eutrophication: nitrogen and phosphorus. Science 123, 1014–1015. https://doi.org/10.1126/science.1167755
- Council of the European Communities, 1991a. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources.
- Council of the European Communities, 1991b. Council Directive 91/271/EEC of 21 May 1991 concerning urban waster water treatment.
- de Jong, J., Akselsson, C., Berglund, H., Egnell, G., Gerhardt, K., Lönnberg, L., Olsson, B., Stedingk, H., 2014. Consequences of an increased extraction of forest biofuel in Sweden - a synthesis from the biofuel research programme 2007-2011: Summary of the Swedish Energy Agency report no. ER2012:08 (in Swedish) (No. TR2014:01), IEA Bioenergy Task 43: Biomass Feedstocks for Energy Markets. IEA Bioenergy.
- Destouni, G., Jaramillo, F., Prieto, C., 2013. Hydroclimatic shifts driven by human water use for food and energy production. Nature Clim Change 3, 213–217. https://doi.org/10.1038/nclimate1719
- Donnelly, C., Yang, W., Dahné, J., 2013. River discharge to the Baltic Sea in a future climate. Climatic Change 122, 157–170. https://doi.org/10.1007/s10584-013-0941-y
- Eklund, A., Mårtensson, J.A., Bergström, S., Björck, E., Dahné, J., Lindström, L., Nordborg, D., Olsson, J., Simonsson, L., Sjökvist, E., 2015. Sveriges framtida klimat - underlag till dricksvattenutredningen (en: 'Sweden's climate - a basis for investigating drinking water) (No. 14), Klimatologi (Climatology). Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden.
- Energimyndigheten, 2016. Energy in Sweden 2015 (No. ET2015:19). Swedish Energy Agency, Eskilstuna, Sweden.
- Energimyndigheten, 2013. Comprehensive assessment of the potential for exploiting high-efficiency cogeneration, district heating and district cooling (No. ER2013:24). Swedish Energy Agency, Eskilstuna, Sweden.
- European Commission, 2013. Communication COM/2013/0216 from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: An EU Strategy on adaptation to climate change.
- European Commission, 2010. Communication COM/2010/2020 from the Commission: Europe 2020 - A strategy for smart, sustainable and inclusive growth.
- European Parliament and Council of the European Communities, 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy.

- European Parliament and Council of the European Union, 2007. Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risk.
- European Parliament and Council of the European Union, 2006. Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration.
- Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P., Sutton, M.A., 2008. Transformation of the nitrogen cycle: recent trends, questions, and potential solutions. Science 320, 889–892. https://doi.org/10.1126/science.1136674
- Gauthier, S., Bernier, P., Kuuluvainen, T., Shvidenko, A.Z., Schepaschenko, D.G., 2015. Boreal forest health and global change. Science 349, 819–822. https://doi.org/10.1126/science.aaa9092
- Gruber, N., Galloway, J.N., 2008. An Earth-system perspective of the global nitrogen cycle. Nature 451, 293–296. https://doi.org/10.1038/nature06592
- Helmisaari, H.-S., Kaarakka, L., Olsson, B.A., 2014. Increased utilization of different tree parts for energy purposes in the Nordic countries. Scand J Forest Res 29, 312–322. https://doi.org/10.1080/02827581.2014.926097
- IPCC, 2014. Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, USA.
- Jacob, D., Petersen, J., Eggert, B., Alias, A., Christensen, O., Bouwer, L., Braun, A., Colette, A., Déqué, M., Georgievski, G., Georgopoulou, E., Gobiet, A., Menut, L., Nikulin, G., Haensler, A., Hempelmann, N., Jones, C., Keuler, K., Kovats, S., Kröner, N., Kotlarski, S., Kriegsmann, A., Martin, E., van Meijgaard, E., Moseley, C., Pfeifer, S., Preuschmann, S., Radermacher, C., Radtke, K., Rechid, D., Rounsevell, M., Samuelsson, P., Somot, S., Soussana, J.-F., Teichmann, C., Valentini, R., Vautard, R., Weber, B., Yiou, P., 2014. EURO-CORDEX: new high-resolution climate change projections for European impact research. Reg Environ Change 14, 563–578. https://doi.org/10.1007/s10113-013-0499-2
- Jonsson, R., 2011. Trends and Possible Future Developments in Global Forest-Product Markets - Implications for the Swedish Forest Sector. Forests 2, 147–167. https://doi.org/10.3390/f2010147
- Lucas, R.W., Sponseller, R.A., Gundale, M.J., Stendahl, J., Fridman, J., Högberg, P., Laudon, H., 2016. Long-term declines in stream and river inorganic nitrogen (N) export correspond to forest change. Ecol Appl 26, 545–556. https://doi.org/10.1890/14-2413
- Luo, Y., Su, B., Currie, W.S., Dukes, J.S., Finzi, A., Hartwig, U., Hungate, B., 2004. Progressive Nitrogen Limitation of Ecosystem Responses to Rising Atmospheric Carbon Dioxide. BioScience 54. https://doi.org/10.1641/0006-3568(2004)054[0731
- Norén, V., Hedelin, B., Bishop, K., in preparation. Use of Risk Assessment and Approach to Risk Management in Swedish Drinking Water Sector.
- NVO, 2011. Drought and low flow in Norway [WWW Document]. URL http://www.nve.no/en/Water/Hydrology/Flood-and-drought/Drought-and-low-flow-in-Norway/ (accessed 10.4.15).
- Richardson, A.D., Andy Black, T., Ciais, P., Delbart, N., Friedl, M.A., Gobron, N., Hollinger, D.Y., Kutsch, W.L., Longdoz, B., Luyssaert, S., Migliavacca, M., Montagnani, L., William Munger, J., Moors, E., Piao, S., Rebmann, C., Reichstein, M., Saigusa, N., Tomelleri, E., Vargas, R., Varlagin, A., 2010. Influence of spring and autumn phenological transitions on forest ecosystem productivity. Philos T R Soc B 365, 3227–3246. https://doi.org/10.1098/rstb.2010.0102
- Roots, E.F., 1989. Climate change: High-latitude regions. Climatic Change 15, 223–253. https://doi.org/10.1007/BF00138853

- Rudberg, P.M., 2013. Sweden’s evolving hydropower sector: renovation, restoration and concession change (No. Project Report 2013-01). Stockholm Environment Institute, Stockholm, Sweden.
- Rytter, L., Johansson, K., Karlsson, B., Stener, L.-G., 2013. Tree Species, Genetics and Regeneration for Bioenergy Feedstock in Northern Europe, in: Kellomäki, S., Kilpeläinen, A., Alam, A. (Eds.), Forest BioEnergy Production: Management, Carbon Sequestration and Adaptation. Springer Science+Business Media, New York, USA, pp. 7–37.
- Sandström, C., Lindkvist, A., Öhman, K., Nordström, E.-M., 2011. Governing Competing Demands for Forest Resources in Sweden. Forests 2, 218–242. https://doi.org/10.3390/f2010218
- Seitzinger, S.P., Harrison, J.A., Dumont, E., Beusen, A.H.W., Bouwman, A.F., 2005. Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: An overview of Global Nutrient Export from Watersheds (NEWS) models and their application. Global Biogeochem Cy 19, GB4S01. https://doi.org/10.1029/2005GB002606
- Sjökvist, E., Mårtensson, J.A., Dahné, J., Köplin, N., Björck, E., Nylén, L., Berglöv, G., Brunell, J.T., Nordborg, D., Hallberg, K., others, 2015. Klimatscenarier för Sverige (en: ’Climate scenarios for Sweden’) (No. 15), Klimatologi (Climatology). Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden.
- Skogsstyrelsen, 2014. Swedish Statistical Yearbook of Forestry. Swedish Forest Agency, Jönköping, Sweden.
- SLU, 2016. Forest Statistics 2016, Official Statistics of Sweden. Swedish University of Agricultural Sciences (SLU), Umeå, Sweden.
- SLU, 2015. Forest statistics 2015, Official Statistics of Sweden. Swedish University of Agricultural Sciences (SLU), Umeå, Sweden.
- Swedish Commission on Climate and Vulnerability, 2007. Sweden facing climate change (Final report of the Swedish Commission on Climate and Vulnerability No. SOU 2007:60), SOU 2007:60. Statens Offentliga Utredningar, Stockholm.
- Swedish Environmental Protection Agency, 2017. Miljömålen - Årlig uppföljning av Sveriges nationella miljömål 2017 (Environmental Objectives - Annual evaluation 2017).
- Swedish Government, 2017. Act (SFS 2017:720) on Climate.
- Swedish Government, 2014. Sustainable use of land and water focusing on the environmental objectives (SOU 2014:50).
- Swedish Government, 2013. A Swedish Strategy for Biodiversity and Ecosystem Services (Gov. Bill 2013/14:141).
- Swedish Government, 2006. Summary of Government Bill 2004/05:150: Environmental Quality Objectives – A Shared Responsibility.
- Swedish Government, 1998. The Swedish Environmental Code (SFS 1998:808).
- Swedish Government, 1993. Ordinance (SFS 1993:1096) on Forest Maintenance.
- Swedish Government, 1979. Act (SFS 1979:429) on Forest Maintenance.
- Teutschbein, C., Grabs, T., Karlsen, R.H., Laudon, H., Bishop, K., 2015. Hydrological response to changing climate conditions: Spatial streamflow variability in the boreal region. Water Resour Res 51, 9425–9446. https://doi.org/10.1002/2015WR017337
- Teutschbein, C., Wetterhall, F., Seibert, J., 2011. Evaluation of different downscaling techniques for hydrological climate-change impact studies at the catchment scale. Clim Dynam 37, 2087–2105. https://doi.org/10.1007/s00382-010-0979-8
- WMO, 2006. Drought monitoring and early warning, WMO - No- 1006. WMO.

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

D5.2: THE MAIN NEXUS CHALLENGES IN 'GREECE'

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Glossary / Acronyms

1 Introduction

Greece is located in the South-Eastern part of Europe in the Mediterranean Sea. Its area is about 131,957 km^2 and its population has been estimated to 10.8 million residents. The Aegean Sea lies to the East of the mainland, the Ionian Sea to the West and the Mediterranean Sea to the South. Greece has the longest coastline in the Mediterranean Basin (approx. 16,300 km) and more than 5,000 islands (227 inhabited). The major economic sectors supporting national GDP are agriculture and tourism.

The natural environment of Greece is of exceptional importance and due to its climatic and geomorphological conditions the biodiversity is very rich. More than 25% of its total area is registered as natural protected areas (e.g 'NATURE2000' network). The available water resources have been classified in 14 water districts. The total groundwater resources are estimated around 10,3hm^3/y. As for the energy sector, a 39% is covered by conventional energy sources, lignite (77%) and RES (photovoltaics, wind parks, small hydro-power plants and biomass) (22%) while 61% of Greece's energy needs are covered by imports (mainly petroleum products and natural gas). The food sector is strongly related to the agri-food sector and the agricultural production. Extensive plains, producing large quantities of agricultural products and food, are primarily located in the regions of Thessaly, Central Macedonia, Thrace, Peloponnese and Crete. Finally, the tourist sector dynamically flourishes as Greece attracts a huge number of tourists (~ 20M every year) especially during the period between April to October.

The main questions at stake in the case of Greece have to do with: the rational use of natural resources; the sustainable management of the nexus components (water, energy, land, food, climate); the exploration of pressures put on the nexus components by agricultural, domestic, industrial and tourist sectors; the clarification of interlinkages among the nexus components;

Extremely important role in the progress of the project plays the policy goals and priorities set in the nexus-related policy papers as well as the involvement of stakeholders interested in giving valuable feedback, covering several knowledge gaps and testing as pilot users the Serious Game. Also, the incorporation of data from thematic models and other data sources into the Greek CS is of exceptional importance.

A critical number of stakeholders, representatives of public organizations, businesses, NGOs and academic/research institutes have already been involved in the project in order to provide their knowledge, experience and expertise. The Greek team conducted personal interviews with each of them while the first stakeholders' workshop took place in Athens, on June 23, 2017. Several knowledge gaps and misunderstandings were clarified. The Greek team received valuable comments and feedback regarding: the interlinkages among the nexus components, the main productive sectors that put pressures on them, the main policy goals and policy instruments concerning the nexus components as well as several inconsistencies with respect to the policy implementation phase. The role of stakeholders (formal or informal) during the policy design and decision making process, their influence/power over policy decisions and their interests with respect to the nexus-related policies have been also explored. The number of stakeholders is constantly increasing as the case study develops.

Among the main societal challenges addressed so far are:

- the decline of Greek population according to the relative trends provided by Eurostat;
- the decline of the national GDP due to the fiscal crisis that takes place in Greece during the last seven years and;
- the extreme increase of unemployment.

The prevailing economic sectors that support national income are agriculture and tourism. Agriculture is strongly related to the food sector while both agricultural and tourist sectors offer employment and contribute to the establishment of a balanced pattern of development between urban and rural regions.

The nexus sectors investigated in the case of Greece are: water, energy, climate, food, land as well as the agricultural and tourist sectors. It should be mentioned that agriculture and tourism put extra pressures to the nexus components in order to cover their needs. Regarding water use, about 85% of the available fresh water resources is used by the agricultural sector, 3% is disposed for industrial use and the rest 12% for domestic water supply. Energy production is supported by both conventional and renewable energy resources with households/services being the most energy consuming sector. The highest percentage of electricity is produced by coal while RES follow with a total sharing percentage of 29%. As for land, the prevailing land uses in Greece are cropland, woodland and broadleaved woodland.

The agricultural sector contributes about 3.8% of the national GDP. The most representative Greek agricultural products are grapes, olives and olive oil. As for the tourist sector, it has a long tradition due to the multiple historic natural and cultural resources of Greece. It contributes about 18.5% of the national GDP (Eurobank, 2016).

Climate change has already affected and it will further affect Greece in the future. National policy priorities for climate change adaptation and mitigation strategies are under structure. The Ministry of Environment and Energy has published a National Strategic Plan for Climate Change adaptation concerning the adaptation of Greek society and the economic sectors to the new climatic conditions. In addition, regional plans (NUTS 2 level) are prepared exploring the specific impacts of climate change for each Greek NUTS 2 region and the necessary measures that have to be taken. According to a study published by the Bank of Greece (2011), the minimum winter temperature will be increased by 1.5^0 C during the period 2021-2050 and the average highest summer temperature will be increased by 1.5^0 C – 2.5^0 C during the same period. The total annual rainfall will be declined while heavy and short-term storms will be increased resulting in an increased flood risk in urban and rural regions.

The sustainable management and effective use of the nexus sectors is regulated by the respective legislative framework (binding and non-binding) that sets the terms under which several activities (e.g. agricultural, industrial, tourist etc.) can take place. The main links of the nexus sectors with the relative policy framework concern:

Climate:

- Reduction of GHG emissions
- Increase of the adaptation ability and resilience against climate change
- Adaptation of productive sectors to climate change impacts
- Development of regional/local action plans with respect to climate change
- Increasing the adaptation capability of Greek society – Increasing awareness
- Establishment of a GHG emissions trading system

Water:

- Protection and management of surface water and groundwater (reconciliation of the national legislative framework for water resources with the WFD 2000/60/EC)
- Assessment and management of flood risk
- Water pricing
- Water savings practices

Agriculture and food:

- Preservation and sustainable use of plant genetic resources for food and agriculture
- Regulations determining the spatial organization of livestock activities and the sustainable

development of livestock
- Rational use of pesticides - Rules regulating pesticides’ market
- Sustainable development of aquaculture
- Food security and fodder safety
- Sustainable development of agriculture / Organization of agricultural land / Establishment of agricultural associations

Energy:

- Spatial planning, installation and sustainable management of RES
- Electricity production from RES
- Co-generation of high performance electricity and heat
- Rules regulating electricity market
- Promotion of natural gas / Rules regulating natural gas market
- Energy pricing

Land:

- Sustainable spatial development / Protection of biodiversity and natural resources
- Establishment of a balanced spatial pattern between rural and urban regions
- Development of a balanced and competitive economy
- Sustainable spatial planning of aquaculture
- Sustainable spatial planning of the industrial sector

Tourism:

- Sustainable development of tourism
- Strengthening tourist entrepreneurship
- Organization of tourist training activities

Background of the case

The Greek case study is a national case. The nexus sectors (water, land, energy, climate, food) along with the agricultural and tourist sectors are deeply explored under the framework of existing and future trends in combination with the socio-economic context that ‘forms’ the background of the case study. In the next paragraphs some basic characteristics of the case study, shaping its profile, are briefly summarized.

According to the most recent Eurostat data, the population of Greece for the year 2016 was 10,783,748 residents. As projected by Eurostat, it is expected that by the year 2030 the Greek population will have been declined (about 9,944,658 residents) while by the year 2050 it is estimated to 8,918,545 residents. Approximately 35% of the Greek population lives in the metropolitan area of Athens while the less populated NUTS 2 regions are the Islands of Northern Aegean and the Ionian Islands.

The GDP per capita (main GDP aggregate per capita), measured in euro per capita, for the year 2015 was 16.200 euro declined by 23.22% in comparison to the year 2007 due to the fiscal crisis that takes place in Greece during the last seven years.

Unemployment is one of the major existing problems as it has experienced an extreme increase between 2007 and 2016. After 2010, the beginning of economical crisis, the unemployment rate has been exploded especially during 2013 and 2014. In 2016, the unemployment declined by 1.3%.

The energy sector follows the general principles having been determined by the European Union and it has been totally reconciled with the respective European policy priorities. The national goals set for the year 2020 in combination with the European Energy Policy are (Ministry of Environment and Energy):

- 20% reduction of GHG emissions in relation to the respective 1990 emissions levels
- 20% penetration of RES in the gross final energy consumption
- 20% saving of primary energy

The agricultural sector continues to occupy a prevailing position in the Greek economy while its future development is strongly based on the priorities defined by the Common Agricultural Policy (CAP).

Finally, of particular importance is the promotion and further development of the tourist sector. Emphasis is placed on the sustainable tourist development, extension of the tourist season, the tourist specialization and training as well as the improvement of the offered tourist product and services.

1.1 Description of the Nexus challenges

Five thematic models (E3ME, MAGNET, CAPRI, IMAGE-GLOBIO, OSeMOSYS) have been chosen in order to explore the main trends of the nexus sectors in Greek CS. The first results of the models are in line with the SSP2-scenario. At this point, it should be mentioned that the SSP2-scenario is the baseline scenario that corresponds to the 'middle-of-the-road' socio-economic pathway as a representation of a moderate capacity to face future mitigation and adaptation challenges in the medium term (O'Neill et al., 2017). It incorporates factors such as population, economic development, land use and energy use.

Some indicative trends of the nexus sectors in Greece are briefly presented in this section, based on the outcomes of the thematic models.

According to the results provided by E3ME, CO_2 emissions seem to decline constantly until 2050 and the same trend applies also to energy demand for coal and oil. On the other hand, energy demand for gas seems to increase. As for electricity generation, the use of coal and oil decreases while the share of RES seems to constantly increase until 2050.

According to the results provided by MAGNET, the production of agricultural and dairy products seems to follow increasing trends until the years 2030 and 2050. As for land, the land demand per sector depends on the activity and the type of crop. For example, the land demand for wheat increases while land demand for grain decreases.

According to the outcomes of CAPRI, the total utilized agricultural area follows a decreasing trend until the year 2030 but it doesn't decrease significantly. As for water demand for irrigation, it increases between the years 2010 and 2030, something that it is partially justified due to the climate change impacts.

Finally, according to the results provided by OSeMOSYS, the total annual emissions seem to significantly decline until 2030 (in comparison to the year 2010) while RES are constantly increasing their share in the national electricity generation system.

Based on the Deliverable 1.1 (Scientific Inventory of the Nexus) the main interlinkages between the nexus sectors related to Greek CS are briefly the following:

- Climate to Water: Climate change affects precipitation and evapotranspiration. Increase of intensive storms and increase of evaporation are representative impacts of climate change. Climate change also affects river runoff and water level (e.g. sea level rise) while it also increases flood risk and the danger of drought.
- Climate to Land use: Floods, landslides, forest fires, hailstorms and heat waves are among the main impacts of climate change on land that may impose the need for changing current land use patterns.
- Climate to Energy: Climate change is in strong relationship with energy production as it affects energy production patterns (e.g. less fossil fuels – more RES) while it also increases cooling and

heating requirements.

- Climate to Food: The production of agricultural and dairy products depends on weather conditions in agricultural regions and pastures. Climate change affects such land uses and consequently the agricultural and livestock production.
- Energy to Water: High amounts of energy are used by water systems for pumping, purification of water, wastewater treatment, heating of water, etc.
- Energy to Land use: Energy production from both fossil fuels and RES requires the installation and operation of the respective power plants. As a result, land is used for energy production purposes with impacts on soil quality and landscape.
- Energy to Climate: Energy consumption entails increase of environmental heat mainly through the increase of GHG emissions that contribute to the increase of greenhouse effect.
- Energy to Food: High amounts of energy are needed for food production by both the agricultural and industrial sectors. Consequently, as the standards of living are improved, more energy is needed in order to process and transport food.
- Food to Water: The production of food needs vast amounts of water, especially when we are talking about agricultural products. Water is also needed for food consumption.
- Food to Land use: Food production presupposes the availability of land for the development of agricultural and livestock activities as well as for the development of food industry.
- Food to Climate: The production and consumption of food contributes to the increase of GHG emissions in the atmosphere (e.g. agricultural and livestock production systems).
- Food to Energy: The food sector depends on fossil fuels. On the other hand, food waste can be used for energy production (biodiesel, ethanol, biofuels, etc.).
- Land use to Water: Land uses affect water quality and water quantity. Agricultural land use (enormous irrigation needs), urban land use and industrial land use are main consumers of water that simultaneously have negative impacts on water quality.
- Land use to Food: Land is strongly related to the production of food, especially agricultural land and pastures.
- Land use to Climate: Several land uses produce GHG emissions that affect climate. Also climate is affected by changes on land uses such as deforestation and conversion of wetlands into agricultural land.
- Land use to Energy: Changes of land uses entail changes to energy production and consumption patterns as a consequence of differences in energy demand.
- Water to Land use: Any kind of land use and human activity requires water. As an example, in urban areas water is necessary for covering citizens’ needs, in agricultural areas water is used for irrigation purposes, etc.
- Water to Food: Water is necessary for food production and consumption. Water quality and water quantity strongly affect the quality and quantity of food products.
- Water to Climate: The evapotranspiration is the basic factor through which water affects climate.
- Water to Energy: The availability of water resources affects energy production from hydroelectric power plants. Also, water is needed for fossil fuel extraction, fuel processing and energy conversion (e.g. transportation, electricity generation)

Several trade-offs may be identified among the nexus sectors and the activities related to them. Some indicative trade-offs are summarized in this section.

Regarding the sectors of food and water, a future increase of global population will entail an increase for food. Thus, more water will be needed for food production. On the other hand, water resources availability decreases, causing conflicts with respect to water uses (e.g. drinking water and agricultural water). Also, increasing need for food entails ‘more’ land for food production which in turn entails land use conflicts with other sectors (e.g. energy sector).

Another issue is related to energy production from hydroelectric power plants. Such power plants presuppose the availability of water resources for energy production but according to the future trends, the available water resources will decrease due to climate change impacts. As for the energy needs, they follow increasing trends, entailing increased GHG emissions, except for the case that the share of RES will contribute significantly to energy production.

As for possible synergies among the nexus sectors, these could be:

- The exploitation of food waste for energy production purposes
- The exploitation of agricultural waste and biomass for energy production
- Water saving practices in reservoirs for energy production and agricultural use
- Reduction of energy consumption (energy savings) in order to limit GHG emissions and the respective impacts on climate
- Rational management of land in order to avoid possible conflicts among several productive sectors (e.g. energy sector, agricultural sector)

1.2 Description of the pathways

This section focuses on the description of pathways for the Greek CS that have been classified per nexus sector. The exploration of possible pathways was mainly based on policy analysis (WP2) and the policy goals, priorities and instruments identified in the relative policy papers.

Regarding the energy sector, the general goals for 2020 have already been set in the general context of EU energy policy while the energy goals for 2030 are now under consideration. The general energy goals for 2020 are:

- 20% reduction of GHG emissions in relation to the respective 1990 emissions levels
- 20% penetration of RES in the gross final energy consumption
- 20% saving of primary energy

Especially for Greece, the national goal for emissions (year 2020) is the reduction of GHG emissions by 4% in sectors not included in the emissions trade system with respect to 2005 emissions levels. Moreover, according to the law 3851/2010, the goal concerning RES penetration has been modified and it is expected that RES share will be raised to 20% (it was initially 18%). Exploitation of biomass and development of energy crops for biofuels production are also main priorities of the Greek energy sector. Energy models have shown that by the year 2020, 13300MW of the total electricity will be produced by RES (7500MW from wind parks, 3000MW from hydropower plants and 2500MW from photovoltaics) (Ministry of Environment and Energy). Emphasis is also placed on the promotion of co-generation technologies and use of natural gas.

Concerning climate, Greece has adopted:

- The commitments of Kyoto Protocol for reducing GHG emissions until 2020 (scenario of the expected progress) by monitoring emissions, supporting energy efficiency, adopting technologies that capture CO_2, reducing methane emissions, promoting RES use and adopting energy saving technologies in buildings.
- The commitments of Doha's amendment on Kyoto Protocol concerning the limitation or reduction of emissions – 80% for the base year.
- The commitments of the Paris Convention for keeping the global temperature rise below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.
- A National Strategic Plan (released in 2016) aiming at strengthening the country's adaptation

ability and resilience against climate change impacts (adaptation of productive sectors).

- Commitments with respect to the establishment of a GHG emissions trading system including air transport GHG emissions that aim at the limitation of GHG emissions in a cost-effective and economic-efficient way.

Regarding water resources, Greece has adopted the WFD 2000/60/EC for the protection and sustainable management of water resources in 2003 (Law 3199/2003). Also, flood risk maps have been prepared in order to identify possible future flood risks and zones with high flood risk. Finally, a discussion about water pricing and costs of water services on the basis of the rational and sustainable use of water resources by the several productive sectors (e.g. agriculture) is planning on starting

In the agricultural and food sector, emphasis is placed on the sustainable future development of agriculture (rational use of natural resources by the agricultural sector), the preservation and sustainable use of plant genetic resources, the rational use of pesticides, the creation of a national registry including farmers and their plots, the safety of food and fodders (high quality food products) and the sustainable development of livestock (mapping of pastures, etc.).

As for land use management, the main priorities are focusing on: the organization of the national cadastre, the regulation of land uses, the identification of strategic directions for the integrated and sustainable spatial development until 2023, the establishment of a balanced and competitive economy, the spatial organization of aquaculture until 2024 and the spatial organization of the industrial sector until 2021.

Finally, the priorities concerning the sustainable development of tourism are mainly the promotion of tourist entrepreneurship, the undertaking of tourist training activities and the development of alternative tourism adapted to the specific characteristics of each region.

1.3 Develop a conceptual model

The conceptual model of the Greek Case Study has been finalised and now the System Dynamics Model is under construction and it will be finalized by Jan 2018. The conceptual model incorporates all the nexus sectors and it sheds light on the basic interactions existing among them. Except for the general framework of the conceptual model, five sub-models (one per each nexus sector) have also been constructed providing more detailed information about the specific inter-relations that each nexus sector has with the others.

The general framework of the conceptual model is presented in the next Diagram.

SIM4NEXUS

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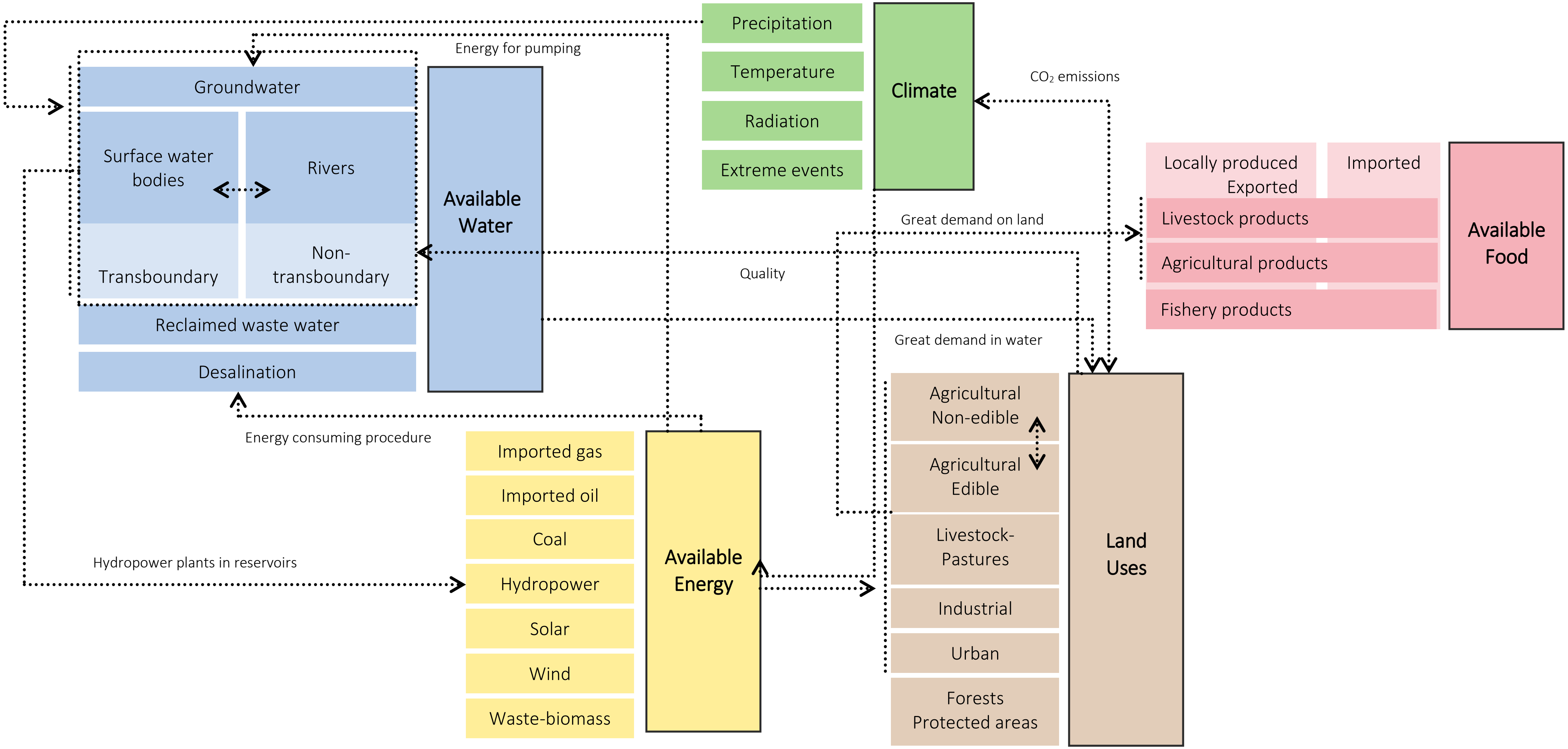

Groundwater

Surface water bodies

Rivers

Transboundary

Non-transboundary

Reclaimed waste water

Desalination

Available Water

Energy for pumping

Precipitation

Temperature

Radiation

Extreme events

Climate

CO_2 emissions

Locally produced Exported

Imported

Livestock products

Agricultural products

Fishery products

Available Food

Great demand on land

Quality

Great demand in water

Energy consuming procedure

Imported gas

Imported oil

Coal

Hydropower

Solar

Wind

Waste-biomass

Available Energy

Hydropower plants in reservoirs

Agricultural Non-edible

Agricultural Edible

Livestock-Pastures

Industrial

Urban

Forests Protected areas

Land Uses

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The conceptual model includes the basic interactions among the nexus sectors. Its structure was based on the existing interlinkages among the respective sectors, the goals that have been set for the Greek CS, the available data and the strategic directions upon which the future development of Greece will be based on. The more representative interactions are:

- The energy used for pumping (Energy-Water)
- The energy used for desalination purposes (Energy-Water)
- The exploitation of water resources for energy production by hydroelectric power plants (Water-Energy)
- The water demand by several land uses (Water-Land)
- The impacts of land uses on water quality (Land-Water)
- The demand of land for food production (Land-Food)
- The CO_2 emissions by several land uses/activities (Land-Climate)

1.4 Use of thematic models in understanding the Nexus

Five thematic models have been chosen in order to provide data for the Greek CS. These models are:

- E3ME (**E**nergy-**E**nvironment-**E**conomy): A model used for the assessment of long-term impacts of climate and energy policy on economic activity and employment. It is designed to handle interactions between the economy and the energy system.
- MAGNET (**M**odular **A**gricultural **G**e**N**eral **E**quilibrium **T**ool): A general computable equilibrium model, with an additional focus on agriculture, designed for economic impact assessment. It is a tool for analysis of trade, agricultural, climate and bioenergy policies.
- CAPRI (**C**ommon **A**gricultural **P**olicy **R**egionalised **I**mpact modelling system): Agro-economic model designed for the ex-ante impact assessment of agricultural, environmental and trade policies with a focus on the European Union. It integrates economic, physical and environmental information in a consistent way. It includes irrigation and livestock water use while it also represents biofuel markets.
- IMAGE-GLOBIO (**I**ntegrated **M**odel to **A**ssess the **G**lobal **E**nvironment): It is a comprehensive integrated modelling framework of global environmental change. It gives large-scale and long-term assessments of the interactions in the society-biosphere-climate system. GLOBIO model is used to assess the consequences of global environmental change on biodiversity and ecosystem services.
- OSeMOSYS (**O**pen **S**ource **E**nergy **Mo**delling **Sys**tems): Open-source energy system optimization model, designed to inform the development of national and multi-regional energy strategies.

The first results of the thematic models, with respect to the baseline scenario, have already been provided by the modellers. The Greek team has access to all data and tries to incorporate them in the System Dynamics Model that is now under construction. Stakeholders have been informed about the role of the thematic models and the respective data. More analytically, the data provided per each thematic model are:

- E3ME: Data from 2003 until 2050, yearly time step.
- MAGNET: Data for the years 2011, 2015, 2020, 2030, 2040, 2050.
- CAPRI: Data for the years 2010 and 2030.
- IMAGE-GLOBIO: No data yet.
- OSeMOSYS: Data for the years 2010 and 2030. Also, data used as input to the model until 2040 (yearly time step).

Most of the nexus challenges will be addressed by the use of the aforementioned thematic models. However, in case data is lacking, the Greek team will use data from other national or European data sources. Until now, there are no misunderstandings regarding the outcomes of the thematic models. The Greek team is in contact with the modellers in order to solve any possible problems.

As the SDM has not been yet finalised, a total assessment concerning the usability of the thematic models or the existence of possible knowledge gaps cannot be concluded in this report. Nevertheless, thematic models will help the Greek team to understand the nexus challenges and more specifically, issues having to do with the:

- demand for irrigation water by the agricultural sector
- area (land) occupied by livestock and agriculture (per crop)
- production of biofuels
- production of agricultural and dairy products
- prices (market prices) of agricultural and dairy products
- energy prices
- exports and imports of the energy sector
- GHG emissions
- future GDP
- employment per sector

These are some indicative issues covered by the thematic models. There is much more information provided by each of them that is useful to ‘feed’ the SDM and better understand the future trends of the nexus sectors.

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

Since November 2016, the Greek team started to set some preliminary contacts with possible stakeholders that may be interested in the project and wish to give their feedbacks on several issues addressed by SIM4NEXUS.

At a first stage, they involved in the policy analysis phase. Stakeholders’ engagement is very important in almost any case where policy decisions are received. They can affect either positive or negative a policy process and its implementation. According to the power or means of action that any stakeholder possesses, he/she can boost or block policies that promote or contradict his/her interests. Moreover, stakeholders’ activities are strongly affected by the policy framework that sets the conditions within which an action may take place.

After sending them informative material about the project (brochure, link of the project, project flyer), a number of personal interviews with each of them is conducted. In this context, representatives of public and private organizations offered their knowledge, experience and expertise with respect to the nexus-related policies. Stakeholders’ involvement provided a better understanding of the decision-making and the policy design process, in order to clarify policy priorities and interactions and also to eliminate any misunderstandings. The choice of participants was based on the nexus components investigated in the Greek CS.

Until now, seventeen interviews (1-5 persons) have been conducted with stakeholders already engaged in the project. Among these stakeholders are: the Ministry of Environment and Energy, the Ministry of Foreign Affairs, the Ministry of Tourism, the Hellenic Public Power Corporation S.A. (PPC), the Center of Athens Labor Unions, the Piraeus Bank, the Hellenic Association of Photovoltaic Energy Producers, the Greek Ombudsman, academics from National Technical University of Athens, the Ministry of Infrastructures, the National Documentation Centre, the Hellenic Association for Cogeneration of Heat and Power, the National Cadastre and Mapping Agency, representatives for the agri-business sector ('Mills of Crete' and the agricultural multi-shareholders Company 'Monopati-Monakrivo'), the Greek branch of WWF. Stakeholders are enriching the Case Study with useful information about issues concerning: policy design, strategic policy priorities, interactions among decision makers, policy implementation in a practical level, policy coherence and existing conflicts as well as their interests as to the nexus-related policies. Additional information about their formal and informal role during the policy making process, the source of their power as well as their interests with respect to the nexus-related policy sectors was also gathered. It should be mentioned that as the project develops, more stakeholders will be engaged and the relevant information will be constantly updated.

In general, public decision makers (mainly Ministries and Central Government) are the key players during the policy design process. Private stakeholders are interested in the relative policies setting the framework for the development of specific actions and the implementation of investments. It should be mentioned that in cases where cross-sector policies are structured, collaboration among the interested parts takes place.

The first stakeholders' workshop for the Greek CS took place on June 23, 2017 in Athens. The Greek team made a brief introduction concerning the issues that would be discussed during the workshop. Such issues included:

- The general overview and goals of SIM4NEXUS
- The conceptual model
- The interlinkages among the nexus components
- The policy framework regulating the management of the nexus components
- The basic concepts and principles of a serious game

After the introductive presentations, a fruitful discussion took place and the Greek team received valuable comments and feedback regarding:

- The interlinkages among the nexus components
- The main productive sectors that put pressures on the nexus components
- The main policy goals and policy instruments concerning the nexus components
- The existing knowledge gaps with respect to the policy implementation phase
- The conflicts arising at the policy implementation stage

Among the stakeholders who attended the workshop were representatives of ministries and public organizations, representatives of the business sector and academic institutions (about 15-20 participants). It should be mentioned that stakeholders covered several knowledge gaps and raised policy issues that have not been considered until that point in the development and the analysis of the Greek CS.

Right after the end of the workshop, a questionnaire was shared and the stakeholders were asked to provide further information on:

- Possible conflicts among stakeholders that use the same resources (water, land, energy) for the

achievement of their goals
- The availability of resources
- The complementarity among the several productive sectors
- The issues that captured their attention
- Their expectations with respect to the serious game
- The issues that need further clarification
- Their comments on the nexus interlinkages

The answers of stakeholders were disseminated and incorporated into the conceptual model.

The second stakeholders' workshop will take place in the forthcoming months. Stakeholders will be informed about the progress of the project and they will be asked to validate the policy coherence study that is now under development. Feedback concerning the construction of use-cases will be also gathered.

2 Conclusions and follow-up

Conclusively, until now the main issues covered for the Greek CS include:

- The inventory of the nexus sectors
- The study of the nexus interlinkages
- The policy analysis as to the nexus-related policies
- The engagement of stakeholders
- The organization of the first stakeholders' workshop
- The development f the conceptual model
- The construction of the Systems Dynamics Model (SDM)
- The inventory of possible pathways
- The assessment and exploitation of data from the several thematic models
- The collection of additional data that will be incorporated in the SDM

In the forthcoming months the policy coherence study will be finalised. Missing data from the thematic models will be provided by the modellers while by January 2018 the SDM will be ready for the 'Business As Usual Scenario'. In addition, we are planning to develop SG Use Cases (Task 1.2) based on the needs of the Greek CS. We are also trying to disseminate the concept of S4N at national level (mainly at central administration). S4N will be included in the Voluntary National Review report that will be presented at the high level political Forum of UN next July as a research project that contributes to the implementation of SDGs at national level.

3 References

- Bank of Greece (2011), Environmental, economic and social impacts of climate change in Greece, Study Committee for the impacts of climate change (in Greek).
- Eurobank: http://www.naftemporiki.gr/finance/story/1111257/eurobank-kali-xronia-gia-ton-tourismo-to-2016 (in Greek).
- Law 3851/2010: Acceleration of RES development for combating climate change (2010) (in Greek).
- 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.

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

D5.2: THE MAIN NEXUS CHALLENGES IN CASE STUDY ‘LATVIA’

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Glossary / Acronyms

TERM	EXPLANATION / MEANING
GHG	GREENHOUSE GASSES
RES	RENEWABLE ENERGY SOURCES
HPP	HYDROPOWER PLANTS

1 Introduction

Low-carbon development is the key focus of the Latvia case study. According to the goals and priorities set by national policy documents, Latvia is seeking for possibilities to reduce energy dependency from imported fuels, increase sustainable use of renewable energy sources and ensure economic development while reducing greenhouse gas emissions. For selection of the appropriate direction of the case study the key stakeholders from ministries (Environment, Agriculture), scientific institutes, regional and local authorities were approached already at an early stage of the project. Several small bilateral meetings, followed by a thematic event on energy & waste topic and a stakeholder workshop on 15 November 2017, involving stakeholders from various institutions, have been organised. During the discussions with the stakeholders, the key research questions of the case study have been identified: (i) is it possible to enlarge energy self-supply, by widening the use of renewable energy sources in the country; (ii) which trade-offs would be acceptable and what are the possible solutions towards low carbon economy.

Latvia has a high potential for renewable energy (e.g., hydro, biomass), but remains largely dependent on imported fossil fuels and electricity. Thus, energy security is of a key concern and ensuring the energy supply, competitiveness, energy efficiency and the use of renewable energy. At the same time along with significant reduction of total GHG emissions since 1995, the current level of GHG emissions in Latvia remains high and is between the highest values in the European Union. Accordingly, already now much effort must be paid to reduce emissions and reach mandatory CO_2 reduction targets set for 2030. Increasing use of bio-resources and renewable energy sources (RES) can be considered as an option. However, it rises several questions of concern e.g., harvesting of biomass puts a pressure on forestry and growing energy plants compete with crops and food production. Growing energy plants require large amounts of fertilizers resulting in a negative impact on water quality and causing eutrophication of water bodies thus posing a risk to climate change adaptation. Climate change has an impact on water resources e.g., increasing autumn and winter precipitation generates higher flood risks. During these periods soils in Latvia suffer from excessive moisture. On the other hand, periods of droughts in summer have an impact on use of hydropower, particularly for small scale applications, as well as on agriculture. Thus, preparedness to resist climate change and reduce adverse effects is becoming of high importance for national economy and the society in general.

Energy, climate, agriculture, land use, water, food production, forestry, biodiversity are the key policy sectors of concern in this case study. In Latvia, low carbon development is getting an increasing attention on various policy levels along with elaboration of the “National strategy on low-carbon development 2050” (due for the end of 2017). Low carbon development calls for reduction of greenhouse gas (particularly CO_2) emissions as well as maintaining or even increasing CO_2 sequestration at the same time having positive environmental, economic, and social impacts. Potential directions of low-carbon development in Latvia comprise sustainable energy, comprehensive energy efficiency; resource efficient and environmentally friendly transport; sustainable land management, consumption, and production; research and innovation on low carbon technologies[1].

Acknowledging the need to increase the use of natural resources, a draft national strategy “Bio-economy strategy 2030” has been elaborated and submitted to Cabinet of Ministers on 3 August 2017. According to the strategy, the priority directions comprise promotion and maintenance of employment level in the branches of bioeconomy (e.g., agriculture, forestry, fishery, food production), increasing the

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[1] http://ilgtspejigaattistiba.saeima.lv/attachments/article/719/2017-03-28_OMAstratUnPielagStrat_IPruse.pdf

added value of products of bioeconomy, increasing the export value of products of bioeconomy branches. Substitution of fossil fuels with bio-resources is one of the main goals of the strategy.

The Latvia case study is a study on a national scale having a projection in a time path from 2010, 2020, 2030, 2040 up to the year **2050**.

1.1 Description of the Nexus challenges

1.1.1 Main trends in the case study for each of the nexus sectors

Latvia is among the fastest growing economies in the European Union[2]. Experts predict ~4% economic growth until 2018[3],[4],[5] (the GDP growth rate in Latvia averaged 0.98% from 1995 until 2017[6]). The cornerstones of Latvian economy are agriculture, chemicals, logistics and woodworking, complemented by textiles, food processing, machinery production and green technologies[7]. Exports contribute to more than half of GDP. In 2015 Latvia mostly exported wood and wood products, wood charcoal, electrical machinery, and equipment, as well as mineral products. Due to its geographical location, transit services are highly-developed, along with timber and wood-processing, agriculture and food products, and manufacturing of machinery and electronics industries[8].

Energy

The growing economy requires energy. According to national statistics, the total consumption of energy sources in 2015 was 183.9 PJ being (1.2% less than in 2014). The total consumption of energy sources during 2005-2015 has not changed significantly: 192.1 PJ in 2005 (4.3% more than in 2015)[9]. Latvia is not rich in local energy sources and is dependent on imported energy. Nevertheless, the dependence on imported energy resources reduced from 63.9% in 2005 to 40.6 % in 2014 due to the increased gross consumption of renewable energy sources. Renewable energy sources (RES), particularly wood fuels and hydro energy, along with the oil products and natural gas imported from various countries play the most important role in energy balance of Latvia. The remaining share in the primary energy structure of Latvia is comprised by electricity import, peat, coal, and waste (Figure 1.1.).

Latvia has the second highest share of RES in the energy consumption in the EU; in 2014 Latvian indicator constituted 38.7 % (EU average – 16.0 %)[10]. Latvia is rich in forests (forests[11] covered 3260 th. ha in 2014)[12] and respectively wood fuel is an important local fuel used in centralized, local, and

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[2] www.weforum.org/agenda/2016/02/europe-s-10-fastest-growing-economies/

[3] http://eng.lsm.lv/article/economy/economy/swedbank-latvias-economy-to-grow-4-4.2-this-year-and-next.a248282/

[4] www.tvnet.lv/financenet/finansu_zinas/722017-latvija_gaidama_straujaka_tautsaimniecibas_izaugsme_baltijas_valstis

[5] www.oecd.org/latvia/latvia-economic-forecast-summary.htm

[6] https://tradingeconomics.com/latvia/gdp-growth

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

[8] IndexMundi, Latvia Economy Profile 2017, www.indexmundi.com/latvia/economy_profile.html

[9] www.csb.gov.lv/sites/default/files/nr_03_latvija_galvenie_statistikas_raditaji_2017_17_00_lv.pdf

[10] www.csb.gov.lv/en/notikumi/consumption-renewable-energy-resources-2015-44050.html

[11] Forest: An ecosystem in all stages of its development, dominated by trees, the height of which at the location may reach at least five metres and the present or potential tree crown cover accounts for at least 20% of the stand area.

[12] Central Statistical Bureau of Latvia

individual heat supply, as well as in co-generation. It is estimated that the amount of biomass used in energy sector will increase, although in general, significant changes in primary energy structure are not envisaged until 2020[13].

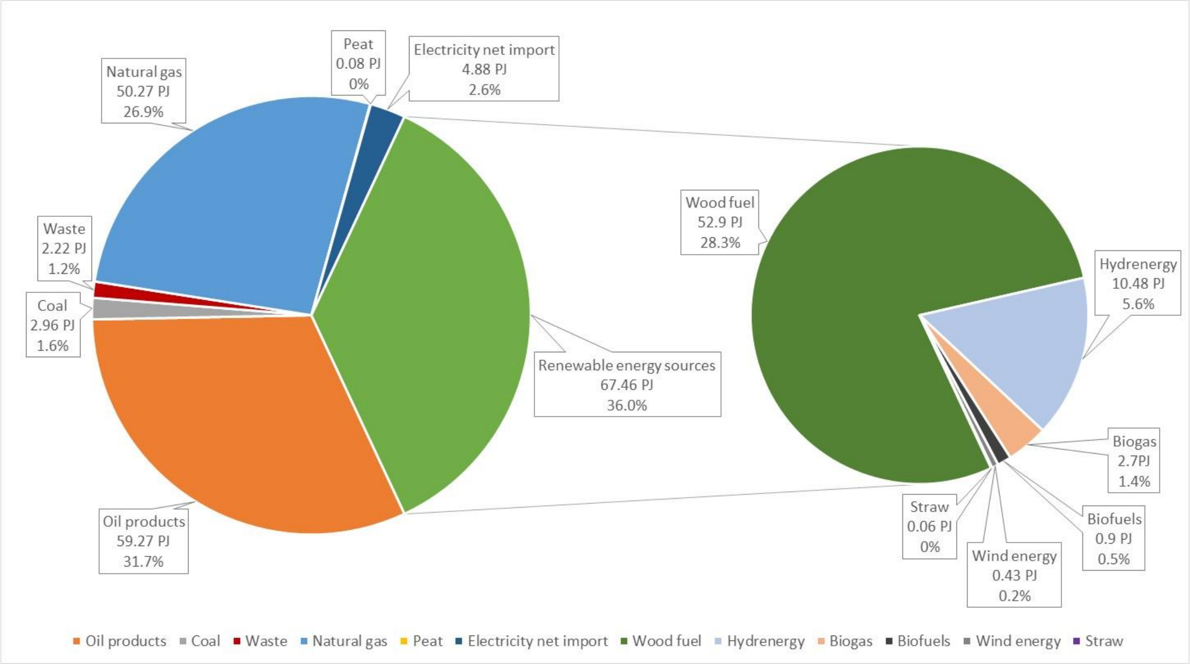

Figure 1.1. Consumption of primary energy sources In Latvia in 2013 (PJ, %)[14]

Latvia has suitable circumstances for use of hydropower (HPPs ensure ca. 40% of electricity consumption). The biggest share of electricity is produced in 3 hydropower plants (HPPs) installed on the Daugava River (see Figure 1.2).

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[13] The Guidelines for the Development of Energy Sector for 2016-2020

[14] The Guidelines for the Development of Energy Sector for 2016-2020

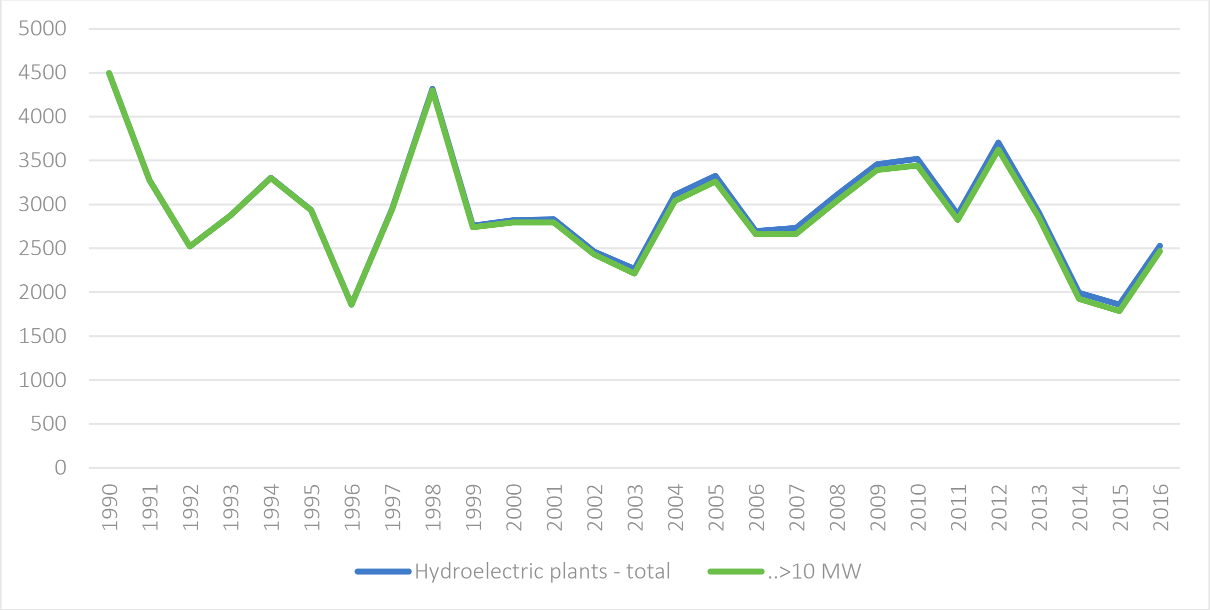

Figure 1.2. Electricity production in Hydropower plants in Latvia (GWh)

During the recent years, installed electrical capacity of hydropower plants has not changed significantly while wind power plants and combined heat and power (CHP) plants using renewable resources has increased notably.[15] The share of solar power in the total energy balance is negligible mostly due to high initial investment costs in technologies. The total share of RES is increasing, nevertheless is has been estimated that further efforts are required to achieve the target of 40% set by the Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC[16].

Climate

Latvia is in the temperate climate zone, it climate conditions are influenced by the vicinity of Baltic Sea and the transfer of air mass by the atmospheric circulation from the Atlantic Ocean, thus creating mild climate. The average annual precipitation is 600-700mm. The mean temperature in January, the coldest month of the year, 2016 was -7.1°C, while in July, the hottest month of the year, it was +18.1 °C (1.7 °C higher than the norm).[17] The sun shines on average 1790 hours a year; the months from May to August have the most days when the sun shines (with monthly averages between 28 to 30 days). The winds from the south, southwest and west are prevailing. The monthly average wind speed varies from 2.8 to 4.0 m/s. The highest wind speed observed so far is 30 m/s, the strongest gusts are 48 m/s. Long term observation data of the Latvian Environment, Geology, and Meteorology Centre show that climate changes are happening in Latvia. During the 20th century the average air temperature in Latvia has risen by 1°C. During the past 100 years, there have been fluctuations in annual rainfall, which tended to rise from the beginning of the second half of the 20th century.[18]

Land

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[15] www.csb.gov.lv/en/notikumi/consumption-renewable-energy-resources-2015-44050.html

[16] Ecologic Institute, Eclareon (2013), Assessment of Climate change policies in the context of the European semester. Country report: Latvia, https://ec.europa.eu/clima/sites/clima/files/strategies/progress/reporting/docs/lv_2014_en.pdf

[17] www.csb.gov.lv/sites/default/files/nr_03_latvija_galvenie_statistikas_raditaji_2017_17_00_lv.pdf

[18] https://meteo.lv/en/lapas/environment/climate-change/climate-of-latvia/climat-latvia?id=1471&nid=660

The total area of Latvia covers 64.6 thousand sq.km where 62.1 thousand sq.km is land, including 30.6 thousand sq.km forest and 23.5 thousand sq.km agricultural land. Inland waters cover the area of 2.5 thousand sq.km.[19]

Water

Latvia is rich in water resources but having different quality. It is assessed that freshwater resources far exceed present and future requirements for water consumption. In Latvia (total) surface water resources are 36882 mill.m^3 per year and ground water resources are 2000 mill.m^3 per year.[20] The Water Exploitation Index (WEI) is one of the lowest in the European Union and it has decreased from 0.013 in 1990 to 0.007 in 2005, due to economic and institutional changes and water saving and water efficiency measures. The main concerns are related to the water quality. For example, eutrophication of inland surface water and marine water is a major environmental problem. It has been observed that the nitrogen concentration in rivers is increasing slightly. The annual average phosphorus concentration in rivers varies between rivers and depends on the different socioeconomic, climatic, and hydrological conditions in each river basin district. On the other hand, the concentration of oxygen-consuming substances in rivers is low and this generally indicates good water quality. It is evaluated that the main reason for inadequate surface water quality in water bodies of Latvia is eutrophication. Pollution from point and diffuse sources, morphological changes in rivers and an influx of biogens from neighbouring countries via transboundary watercourses are the main reasons for eutrophication.[21]

Food

Food processing is one of the oldest and most important industries in Latvia. The food production sector has a steady and stable growth over an extended period (see Figure 1.3). Dairy farming, meat production, beverages, fish processing, growing of fruits and vegetables are the largest agricultural sectors in the country).[22]

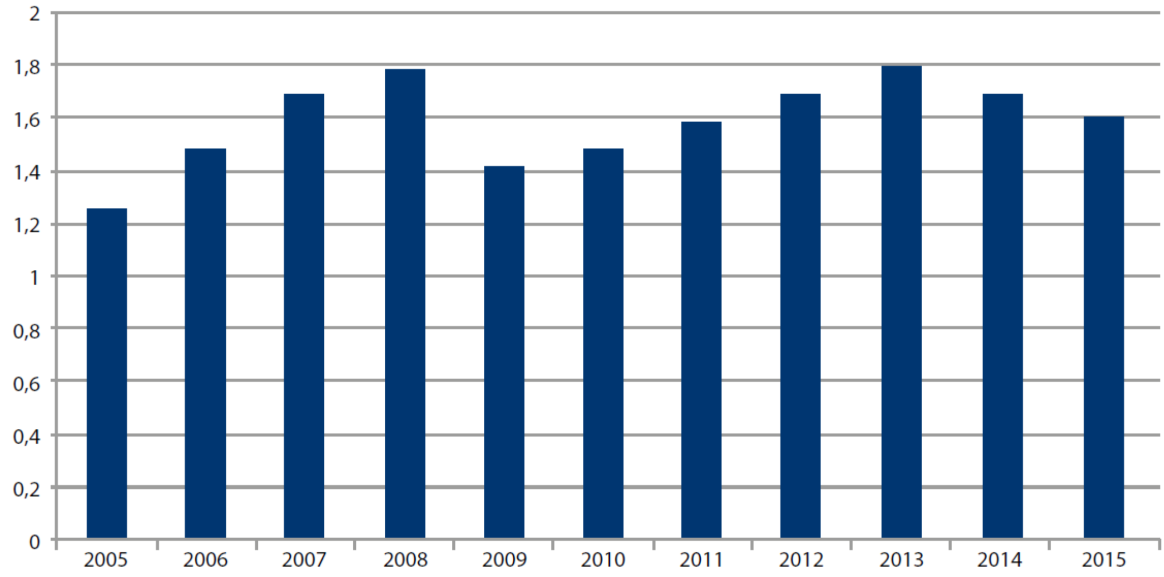

Figure 1.3. Food and beverage output (billion EUR).

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[19] www.csb.gov.lv/sites/default/files/nr_03_latvija_galvenie_statistikas_raditaji_2017_17_00_lv.pdf
[20] www.meteo.lv/lapas/vide/udens/udens-apsaimniekosana-/udens-apsaimniekosana?id=1108&nid=423
[21] www.eea.europa.eu/soer/countries/lv/freshwater-state-and-impacts-latvia
[22] www.liaa.gov.lv/files/liaa/attachments/food_industry_in_latvia.pdf

The food industry is traditionally oriented to the internal market.[23] However, many food products are exported abroad e.g., cheese, butter, milk and milk powder, canned fish, fruit and berry preparations, pickles, various grains, meat products, confectionery, and alcoholic and non-alcoholic beverages.[24]

1.1.2 Interlinkages between Nexus sectors and the trade-offs

In the Case study of Latvia focusing on low carbon development various interlinkages between Nexus sectors have been identified and various trade-offs shall be tackled in the further analyses. This section has been prepared using the summary table of interlinkages from the Deliverable D1.1. The interlinkages relevant for the Latvia case study have been selected.[25] Important interlinkages between Nexus sectors were identified at the discussion with key stakeholders (First stakeholder workshop on 15.11.2017) to complement the section.

Energy

Increasing use of different renewable energy sources (RES) to substitute fossil fuels, reduce dependency on energy import from third countries at the same time reducing CO_2 emissions is the key aspect of the case study. Increasing use of RES creates several interlinkages with other sectors. Here also the question of many possible trade-offs raises:

- Hydropower. Having sufficient water supply, the country is utilising its hydro energy potential on inland water bodies through artificial dams constructed on rivers. Use of electricity produced by hydropower prevent GHG emissions, but can cause implications to water quality, land use and biodiversity, flora and fauna. Hydropower installations depend on climate conditions. Increased precipitation and intensification of extreme events (floods & droughts) due to climate change lead to acceleration of the hydrological cycle and impacts hydropower generation.
- Biomass. Use of solid biomass (e.g., wood fuels) for energy production in Latvia helps reaching GHG emission targets, but at the same time is putting pressure on forests, including the impact on biodiversity, CO_2 sequestration, as well as is competing with production of high added value products. Moreover, growing of energy trees (e.g., willows) may compete on arable land to be used for food production. It also requires application of fertilisers and pesticides affecting the water quality in water bodies.
- Biofuels. Biofuels (e.g. 1st generation) can be produced from crops used for energy production (biocrops/biofuel/biodiesel). Use of biofuels instead of fossil fuels help to reduce GHG emissions from the transport sector, but various processes are needed to make the energy source feasible. Moreover, increase in biofuels production may result in indirect land use change (biofuels take land from food for human consumption), increasing the price of agricultural land which will induce the conversion of non-agricultural land that tends to be carbon-rich into relatively carbon-poor agricultural land. Accordingly, more efforts shall be paid to utilise 2nd generation biofuels.
- Biogas. Agriculture areas use energy as an input to production, but can also provide renewable fuel feedstock (manure, maize, grass, etc.) for the energy sector. There are ca. 60 biogas plants

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[23] www.zm.gov.lv/en/partika/jaunumi/food-industry-is-the-largest-processing-sector-in-latvia-and-it-stands?id=4099

[24] www.liaa.gov.lv/files/liaa/attachments/food_industry_in_latvia.pdf

[25] C. Laspidou et al. (2017). D1.1: Scientific Inventory of the NEXUS

in Latvia. Production and use of biogas can affect energy sector, Anaerobic decomposition of food waste produces methane, which can be converted to electrical power or heat. Use of biogas promotes reduction of GHG, but can cause significant changes to the land use (e.g. growing of energy crops). Another product of anaerobic digestion of food waste is a residual digestate, that can be used as fertilizer and applied e.g., on arable lands.

- Installed technologies for energy production from RES help to reduce GHG emissions, but solar panels, and windmills for power generation, etc. involve direct impacts on land such as removal of vegetation, soil, and alters topography. At the same time, meteorological conditions directly govern the actual output of thermal solar panels, photovoltaics and wind turbines. Currently wind and solar energy does not have an important role in the energy balance of Latvia, although recent developments show a good prospect for penetration of the respective technologies in a broader scale.
- Biodiversity. Growing of energy plants has a negative impact on biodiversity and diminishes areas suitable for protected species. Erection of HPPs creates unfavourable conditions for fish population (e.g., disturbs fish migration).

Water

Being rich in fresh water, Latvia does not experience the water scarcity problem – consumption of water by inhabitants, industry, agriculture etc. are far below the water resources available.

- The problem of water quality mainly due to eutrophication prevails. This is largely caused by leakage of nutrients (nitrogen and phosphorous) from point and diffuse pollution sources (e.g., agricultural land, forests). More frequent rain events will increase the load of suspended matter and nutrients to lakes and rivers. Moreover, nutrient concentrations in lakes will likely rise, the risk of low-oxygen periods will increase, and CO_2 concentration will increase.
- Water quality is an essential issue for uses e.g., in drinking water and food production, but agro-chemicals (crop protection products), antibiotics and possibly hormones have an impact on water quality.

Land

About 47% of the territory of Latvia is covered by forests and ca. 36% of the territory is agricultural land.

- Forests provide the resource for timber production as well as give non-timber products. Forests and semi-natural areas provide resources that can be made available for use in the bioenergy sector to produce both heat and electricity. At the same time forests affect the climate by absorbing CO_2, thus reducing GHG emissions. Moreover, export of forest biomass (e.g., timber, wood and wood based fuels) plays an important role in national economy at the same time reducing the source available for local use in the country.
- Wetlands act as a retention buffer for water, conserve water, moderate runoff, function as a natural purifier, reduce flood risks at downstream locations, and improve water quality. Wetlands can be source of energy peat and could affect the energy sector by enhancing the use of domestic source, but loss of climate regulation services of converted peatlands and wetlands can have a negative impact on climate.
- Biodiversity. Land use change can cause fragmentation of eco-systems which can lead to extinction of protected biotopes and habitats of species.

Food

Food production plays an important role of the economy of Latvia. At the same time the sector is largely contributing to emissions of GHG and lowering the water quality, mainly because of fertilisation of lands.

- Pastures, cropland, wetlands have a food production role. Agriculture also contributes to CO_2 sequestration, by absorbing CO_2. The growing demand for food, as well as non-food biomass, can lead to an expansion of croplands and deforestation creating consequences on the microclimate.

- Cropland areas are assessed to be expanded rapidly (by 2030[26]), particularly for wheat due to increasing market demand. Availability of high quality arable land is considered as a limiting factor. Increasing yield may require application of higher amount of (nitrogen) fertilizers thus causing additional pressure on water quality due to leakages from fields.
- Food waste: a large amount of energy put into food production is wasted, since the food is not consumed. On the other side, food processing waste that has high contents of oil and grease can produce biofuels and food processing waste that has high contents of hydrocarbon can produce ethanol.
- Biodiversity. Expanding of arable lands on territories covered by natural/ semi-natural grasslands abolishes valuable natural biotopes. On the other hand, extensive approach to agricultural practices, e.g., grazing allows maintenance of biologically valuable grasslands.

Climate

Reduction of GHG emissions in various sectors of economy has become an important target for Latvia. Reduction shall be achieved by increasing energy efficiency, increasing use of RES, improving agricultural practices, introducing “green” alternatives for transport and fuels.

- Climate change will lead to more air-conditioning in summer and less heating in winter; as heating is usually provided by fuel burning and while air conditioning is operated by electricity, the demand would shift towards electrical energy.
- Extreme temperatures lead to increased usage of heating and cooling systems thus require higher energy production and possibly lead to increase of GHG emissions (in case fossil fuels are used).
- Biodiversity. Potential effect of climate change is succession of indigenous flora and fauna with alien species.

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[26] www.zm.gov.lv/public/ck/files/Lauksaimniecibas_prognozes_2050_gads.pdf

1.2 Description of the pathways

There are three pathways identified so far in the NEXUS framework for the Latvia case study. Keeping in mind the explicit goal of low carbon development in Latvia, the challenge is to meet the energy goals (in terms of CO2 and other GHG reduction, water quality, and land-use) by lowering the national imports of fossil fuels and increasing the use of RES to produce energy for consumption by residential, transport, industry, tertiary and agriculture sectors.

Pathway to increased use of RES to produce electricity and heat in centralized power plants. Production of electricity and heat in centralized systems is highly predominant in Latvia.
At present, the electricity generation in the country is ensured at few large-scale plants: CHP (using imported natural gas) and HPP (on the River Daugava) to provide the capacity baseline. On top, the electric energy production is performed also in number of smaller plants using natural gas and the renewables mix: biomass CHP, biogas CHP, wind power plants and small HPPs (predominantly <1MW). The self-supply is ca.70% of electricity. For Latvia being incorporated into the common electricity grid, the deficient share of electricity is imported (bought through *Nord Pool)* to secure the demand. Electricity demand may increase in future due to extended applications, e.g., electric cars, potential switch to electricity in heat production. Thus, the additional capacities for electricity generation from RES are seen as a pathway to develop.

Production of heat in centralized systems is mainly ensured by imported natural gas and biomass sources. Few large-scale plants (CHP) are in operation to supply heat in larger cities, while the number (ca. 550 plants) of small-scale (<5MW) installations are scattered throughout the country to serve for smaller settlements. It can be foreseen that heat demand will decrease in future due to improvements in energy efficiency of buildings and shrinking population, and potential effects of climate change. This can lead to the strategy for innovative solutions for even smaller systems backed-up by the technology development and the replacement of the traditionally used biomass sources by other RES options. Thus, the patterns for use of biomass resources can be changed from the currently deployed combustion to increased production of high added value wood-based products. On top, the biomass is known as an export product, both, as a wood timber and as a fuel for combustion plants. The pathway would also explore on balancing the gains and trade-offs from the biomass export.

Pathway to dissipated power generation at localities. At present, the main electricity generation capacity in Latvia is highly concentrated and centralized within the limited space (the territory areal ca.80 km vicinity of the capital – Riga). The pathway would explore the options to electricity production from RES at small scale installations. The conditions have to be assessed: socio-economic development to secure the initial investments (e.g., solar PV panels) from inhabitants, potential support schemes to foster the investments from public, and conditions for feed-in of the power generated.

Pathway for the biofuels (first and second generation). At present, the growing of energy crops (e.g., rape) is on increasing capacity in Latvia and the projections indicate continuation of this trend for future. Produced biofuel (1st generation biodiesel and ethanol) is mainly exported (>70% of the production). Use of 1st generation biofuel may be limited in future to avert subsequent negative consequences on land-use and water quality, and climate caused by intensive energy crops production practices. Thus, the pathway for biofuels will be explored by a potential of the 2nd generation biofuels. The conditions have to be assessed: availability of resources for production (e.g., biodegradable waste), technological readiness level, affordability of investments.

1.3 Develop a conceptual model

According to the timeline developed during the project partners meeting (1-2 June 2017, Trebon, Czech Republic) systematic work on the development of conceptual model for the Latvia case study has started in October 2017. The case study team was taking part in regular (weekly) WP3/WP4 skype conferences initially learning from experiences presented by fast track case studies. As the next step, the conceptual model for the Latvia case study was drafted and discussed with project partners. Along, the SDM team supported the Latvia case study team by reflecting interlinkages and drafting SDM schemes. Such approach to simultaneous elaboration of the conceptual model and SDM was mutually complementing better understanding of Nexus interlinkages. To date of this report the work is continued to finalise the models and populate these with data.

The Conceptual Model of the Latvia case study reflects the focus on low carbon development by respecting the GHG thresholds and increased use of RES (see Figure 1.4).

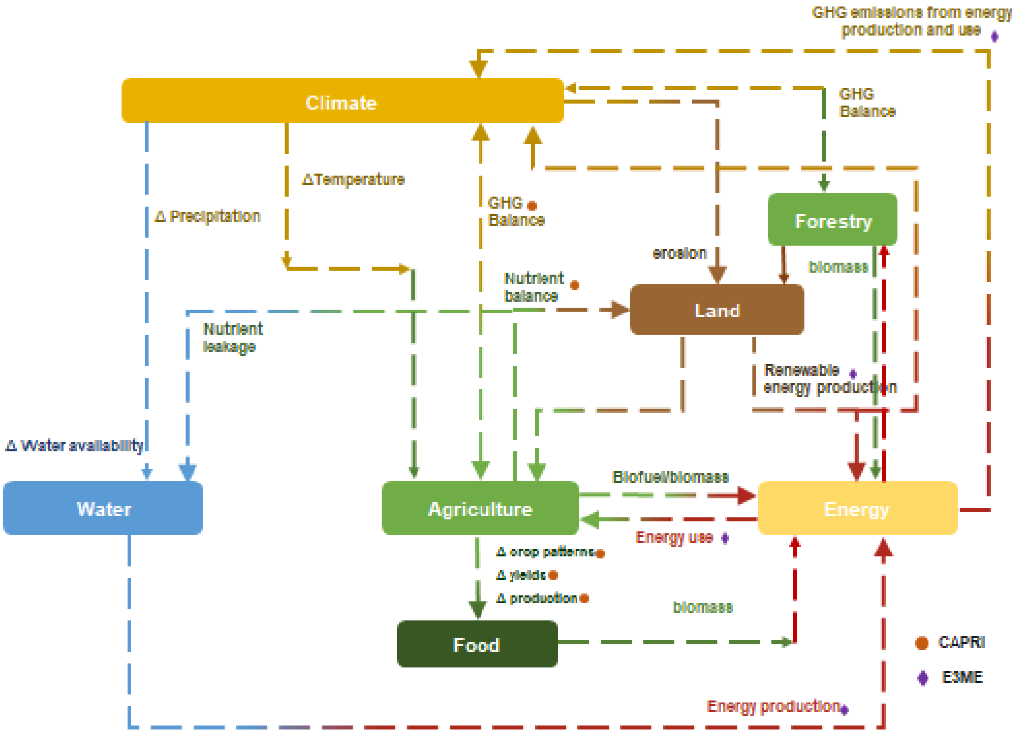

Figure 1.4. Conceptual model of Latvia case study.

Water. Being rich in water resources, the Latvia case study considers water availability for application in energy production by hydropower plants where potential effects from precipitation and water level fluctuations can have an effect. Latvia case study will focus on water quality affected by nutrient leakage (erosion) from land use activities being enhanced by climate e.g., heavy rainfalls, wind.

Agriculture & Food. Having well developed agriculture sector, the Latvia case study considers crop production as an important activity. Thus, the conceptual model includes potential effects from climate on crop patterns, yields and production. In addition, growing of energy crops (mainly rape) is a common agricultural practice and thus has links to energy production. Agricultural activities have an impact on GHG balance (GHG emissions from agricultural land, GHG sequestration of plants). Agricultural and food residues (biomass) can be utilised for energy and biofuel production (2nd generation biofuels).

Energy. Energy production from renewable energy sources and fossil sources (mainly imported natural gas) play an important role in the energy balance of the country. The conceptual model describes interlinkages with Water, Land, Agriculture, and Forestry sectors related to energy production from RES while fossil sources are not distinguished separately in the scheme. “Energy” refers to the total energy produced with the country, import and export.

Land & Forestry. Latvia is rich in areas covered by forests and agricultural land including arable land for crop production, meadows, and pastures. Forests in Latvia play an important role in biomass production as well as in GHG balance of the country. The conceptual model highlights interlinkages of land use and agriculture, forestry, and energy sectors. Strong interlinkage of land use and water is on nutrient leakage affecting water quality. Climate effects (rain fall and wind) intensifies land erosion negatively affecting water bodies.

Climate. Climate is impacting all other Nexus sectors by temperature and precipitation regime. It can be considered that climate effects will play increasingly important role by 2050. On the other hand, GHG emissions from energy, land use, food production etc. causing climate change are included in the conceptual model along with effects of GHG sequestration mainly from forestry.

1.4 Use of thematic models in understanding the Nexus

Latvia case study will utilise three thematic models – E3ME, CAPRI, and MAGNET. By the date of this report (15 December 2017) all three thematic models have been contacted to obtain the baseline scenario data up to 2050.

The first run data for Latvia from E3ME are obtained for GDP (EUR 2005m); Output by sector (EUR 2005m); Employment by sector (thousand persons); CO2 emissions by sector (thTC); Energy demand for Coal, Oil, Gas, Electricity and Heat, Biomass & Combustible waste by sector (th toe); Electricity generation by technology (GWh/y). These data are compared with the data from national statistics up to the year 2015. Skype session has taken place between Cambridge Econometrics and BEF team to discuss the baseline scenario results: (i) calibration based on actual data; (ii) adjustment of HPP production prognosis based on current resource availability, (iii) agreement to extend output lists with other GHG emissions; (iv) clarifications of terms and definitions. Pre-discussion on alternative scenarios by including enhanced application of wind energy, increased electricity consumption by electric vehicles for additional runs of E3ME model was held. Bilateral discussions on model applications will be continued. Examples of outcomes from CAPRI and MAGNET have been received and will be further communicated with model teams to understand the outcomes and apply results.

Outcomes from the thematic models are planned to be used in 2018. Firstly, projections up to 2050 will serve for SDM model to feed the Serious game engine. To account for regional differences, it has been decided to disaggregate the national data according to 6 statistical regions (NUTS 3) in Latvia. BEF team is in consultation with the SDM team on population of the model with data in appropriate format.

Results of the baseline scenarios are planned to be presented at the 2nd stakeholder workshop (to be held in Spring 2018). Discussion at this workshop will be directed to highlight potential areas for policy interventions towards low carbon development in Latvia. Outcomes of the discussion will serve to select the alternative scenarios to be applied for additional runs of thematic models.

The initial assessment of Nexus components relevant to the Latvia case study was prepared and presented at 2nd project partners meeting (1-2 June 2017, Trebon, Czech Republic). The Assessment of coverage by the thematic models E3ME, CAPRI and MAGNET was based on the Deliverable 3.1 «Report on the «first run» simulation results of the thematic models: identifying the gaps», Fact sheets on thematic models and Technical Manuals. E3ME considers impacts of climate and energy policy on economic activity and employment; CAPRI considers climate change and water availability on agricultural production, and MAGNET covers the whole economy, with an additional focus on agriculture, food processing and the rest of the bioeconomy. The initial assessment highlighted that: (i) from the models selected there is no complete coverage of NEXUS components identified in the case study, (ii) combination of models would be able to cover NEXUS components (except for GHG sequestration), however compatibility of results needs to be clarified due to model specifications, (iii) Poor coverage of GHG sequestration can be seen as a gap from the models assessed in this case study, (iv) by evaluation of coverage on NEXUS components a crucial role will be on data accessibility and attribution, thus the practical outreach of the model results may be further altered.

Further assessment on coverage by the thematic models is combined with the development of the conceptual model, SDM and outcomes from model calculations. The main Nexus challenges to be addressed in the Latvia case study are summarised and capabilities of the selected thematic models E3ME, CAPRI and MAGNET are attributed to these challenges. An overview is presented in Table 1.

Findings on Nexus challenge coverage by the thematic models:

- Water quality in terms of nutrient (N, P) discharge and contraction, Land erosion and potential leakage from fields and GHG sequestration are not covered by these thematic models considered;
- Economic variables are well covered by all three thematic models, although the compatibility of results needs to be assessed;
- Majority of Nexus challenges identified so far in Latvia case study are covered by thematic models to an extent.

Table 1. Main Nexus challenges to be addressed in the Latvia case study.

Thematic model / Nexus challenge	UNITS	E3ME	CAPRI*	MAGNET*
Water quality (discharge, concentration)	tN; tP; mg/l	*Not covered*	*Not covered*	*Not covered*
Agricultural food (crops)	t; t/ha; USD	*Not covered*	Crop yield, Production, Consumption, Import/Export	Crop yield, Production; Consumption, Import/Export
Energy crops (e.g. rape)	t; t/ha; USD	*Not covered*	Crop yield, Production, Consumption, Import/Export	Crop yield, Production; Consumption, Import/Export
Fertilizers	t/ha	*Not covered*	Fertiliser use	*Not covered*
Biofuel (1st & 2nd generation)	T; USD	*Not covered*	Biofuels processing	Production; Consumption,
Energy balance	Toe; GWh	Energy production; Energy consumption	*Not covered*	Electricity production
Agricultural land	ha	*Not covered*	Agriculture used area; Area harvested	Agriculture used area; Area harvested
Forest land	ha	*Not covered*	*Not covered*	Area harvested
Wood biomass	t	*Not covered*	*Not covered*	Production; Consumption
Wood biomass for energy	t	*Not covered*	*Not covered*	Production; Consumption
Land erosion/leakage	t/ha; %	*Not covered*	*Not covered*	*Not covered*
GHG emissions	thTC; CO_2eq	GHG emissions by sectors	GHG emissions	*Not covered*
GHG sequestration	thTC; CO_2eq	*Not covered*	*Not covered*	*Not covered*
Economy	EUR, USD, prices	GDP, Employment, Production, Consumption by sector	Producer price; Consumer price	GDP, Production, Consumption, Import, Export, Population

* To be specified with model teams

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

Key stakeholders for the Latvia case study (e.g., ministries, research institutions, regional authorities) were identified and first contacts established already at an early stage of the project in December 2016. The main idea of the project, focus and direction of the case study were introduced, the interest, need and expectations of stakeholders in SIM4NEXUS project results were identified and the main Nexus interlinkages, challenges, and application of thematic models were discussed during several bilateral meetings held. Particular attention has been paid to Nexus issues related to Energy and this topic has been discussed more in details during a thematic event with stakeholders in March 2017. Along with the development of case study, stakeholder mapping was continued, identifying new important stakeholders. Communication with stakeholders was maintained informing them on project implementation. Seven stakeholder groups important for the Latvia case study and their roles and interlinkages have been identified in relation to the Latvia case study. These stakeholder groups are: national governmental institutions, research institutions, educational establishments, municipalities, entrepreneurs, trade unions and non-governmental organisations (see Figure 1.5).

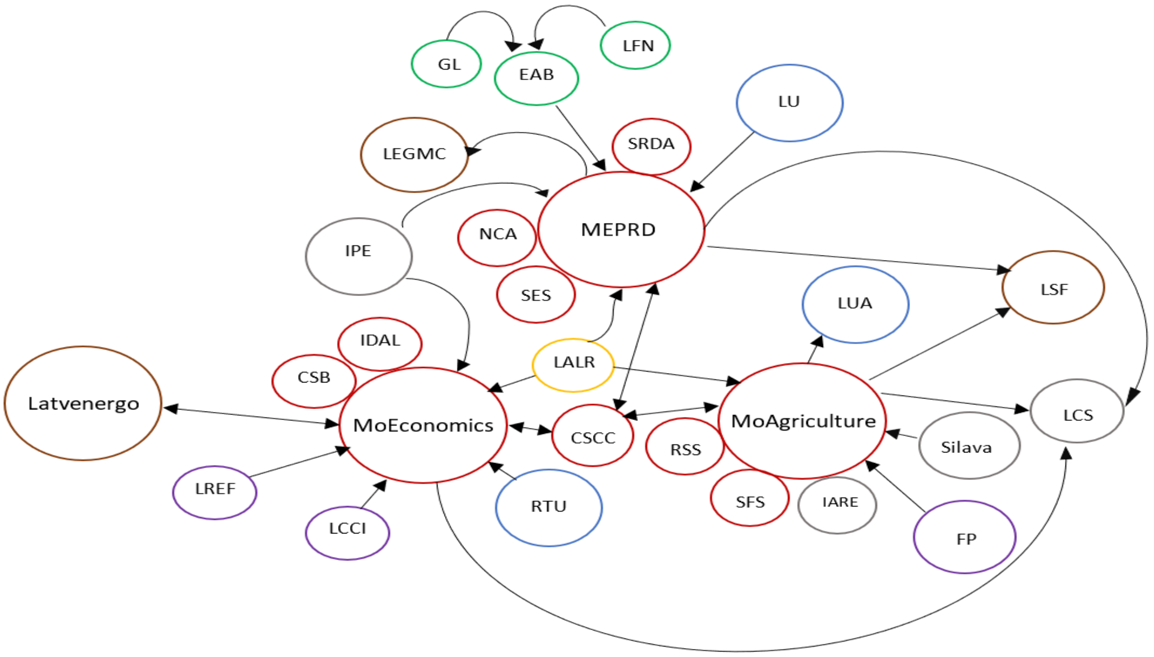

Figure 1.5. Map of stakeholders and relationships for Latvia case study

Ministry of Environmental Protection and Regional Development (MEPRD); Institute of Agricultural Resources and Economics (IARE); Ministry of Agriculture (Mo Agriculture); Latvian State Forestry Research Institute "Silava" (Silava); Ministry of Economics (Mo Economics); Latvian Council of Science (LCS); Investment and Development Agency of Latvia (IDAL); Institute of Physical Energetics (IPE); Central Statistical Bureau (CSB); Latvian Association of Local and Regional Government (LALRG); Cross-Sectoral Coordination Centre (CSCC); Latvian Chamber of Commerce and Industry (LCCI); State Environmental Service (SES); Association "Farmers Parliament" (FP); Nature Conservation Agency (NCA); Latvian Renewable Energy Federation (LREF); State Regional Development Agency (SRDA); Environmental Advisory Board (EAB); State Forest Service (SFS); Association "Green Liberty" (GL); Rural Support Service (RSS); Foundation "Latvian Fund for Nature" (LFN); Latvian Environment, Geology, and Meteorology Centre (LEGMC); JSC "Latvenergo" (Latvenergo); JSC "Latvia's State Forests" (LSF); University of Latvia (LU); Latvian University of Agriculture (LUA); Riga Technical University (RTU).

Preliminary contacts with stakeholders highlighted the need to analyse interlinkages and implications of actions in the country on its way towards low carbon economy to help policy makers at various levels to develop sound policy decisions and directions of activities at national, regional, and local level. The approach implemented by the SIM4NEXUS combining and utilising the results of several models, several Nexus components, involving various stakeholders in the project implementation process was acknowledged as innovative and valuable.

The 1st Stakeholder workshop was organised on 15th November, Riga, Latvia. The following topics were covered: (i) introduction of the SIM4NEXUS project – aims, activities and the approach utilised for case study analyses; (ii) introduction to the Latvia case study – focus, policy analyses, SDM and thematic models used, purpose and possibilities of the serious game, stakeholder engagement; (iii) discussion on pathways, Nexus interlinkages, identification of the most critical issues (trade-offs); (iv) information exchange on most recent investigations relevant to the case study, data availability and accessibility; (v) next steps and further stakeholder involvement.

In total the workshop gathered 16 participants representing ministries (Ministry of Environmental Protection and Regional Development; Ministry of Agriculture); higher educational establishments (Riga Technical University); research institutions (Institute of Physical Energetics); business (Latvian Environment, Geology, and Meteorology Centre), non-governmental organisations (BEF-Latvia, Foundation “Latvian Fund for Nature”, Foundation “Pasaules Dabas Fonds”, “Green Liberty); others (Nordic Council of Ministers’ Office in Latvia). The fields of interests of participants are covering sustainable use of natural resources, energy modelling, bioeconomy, climate change analyses and modelling, management of water resources (river basins), water quality, pressure of agriculture and food production environment; sustainable use of energy, climate change, low carbon development, use of biofuels, land use, land use change and forestry, biodiversity maintenance. During the discussions at the workshop each stakeholder individually pointed out the most important NEXUS interlinkages and main challenges in Latvia (see Figure 1.6).

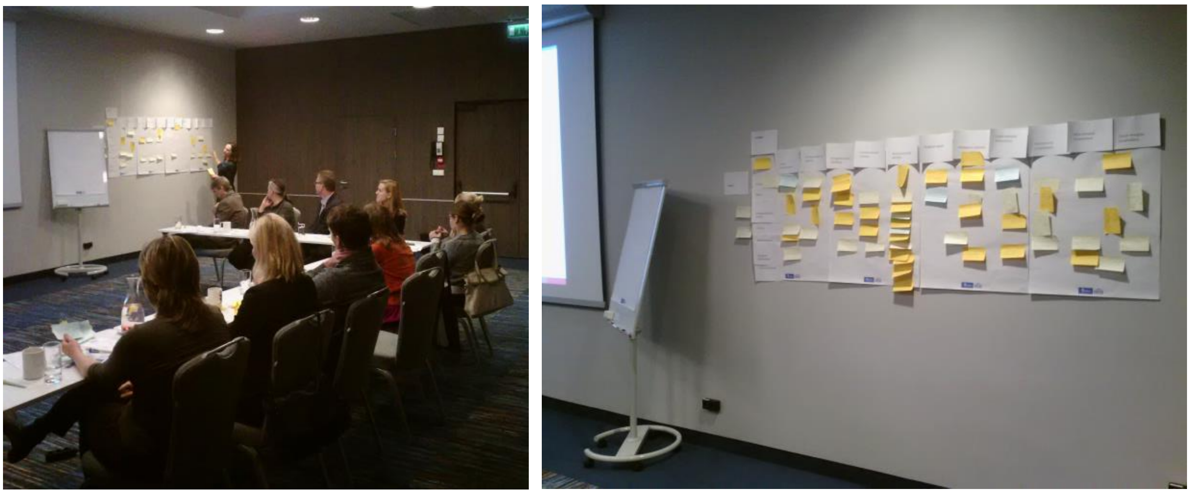

Figure 1.6. 1st stakeholder workshop, 15 November 2017, Riga, Latvia

After the event participants evaluated the workshop by filling in the evaluation forms. All participants gave a positive feedback to the workshop stating that in overall the workshop was personally useful to them. Almost all respondents acknowledged having obtained a better overview on interlinkages between Nexus components during the workshop. All participants admitted that such discussions on sustainable use of resources are valuable and that their individual viewpoints have been heard and considered. Participants pointed out the most useful items of the workshop and suggestions for next events e.g., additional topics. All participants expressed their wish to obtain further information e., by e-mail and participate at next workshops organised. Several participants pointed their interest to have more active role in the project activities e.g., in relation to modelling activities.

The main outcome from the workshop is related to verification of critical Nexus interlinkages, synergies, and conflicts relevant to the Latvia case study e.g., land management, energy production, agriculture, forestry, biodiversity maintenance, water quality, and climate change. The event also better highlighted the stakeholder needs and interests towards the SIM4NEXUS project. The workshop provided information on data availability for the modelling needs.

Participants expressed their readiness to share their experiences in the related fields by participating in interviews and next stakeholder events. Interviews with stakeholders (having participated at the 1st workshop, and also others identified during the stakeholders mapping process) are scheduled starting from mid of December 2017. It was agreed that the next stakeholder workshop could be devoted for discussing the first modelling results for the Latvia case study. Participants also expressed their interest to meet SDM experts to have an opportunity to discuss system dynamic modelling possibilities and approaches applied in SIM4NEXUS project.

2 Conclusions and follow-up

Activities performed for implementation of the case study "Latvia" were mainly targeted to assess background conditions in the Nexus sectors. The main challenges, interlinkages, and the trade-offs have been identified. Efforts have been allocated to elaborate the conceptual model. No major obstacles have been encountered in the development of the case study. However, there are several challenges faced. Assessment of water quality, land erosion and leakage, GHG sequestration are clear challenges of the case study. There is no clear strategy yet on how to model these Nexus challenges. These issues are high on agenda.

Stakeholder mapping has been performed, identifying that there are seven stakeholder groups important for the Latvia case study: national governmental institutions, research institutions, educational establishments, municipalities, entrepreneurs, trade unions and non-governmental organisations. Their roles and interlinkages have been identified.

The 1st Stakeholder workshop was organised (15 November 2017, Riga, Latvia) where the SIM4NEXUS project and Latvia case study were introduced. The main outcome from the workshop is related to verification of critical Nexus interlinkages, synergies, and conflicts relevant to the Latvia case study. The discussion on data availability for the modelling needs was started.

For the coming period implementation of the Latvia case study will focus on data search and collection for modelling purposes. Various options will be considered to complement the data set by using outcomes from the thematic models, climate data, data from national statistics and approaching other sources to cover the gaps e.g., water quality, land erosion and leakage, GHG sequestration. Our approach is to disaggregate the national data in 6 statistical regions (NUTS 3) in Latvia. Compilation of the data set will be adjusted to this level. Contacts will be kept close with modelling teams to complete the data search and apply modelling scenarios. As expressed wish by stakeholders at the 1st stakeholder workshop, it is planned to organise a special session with SDM experts (event planned in Spring 2018) for a deeper discussion on system dynamic modelling approaches applied in SIM4NEXUS project.

The 2nd stakeholder workshop is planned to be held in Spring 2018. Discussion at this workshop will be directed to present results of the baseline scenarios and highlight potential areas for policy interventions towards low carbon development in Latvia. Outcomes of the discussion will serve to select the alternative scenarios to be applied for additional runs of thematic models. Meantime key stakeholders will be approached for interviews to discuss policy developments and the Nexus related challenges. Such discussions are seen necessary to better assess the policy context.

3 References

- Prūse I., (2017). Latvijas oglekļa mazietilpīgas attīstības stratēģijas 2050.gadam un Latvijas pielāgošanās klimata pārmaiņām stratēģija 2030.gadam nepieciešamība un izstrādes progress // Presentation (in Latvian), available at http://ilgtspejigaattistiba.saeima.lv/attachments/article/719/2017-03-28_OMAstratUnPielagStrat_IPruse.pdf
- World Economic Forum (2016). Europe’s 10 fastest growing economies // Article available at www.weforum.org/agenda/2016/02/europe-s-10-fastest-growing-economies/
- Public broadcasting of Latvia (29 August 2017). Swedbank: Latvia's economy to grow 4-4.2% this year and next // Article available at http://eng.lsm.lv/article/economy/economy/swedbank-latvias-economy-to-grow-4-4.2-this-year-and-next.a248282/
- LETA (28 November 2017). Latvijā gaidāma straujākā tautsaimniecības izaugsme Baltijas valstīs // Article (in Latvian) available at www.tvnet.lv/financenet/finansu_zinas/722017-latvija_gaidama_straujaka_tautsaimniecibas_izaugsme_baltijas_valstis
- OECD (2017). Latvia - Economic forecast summary (November 2017) // Report at OECD Economic outlook, Volume 2017, Issue 2, preliminary version available at www.oecd.org/latvia/latvia-economic-forecast-summary.htm
- Trading Economics (2017). Latvia GDP Growth Rate // Forecast available at https://tradingeconomics.com/latvia/gdp-growth
- The Latvian Institute (2017). Economy // Review available at http://www.latvia.eu/lv/economy
- IndexMundi, Latvia Economy Profile 2017 // Available at www.indexmundi.com/latvia/economy_profile.html
- Central Statistical Bureau of Latvia (2017). Main statistical indicators 2017 // Statistical yearbook of Latvia (in Latvian) available at www.csb.gov.lv/sites/default/files/nr_03_latvija_galvenie_statistikas_raditaji_2017_17_00_lv.pdf
- Central Statistical Bureau of Latvia (2016). Consumption of renewable energy resources in 2015 // Overview available at www.csb.gov.lv/en/notikumi/consumption-renewable-energy-resources-2015-44050.html
- The Guidelines for the Development of Energy Sector for 2016-2020 (2016). // Guidelines (in Latvian) available at https://likumi.lv/ta/id/280236-par-energetikas-attistibas-pamatnostadnem-2016-2020-gadam
- Ecologic Institute, Eclareon (2013), Assessment of Climate change policies in the context of the European semester. Country report: Latvia // Available at https://ec.europa.eu/clima/sites/clima/files/strategies/progress/reporting/docs/lv_2014_en.pdf
- State Ltd "Latvian Environment, Geology and Meteorology Centre" (2017). Climate of Latvia. // Overview available at https://meteo.lv/en/lapas/environment/climate-change/climate-of-latvia/climat-latvia?id=1471&nid=660
- State Ltd "Latvian Environment, Geology and Meteorology Centre" (2017). Water management // Overview (in Latvian) available at www.meteo.lv/lapas/vide/udens/udens-apsaimniekosana-/udens-apsaimniekosana?id=1108&nid=423
- European Environment Agency (2010, 2015). Freshwater - State and impacts (Latvia) // Report available at www.eea.europa.eu/soer/countries/lv/freshwater-state-and-impacts-latvia
- Investment and Development Agency of Latvia (2016). Food industry in Latvia // Publication available at www.liaa.gov.lv/files/liaa/attachments/food_industry_in_latvia.pdf

- Ministry of Agriculture (2015). Food industry is the largest processing sector in Latvia and it stands for the fifth part of the added value in the processing // Article available at www.zm.gov.lv/en/partika/jaunumi/food-industry-is-the-largest-processing-sector-in-latvia-and-it-stands?id=4099
- Laspidou C., et al. (2017). D1.1: Scientific Inventory of the NEXUS
- Rivža P., et al. (2015). Lauksaimniecības rādītāju un SEG emisiju no lauksaimniecības sektora prognoze 2020., 2030. un 2050. gadiem ar papildus pasākumiem emisiju samazināšanai // Report (in Latvian) available at www.zm.gov.lv/public/ck/files/Lauksaimniecibas_prognozes_2050_gads.pdf

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

D5.2: THE MAIN NEXUS CHALLENGES IN AZERBAIJAN

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1 Introduction

Transition to a low carbon economy can be a significantly challenging task. Besides economic aspects, social engagement, political actions and physical resource management need to be considered, leading to intricacies and trade-offs. The particular characteristics of a case study such as geography, history, and geopolitics need to be taken into account as well. The Republic of Azerbaijan, hereinafter Azerbaijan, is by definition a transition economy which aspires to open up to a more market oriented pattern. Following the collapse of the Soviet Union in the early 1990s, the country started focusing on the hydrocarbon industry (oil and natural gas), which led to massive economic growth from 2005 onwards. On the other hand, this dependence makes the country vulnerable to the oil and gas prices' oscillation. When the oil prices dropped in 2014/2015, the Azeri currency, the Manat, devalued 30% in February 2015 and 50% further in December of the same year (Pirani, 2016). Although fuel exports constitute the cornerstone of Azerbaijan's economy accounting for more than 90% of its exports (WTO, n.d.), agriculture is the largest employer - in 2014 (UN Data, n.d.) it accounted for 36.8% of employment.

Azerbaijan is located in the southern Caucasus region. The Russian Federation and Iran to the North, Iran to the South, the Caspian Sea to the East and Georgia to the West border it. Although Azerbaijan is technically an Asian country, its relations with the European Union have been gaining momentum. The European Union (EU) is the major trade partner of Azerbaijan while the latter is also part of several EU initiatives namely the European Neighborhood Policy (ENP), Eastern Partnership and the Council of Europe (EEAS, n.d.). Cooperation between both parties spans from trade to securing energy security. Consequently, Azerbaijan is linked to Europe in various aspects and therefore, analyzing certain aspects of the country in conjunction with drivers stemming from EU decisions should be pursued.

This case study aims at exploring the implications of Azerbaijan's transition to a low carbon economy to a range of nexus domains, which have their specific challenges and priorities. Additionally, the impact of external international and transnational policies will be investigated, since Azerbaijan's economy relies greatly on the export of crude oil to European countries, which also aim at decarbonising their economies. The analysis will be carried out following the guidelines and implementing the framework developed under the scope of the SIM4NEXUS project. The current report aims at shedding light on the main nexus challenges in Azerbaijan from a physical point of view and present the initial trends from the application of the thematic models. Stakeholders have been and are expected to be involved in the development of the case study, however this stakeholder engagement process has proven to be quite difficult to achieve.

Below follows a list of the systems under analysis in this study. This list is tentative as it is possible that other sectors will be deemed important after delving deeper in the study and interacting with stakeholders. It is also worth noting that the overall analysis will cover both physical and policy related aspects with the latter being part of the analysis in SIM4NEXUS Deliverable "D2.2 Nexus Nexus-relevant policies at national and regional scale".

- **Water:** over 70% of the water resources of Azerbaijan are transboundary. Water is a key resource to agriculture and dependence on external water resources increases the vulnerability of the food production sector. Water supply and demand will be investigated using a simplified accounting framework.
- **Land Use:** Reforestation is a key priority to the country, due to the importance of forest cover to ecosystems services, hydrology and mitigation potential.

- **Food:** explore food production and consumption under pressures driven by other systems, for example, climate and land use; the food nexus domain is considered in this case study to include livestock production.
- **Energy:** investigate decarbonisation diversification pathways of energy supply, spanning from resources to final consumption of all energy forms in every sub-sector;
- **Climate:** understand the potential implications of climate change across the nexus; assess the greenhouse gas emissions of main economic activities and largest emitting sectors; and investigate corresponding adaptation and mitigation solutions.

Four thematic models were selected to explore the nexus interlinkages across the nexus domains of water – land – food – energy and climate. These are E3ME, OSeMOSYS, MAGNET and CAPRI. The application of the thematic models cover the geographical scope of the Republic of Azerbaijan, with the exception of the CAPRI model where other former Soviet republics, namely Armenia, Georgia, Kyrgyzstan, Republic of Moldova, Tajikistan, Turkmenistan and Uzbekistan (along with Azerbaijan).

1.1 Description of the Nexus challenges

Azerbaijan is located in the southern Caucasus region (Figure 1). It is bordered by the Russian Federation, Iran to the North, and Georgia; with the Caspian Sea to the East. The Republic of Azerbaijan has a territorial area of 86,600 km2 and a population of 9.81 million people. Not much difference exists between the share of rural and urban population, with 52% living in urban areas in 2011. In terms of topography, it is characterized by extreme altitude variations, from very high elevation in the mountainous part, to -28m in the Caspian Sea.

Major industries include the extraction of crude oil and gas, and fields spread all across the country. Oil and gas products represent over 90% of the country exports, 65% of which to European countries, with the top importers being Italy, Germany and France (MIT Observatory of Complexity).

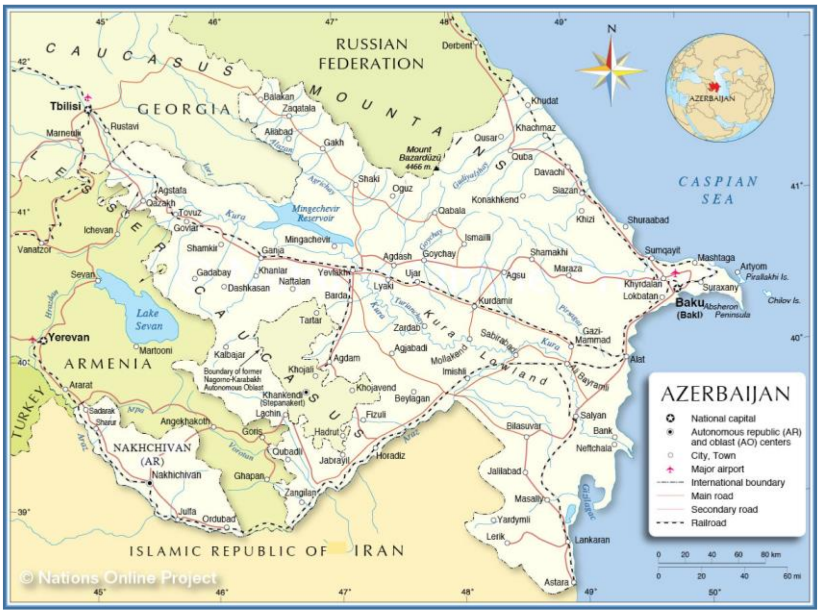

Figure 1. Political mas of the Republic of Azerbaijan (source: nationonline.org).

1.1.1 Main trends of the nexus sectors

Water resources

Only ¼ of the country's renewable water resources is generated in the country, which makes it vulnerable to the quantity, quality and timing of upstream countries. Water losses are an issue. Agriculture is the most water-intensive sector and accounted for more than 70% of freshwater withdrawals in 2014. Agricultural land represents 57% (2013) of the land area and nearly half of it is under irrigation.

Land use

Forests cover 12% of the land but are unevenly distributed and illegal logging is a problem.

Energy

The country relies mostly on domestic oil and gas for electricity generation. Over the past years oil power plants have been decommissioned and replaced by natural gas power plants.

Climate

Azerbaijan is vulnerable to climate change, with the arid climatic region likely to expand affecting the agriculture sector that provides employment to 40% of the population.

The main trends for the modelled nexus sectors, mostly energy and food production, are discussed briefly in section 1.4 Use of the Thematic models. All thematic models have used SSP2 data for the development of the baseline of the Azerbaijan case study.

1.1.2 Interlinkages between nexus sectors

The Azerbaijan case study has identified the nexus interlinkages seen in the figure below:

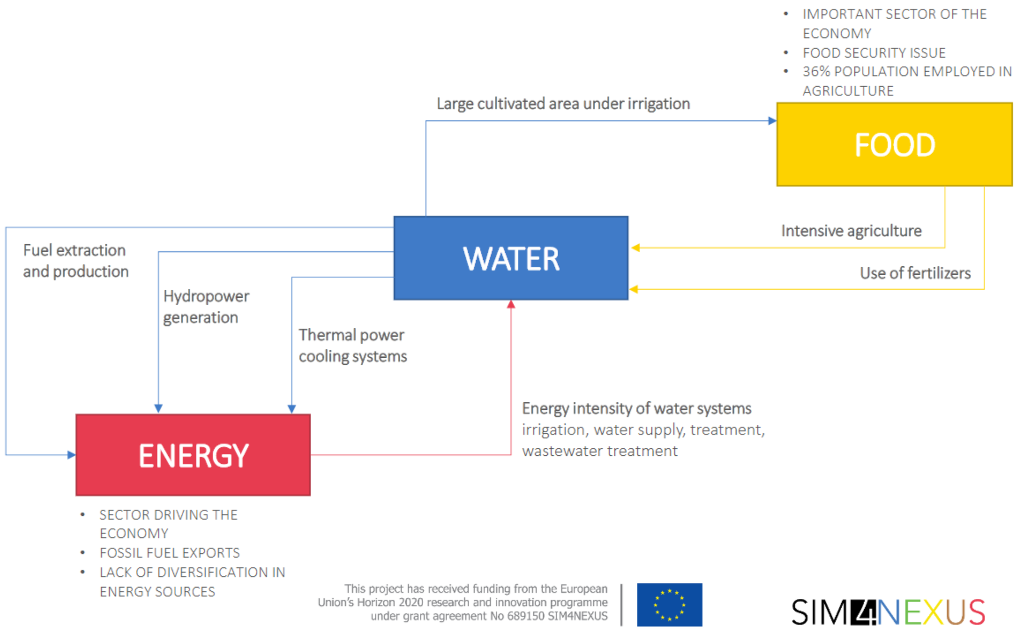

Figure 2. Overview of nexus interlinkages in the Azerbaijan case study, presented in the SIM4NEXUS Project Meeting in Trebon, June 2017.

1.1.3 Trade-offs between nexus domains

Possible nexus questions and policy to be investigated in the case study of Azerbaijan include:

- High dependency on transboundary water resources as the downstream country of the Kura and Aras river basins. Wastewater treatment is practically non-existent. Water re-use is being investigated for irrigation purposes. Alternatives to conventional water supply could be interesting to analyse.
- Irrigated land is located in the lowlands, characterised by less precipitation. The climate is arid, the region is prone to floods and climate change is likely to affect water availability in the future - study options of improved irrigation systems/new irrigation technologies; and/or crop adaptation.
- Potential role of renewable energy sources in decarbonising energy generation (one of the aims of the country) and analysis of emissions reduction from the industry, transport and energy sector.

1.2 Description of the pathways

The main pathway of this study is the transition of a high-carbon intensive economy to a low carbon future, and assess potential side effects from the implementation of low carbon policies by main fossil fuel importers from the Europen Union. Azerbaijan also aims at shifting from being an oil based economy to become a more diversified one, reducing the risks and vulnerabilities of a hydrocarbon-centred economy, while promoting sustainable development.

The outcome of this study could assist decision makers in designing policy for a smooth transition as well as leveraging funding for adapting to the immediate economic effects caused by intensive decarbonisation and changing revenue from oil exports.

1.3 Develop a conceptual model

The development of the conceptual model of the case study of Azerbaijan is yet to start, and scheduled for January 2018. This will require the revision and in-depth comparison of the baseline of thematic models created for the case study. In addition, the structure of the analysis will need to be revised once the policy analysis is completed. The development of the System Dynamics Model is foreseen to start in March 2018 and incorporation of policies in two months later. As decided in earlier stages of the project, the case study of Azerbaijan will not include the development of a Serious Game.

1.4 Use of thematic models in understanding the Nexus

Four thematic models were selected for the quantitative analysis of the nexus challenges identified in the case study of Azerbaijan. These are OSeMOSYS, E3ME, MAGNET and CAPRI. Two of the thematic models cover the energy domain of the nexus and are used here with different purposes: on the one hand, to complement each other coverage of the energy sectors; on the other hand, to facilitate model-linking between the different tools in the pursue of an integrated analysis. The direct use of E3ME-FTT was not possible and a separate Input-Output analysis will be performed and linked to the existing E3ME baseline. Also the application of CAPRI was not possible at a national scale, and results correspond to a regional analysis of Central Asian nations. To cover the specificities of the Azerbaijan context will require the investigation of agricultural statistics for the development of a proxy analysis and downscaling of context-specific outputs. As for MAGNET,

In terms of timeline, different models have different time horizons and temporal resolution. Broadly, the study will cover the period 2010-2050 while the temporal step is (depending on the case) seasonal, annual or every 10 years.

So far, the modelling frameworks were used to develop a single-model perspective of the country, with the exception of CAPRI that covers the Former Soviet Union trade block. The analysis of the insights from each thematic model will allow identifying trends across nexus domains and comparing modelling outputs. This will be followed by an exercise to assess opportunities for model linking, the definition of a sequential process to execute such integration; and, ultimately, the convergence to an integrated baseline of modelling tools arrangement. This section gives an overview of how the different models have been used to represent the context of the case study under each nexus domain covered, the key messages and sectoral and resource use trends, and the challenges identified.

1.4.1 OSeMOSYS

Standing for the Open Source energy Modelling System, OSeMOSYS is a model generator used primarily to analyse the energy sector following a linear optimization principle in which the objective function optimizes the system to the least-cost solution. Although OSeMOSYS was originally developed for long-term energy planning, it is flexible enough to include the representation of other resource systems such as the use of land, water use accounting, food production and GHG emissions.

For the current case study, OSeMOSYS was used to model the electricity system of Azerbaijan. Other sub-sectors of the energy system will be incorporated in the analysis in a later phase of the case study, taking into account the model linking opportunities in informing about the nexus challenges. Its extended coverage is also expected to feed on the stakeholder participation process and policy analysis.

The model, presented at this stage, considers the electricity sector of Azerbaijan including endogenous energy resources, such as crude oil and natural gas; power plants portfolio and investments, transmission and distribution of electricity, as well as the representation of final consumption. Electricity demand is disaggregated in industrial, services, residential, agriculture and transport. The figure below (Figure 3) illustrates how the electricity system is modelled and how the different components are linked to each other, which basically follows a resource-to-use structure.

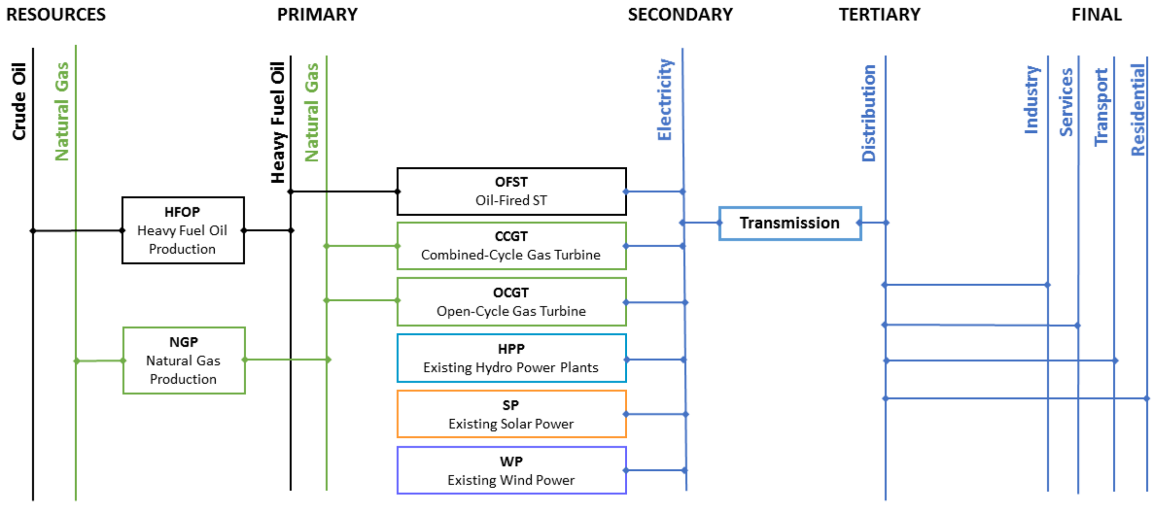

Figure 3. Reference energy system for the OSeMOSYS model of Azerbaijan, focused on the representation of the power sector.

The model covers the period 2010-2050 and results can be retrieved at an annual and time slice basis, where applicable (e.g. production form electricity generation technologies). Each year is divided into 6 time steps that represent 3 seasons (winter, summer and intermediate), one day type, and two day parts (day and night).

The baseline scenario takes into account a growth rate for the national electricity demand based on the GDP growth rate from the OECD projections for SSP2. Final electricity consumption data was retrieved from the national statistics, State Statistical Committee of the Republic of Azerbaijan (SSCRA), for the period of 2010 – 2016 (Figure 4).

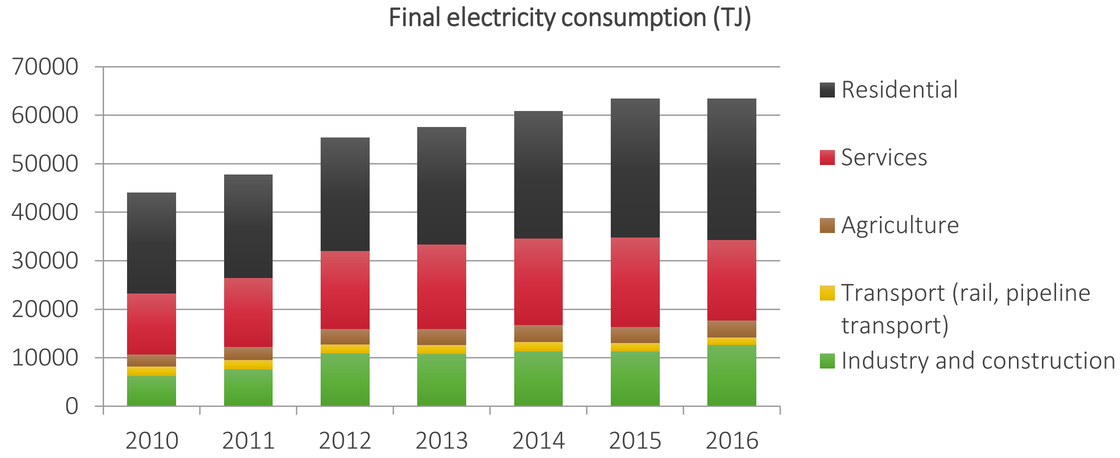

Figure 4. Final electricity consumption for the period 2010 - 2016, in TJ (source: SSCRA, at stats.gov.az).

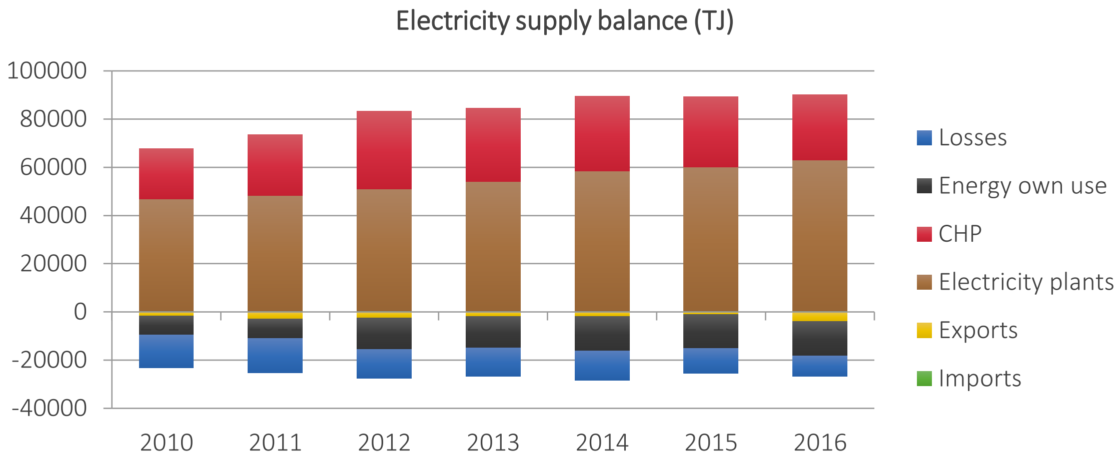

Figure 5. Electricity supply balance of Azerbaijan for the period 2010 - 2016, in TJ (source: SSCRA, available from stats.gov.az).

The input data set for the electricity sector of Azerbaijan results from a combination of national and international open data sources. The technological mix for electricity generation investment's portfolio used data from the Platts database for 2015. Techno-economic parameters were obtained from the ETSAP technology briefs and from the NREL Transparent Cost Database. Natural gas and oil prices were obtained from the Tariff Council of the Republic of Azerbaijan for the latest year available. Fuel prices were considered constant throughout the modelling period.

No particular sectoral policies (e.g. renewable energy or decarbonisation target) have been included in the OSeMOSYS baseline scenario. Policies will be incorporated once the policy analysis is concluded. Despite the fact that the baseline scenario does not feature policy targets, the results can be still insightful as they illustrate particular trends stemming from the system's cost minimization.

1.4.1.1 Results and insights from the OSeMOSYS baseline

Similarly to current trends seen in electricity generation in Azerbaijan, the model suggests that further investments in gas technologies would result in the least-cost option for electricity generation, with electricity produced from natural gas representing more than 80% of the generation in 2050 (Figure 6).

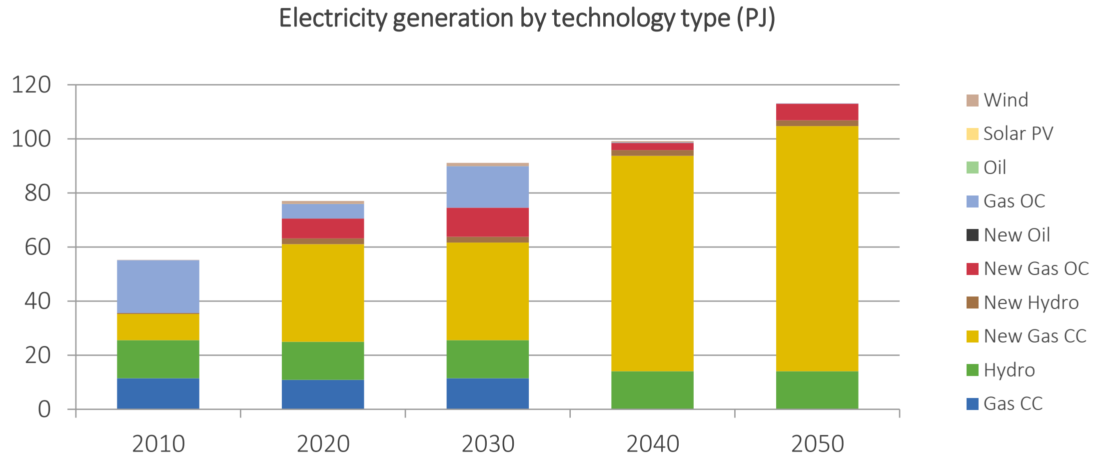

Figure 6. OSeMOSYS baseline results for electricity generation by technology type, in PJ.

Investments in electricity generation infrastructure for the modelling period, shown in Figure 7, are dominated by gas power plants that, once decommissioned, are replaced by newer and more efficient gas technologies – preferably using combined cycle gas turbines. Investments in generation technologies are not required between 2018 and 2030. Renewable energy technologies are installed only in the first 6 years of the modelling period, as they are now part of the existing technological mix. No further investments are made in RE technologies, mainly due to the competitive cost of natural gas and lower capital investments required.

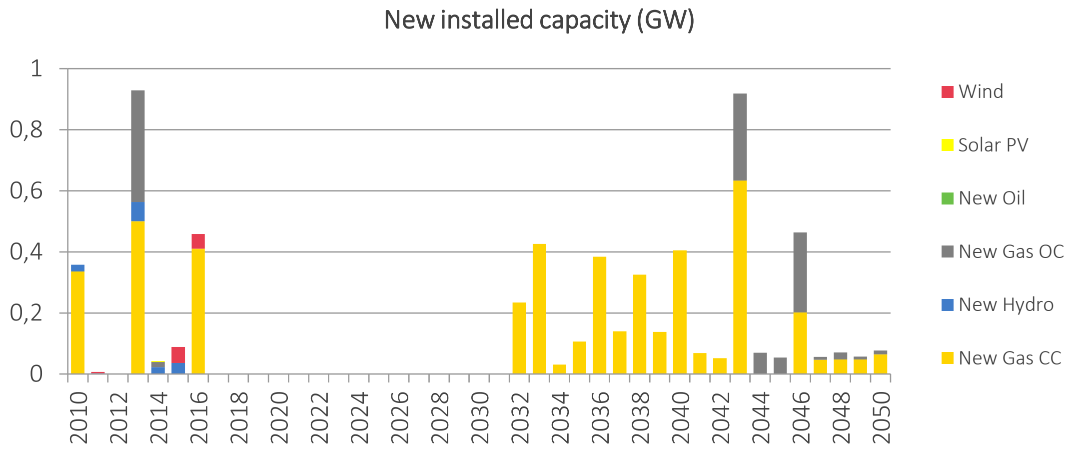

Figure 7. Electricity generation infrastructure investments throughout the modelling period for the OSeMOSYS baseline scenario.

Existing oil-based technologies are not cost-competitive enough and, although still available for operation, it is preferable to produce electricity using natural gas and hydropower technologies, as it can be seen when comparing the electricity generation mix (Figure 6) and the total installed capacity (Figure 8).

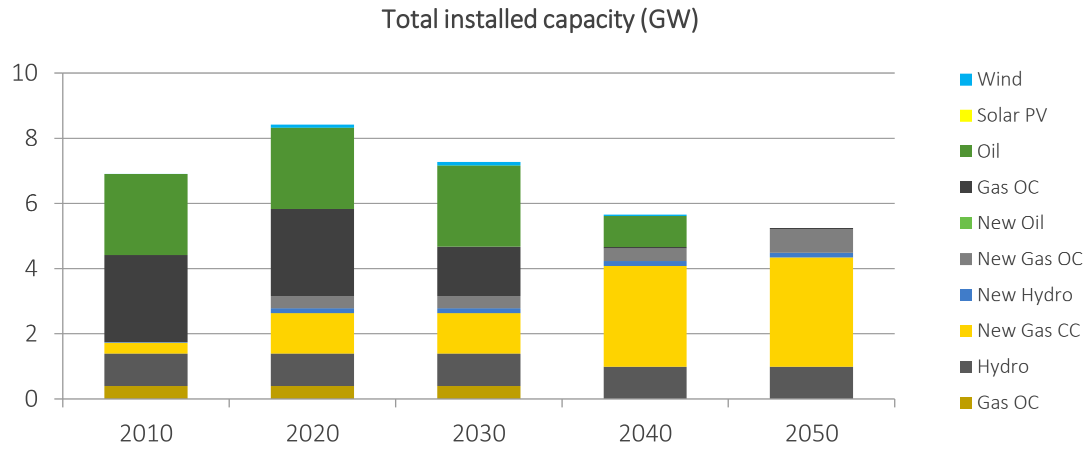

Figure 8. Total installed electricity generation capacity in the OSeMOSYS baseline scenario.

Since natural gas is the main fuel used for electricity generation, and its contribution to electricity production increases over the years, GHG emissions of CO2 and NOx accompany this trend, as they are directly dependent to the use of fossil fuels. As illustrated in Figure 9, CO2 emissions more than double in 2050 in comparison to 2010.

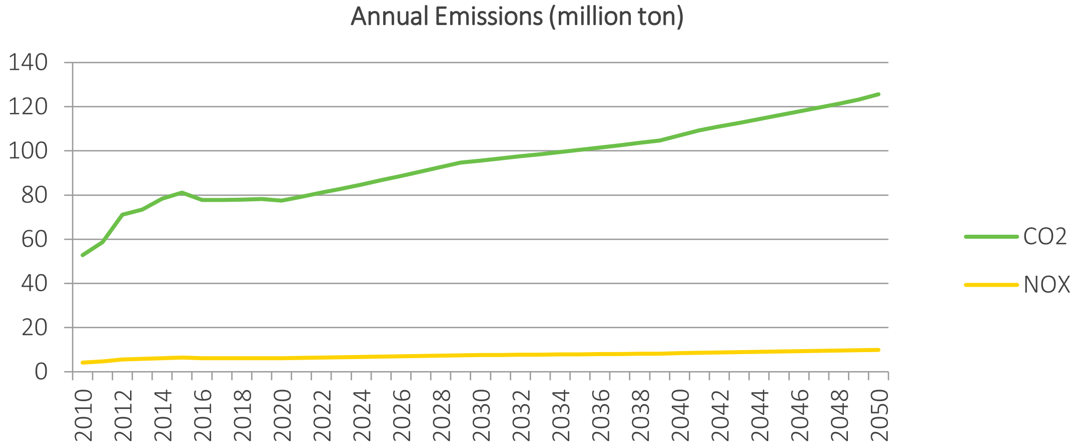

Figure 9. Annual CO2 and NOx emissions, in million tonnes, for the OSeMOSYS baseline case of Azerbaijan.

1.4.2 E3ME

This section focuses on the E3ME thematic model and the on-going work on the single-region model for Azerbaijan. The first part provides a short outline of the E3ME model, followed by an overview of the energy-modelling component of the model. A description of the on-going work on the Azerbaijan's single-region model is explained and some initial results for the Azerbaijan baseline are presented in the second part of the section.

1.4.2.1 Overview of the E3ME model

The theoretical background of the model

Economic activity undertaken by persons, households, firms and other groups in society has effects on other groups after a time lag. These effects, both beneficial and damaging, accumulate in economic and physical stocks. The effects are transmitted through the environment, through the economy and the price and money system (via the markets for labour and commodities), and through the global transport and information networks.

The markets transmit effects in three main ways: through the level of activity creating demand for inputs of materials, fuels and labour; through wages and prices affecting incomes; and through incomes leading to further demands for goods and services. The economic and energy systems have the following characteristics:

- economies and diseconomies of scale in both production and consumption
- markets with different degrees of competition
- the prevalence of institutional behaviour whose aim may be maximisation, but may also be the satisfaction of more restricted objectives
- rapid and uneven changes in technology and consumer preferences

An energy-environment-economy (E3) model capable of representing these features must therefore be flexible, capable of embodying a variety of behaviours and of simulating a dynamic system.

Structure of E3ME model

E3ME is a macroeconomic model of the world's economic and energy systems and the environment that is developed and maintained by Cambridge Econometrics in the United Kingdom (any reference that can be cited?). E3ME was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes (please add references for studies /reports were E3ME was used).

The E3ME model is well suited to analysing the linkages between the economic and energy systems, with links to environmental emissions. Figure 3 shows how the three main components (modules) of the model - energy, environment and economy - fit together. Each component is shown in its own box. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component.

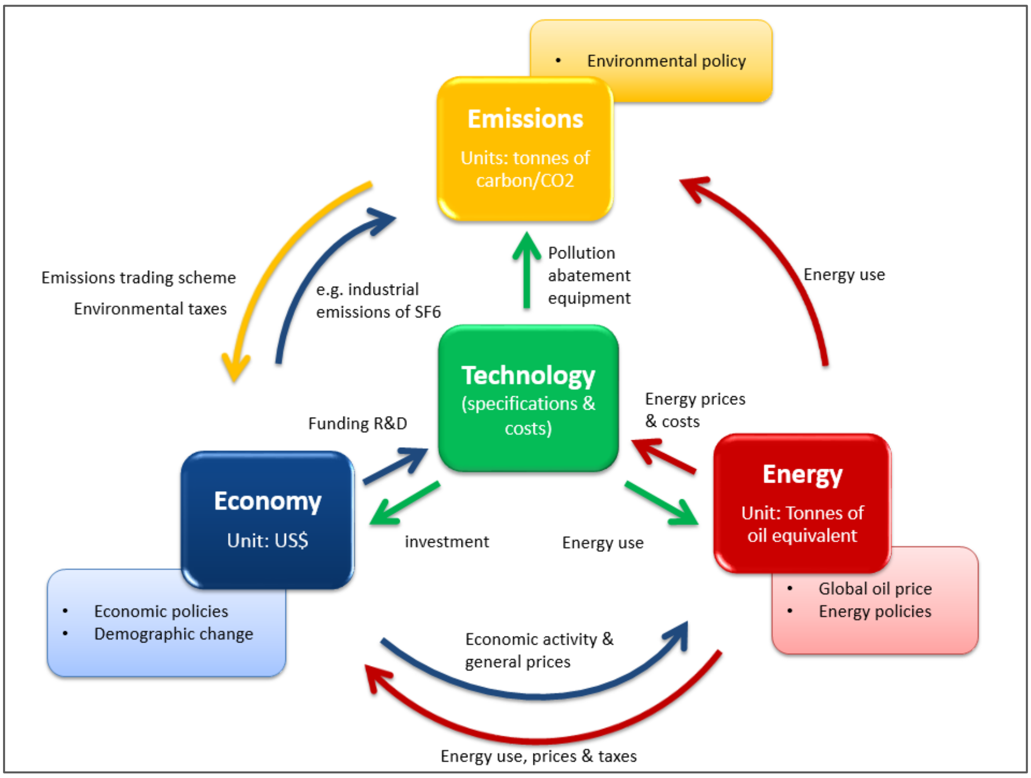

Figure 10. The main modules of E3ME.

Energy-emission modelling in E3ME

This section focuses on the energy-emission modelling part of E3ME. It describes the main 'top-down' energy module in E3ME as well as the bottom-up power generation modelling component Future Technology Transformations (FTT).

The top-down energy demand section of E3ME

Both aggregate energy demand and separate fuel demand equations for four energy carriers (coal, heavy oils, gas and electricity) are estimated in E£ME

The aggregate energy demand is determined by a set of econometric equations, with the main explanatory variables being:

- economic activity in each of the energy users
- average energy prices for each energy user in real terms
- technological variables, represented by investment and R&D expenditure and spill overs in key industries producing energy-using equipment and vehicles

The individual fuel demand equations by energy carriers are set up to allow substitution between the four energy carriers by users on the basis of relative prices, although overall fuel use and the technological variables are also allowed to affect the choice. The remaining fuels are determined either as fixed ratios to aggregate energy use or are assumed to be used in a similar way to other, closely related fuels. It is important to note that the energy demand results by fuel are scaled to match the results from the aggregate fuel demand equation.

Feedbacks to the economy from the energy system

The economic feedbacks are based on the fact that the same transactions appear in the energy data and in the economic data, albeit in different units. The feedbacks from the energy module assume a one-to-one relationship between these two measures, once price changes are taken into account.

There are also feedbacks from the energy module to household final demand. In the same way that an input-output flow provides an economic representation of industry purchases of energy, consumer expenditure on energy in the national accounts is equivalent to the energy balances for household purchases. In E3ME, the approach is to set the economic variables so that they maintain consistency with physical energy flows.

The FTT modelling framework for power generation

The power sector in E3ME is represented using a novel framework for the dynamic selection and diffusion of innovations (Mercure, 2012). It is called FTT:Power (Future Technology Transformations for the Power sector), which is a model of technology diffusion in its own right, but is coupled to E3ME. This is the first member of the FTT family of technology diffusion models.

FTT:Power features 24 types of power technologies that use 13 types of natural resources. It uses a decision-making core for investors wanting to build new electrical capacity, facing several options. The resulting diffusion of competing technologies is constrained by a global database of renewable and non-renewable resources (Mercure & Salas, 2012, 2013).

The decision-making core in the FTT:Power takes place by pairwise levelised cost (LCOE) comparisons, conceptually equivalent to a binary logit model, parameterised by measured technology cost distributions. Costs include reductions originating from learning curves, as well as increasing marginal costs of renewable natural resources (for renewable technologies) using cost-supply curves. The diffusion of technology follows a set of coupled non-linear differential equations, sometimes called ‘Lotka-Volterra’ or ‘replicator dynamics’, which represent the better ability of larger or well-established industries to capture the market, and the life expectancy of technologies. Due to learning-by-doing and increasing returns to adoption, it results in path-dependent technology scenarios that arise from electricity sector policies. **Error! Reference source not found.** shows the basic structure of FTT:Power and how it links to E3ME.

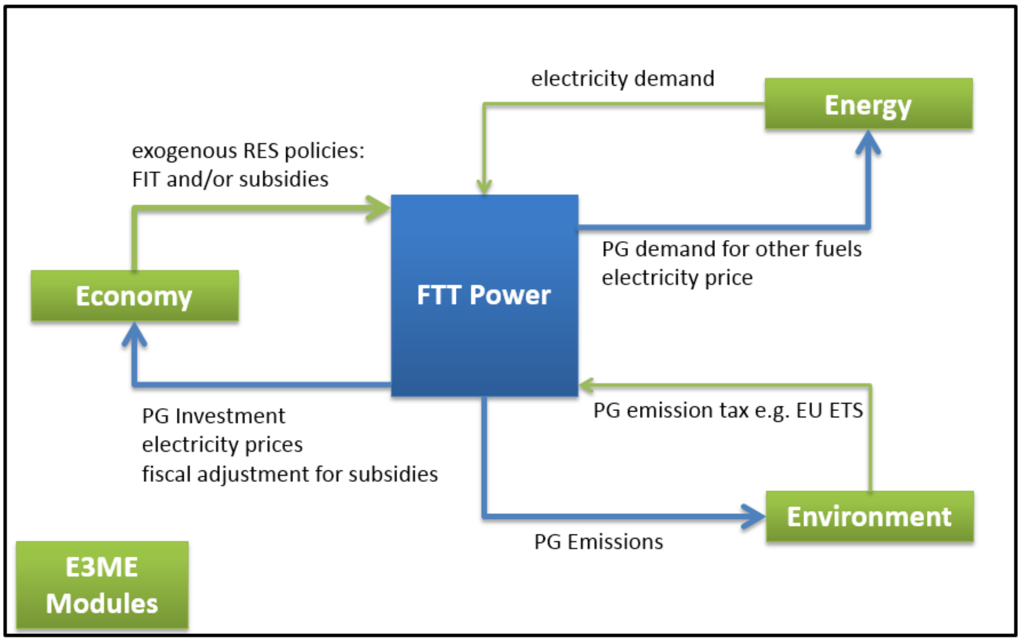

Figure 11. Basic structure of FTT:Power (reference needed).

FTT:Power determines a technology mix by region given a scenario of detailed electricity policy: carbon prices, subsidies, feed-in tariffs and regulations by technology. Changes in the power technology mix result in changes of production costs, reflected in the price of electricity. The model takes electricity demand from E3ME and feeds back a price, fuel use and investment for replacements and new generation infrastructure.

1.4.2.2 The single-region model for Azerbaijan

Because of data availability issues, E3ME could not be extended to include Azerbaijan as a separate region in the model. As a result, it was decided that a single-region Input-Output (IO) model would be developed and soft-linked to the E3ME framework, depending on the policy scenarios that will be explored.

A basic input-output model depicts inter-industry relationships within an economy, showing how output from one industrial sector may become an input to another industrial sector. For example, in the inter-industry matrix, column entries typically represent inputs to an industrial sector, while row entries represent outputs from a given sector. This format therefore shows how dependent each sector is on every other sector, both as a customer of outputs from other sectors and as a supplier of inputs. Is there a generic matrix that can be presented here? Can figureX3 be used to complement the explanation? Each column of the input–output matrix shows the monetary value of inputs to each sector and each row represents the value of each sector's outputs. For example, we have an economy with n sectors. Each sector produces x_i units of a single homogeneous good. Assume that jth sector, in order to produce 1 unit, must use aij units from sector i. Also, assume that each sector sells some of its output to other sectors (intermediate output) and some of its output to consumers and the government (final demand). With the final demand in the ith sector defined as d_i, we have the following identity:

x_i=a_i1 x_i+a_i2 x_i+⋯…………..+a_in x_n+d_i

In other words, total output equals intermediate output plus final demand.
If we name A as the matrix of coefficients aij, x the vector of total output and d the vector of final demand, then our expression for the economy becomes

$x=Ax+d$
which can be rewritten as $(I - A)\,x = d$

The matrix I – A is invertible, this means the above linear system of equations has a unique solution, and so given some final demand vector the required output can be found. Furthermore, if the principal minors of the matrix I – A are all positive (known as the Hawkins–Simon condition), the required output vector x is non-negative.
In the case of Azerbaijan, the IO table available is a 'combined table', representing spending on all products (rather than just on domestically-produced products). As such, imports were deducted from the table. Figure 12 below illustrates this:

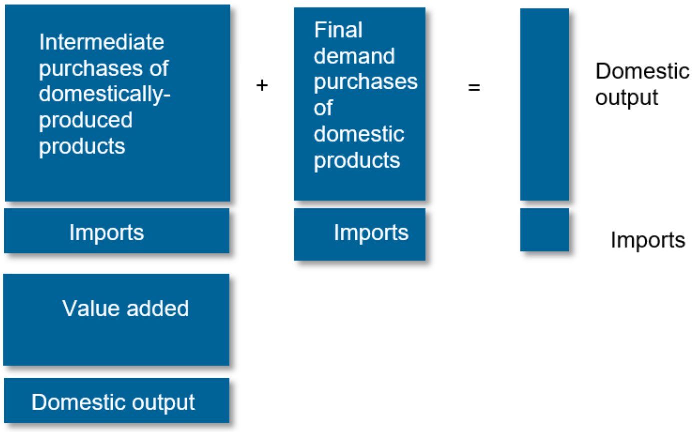

Figure 12. Basic structure for Azerbaijan Input-Output table.

The basic framework was extended to include induced household consumption in the single region model, so we constructed. Further model developments currently being considered are:

- basic modelling for the other final demand components (e.g. consumer expenditure and investment);
- basic modelling for employment;
- introducing the possibility of changing government balances with possible links to potential scenario analysis;
- basic modelling for final energy demand and power generation.

In the case of modelling the other components of final demand currently some basic relationships are being explored. For example, in the case of consumer expenditure, this has been related to changes in income. For investment, the possibility of using the changes to this final demand component in relation to output is being considered. Another option would be to make use of the estimated parameters from the E3ME investment equation from another existing region, which can be used as a proxy. In this approach the relationship between investment and output would be based on the estimated equation coefficient from the selected proxy region. A similar approach is also considered for estimating changes in employment.

Introducing changes to government balances would be done based on the policy scenarios explored. For example, when looking at a scenario with decrease in oil and gas exports, then the adjustment on government balances would be introduced to reflect the loss of government revenues due to such a decrease. In this case, results from E3ME (changes in oil and gas prices and decrease in export volumes) and additional information (tax levels for example) would be used to estimate the loss in revenues. This information would then be fed into the single region model.

The possibility of introducing final energy demand changes and feedbacks into the single region model is also being considered, perhaps using estimated parameters from an E3ME proxy region.

Overview of Azerbaijan baseline data

Economic variables

The GDP is forecasted to keep increasing at a reasonably steady rate with an average annual growth rate of 6.3% over the forecast period (Figure 13). The forecast to 2022 matches that of the IMF growth rates.

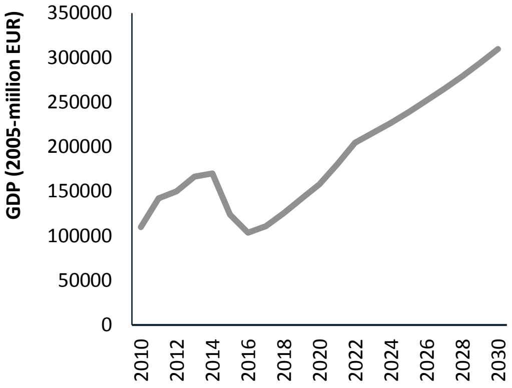

Figure 13. GDP, constant 2005 Millions of Euros.

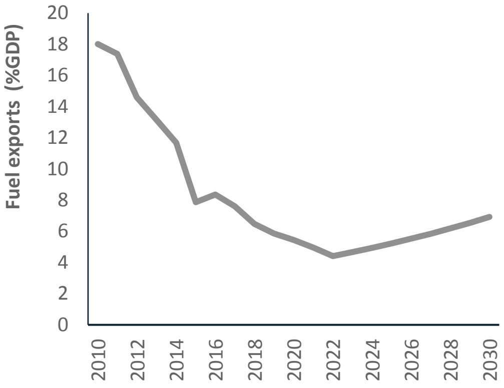

Figure 14. Fuel exports, percentage of GDP (%GDP).

The country's fossil fuel exports make up a significant contribution to the country's GDP. In 2010, fuel exports represented 18% of the GDP, with this figure decreasing to 8% in 2015. The contribution to GDP of fossil fuel exports is forecasted to remain mostly stable to 2030 in comparison to 2015.

In 2010 oil and gas extraction made up the vast majority of total output, around 72%. However, this is forecasted to decrease by 2030, to about 54%, as Azerbaijan diversifies its production. Although this is a significant change, as shown in Figure 15, extraction still makes up the majority of production in 2030.

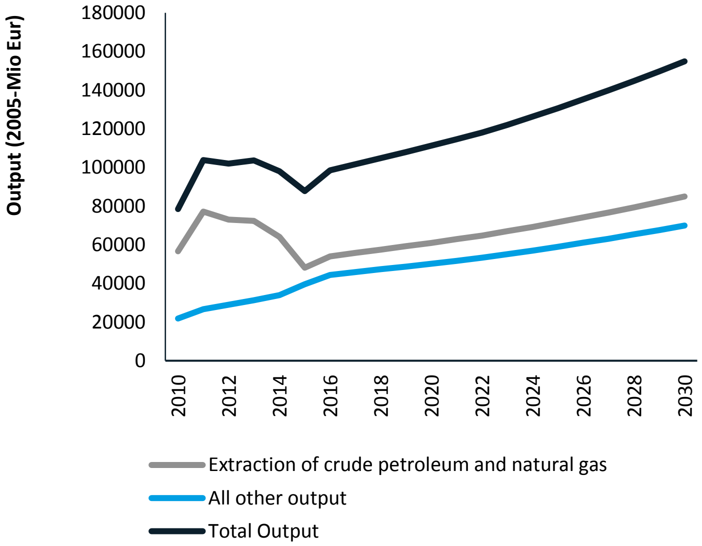

Figure 15. Output, constant 2005 Million Euros.

As shown in Table 1 it is forecast that in all sectors employment increases from 2010 to 2030 expect that of electricity and gas distribution. It is expected that there will be higher growth in sectors such as accommodation and food, professional activities, real estate, and financial activities.

Table 1. Employment in 2010 and 2030, in thousand persons.

	2010	2030	Annual Average Growth Rate
	Thousand persons	*Thousand persons*	*%*
Agriculture, forestry and fishing	1781.5	2043.6	0.7
Mining	41.0	41.1	0.0
Manufacturing	241.1	308.7	1.3
Electricity, gas and steam production, distribution and supply	28.4	25.8	-0.5
Water supply; waste treatment and disposal	26.6	29.7	0.5
Construction	352.9	498.2	1.8
Trade; repair of transport means	727.7	941.0	1.3
Transportation and storage	206.7	264.9	1.3
Accommodation and food service activities	64.5	109.1	2.8
Information and communication	63.3	78.7	1.1
Financial and insurance activities	34.6	61.5	3.0
Real estate activities	94.1	154.8	2.6
Professional, scientific and technical activities	62.5	105.2	2.7
Administrative and support service activities	57.9	83.6	1.9
Public administration and defense; social security	301.4	347.4	0.7
Education	391.8	478.6	1.0
Human health and social work activities	3.4	1.7	1.0
Art, entertainment and recreation	42.1	43.3	1.8
Other service activities	100.1	51.1	2.1

Environmental and energy variables

Carbon dioxide emissions in Azerbaijan are forecast to grow with a 3.3% annual average growth rate over the forecast period as shown in Figure X8. The forecast is in line with the growth of carbon dioxide equivalent emissions of Azerbaijan in the non-OECD Asian from the World Energy Outlook (IEA, 2015).

Demand for gas remains the largest for the fuels over the forecast period (Figure 17). Comparing with the CO2 emissions figures, it indicates that emission levels from the energy sector will not vary expressively and that the increase in emissions should have another source than energy-related.

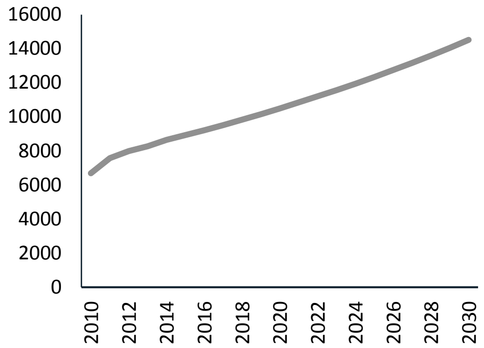

Figure 16. CO2 emissions (th tC).

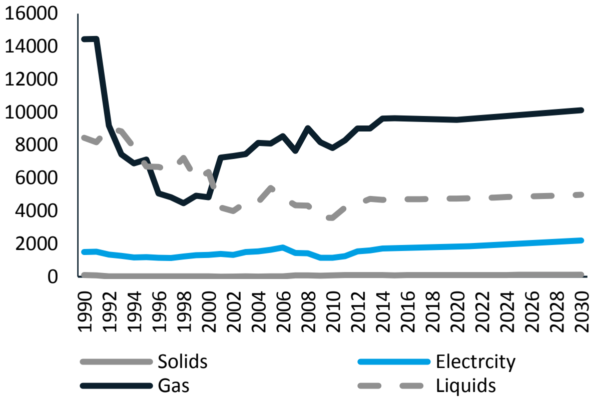

Figure 17. Demand for fuels, in thousand toe.

1.4.3 MAGNET

Agricultural activities are highly diverse in Azerbaijan with a wide range of agricultural produce, including cereals and dried pulses, cotton, potatoes, vegetables, melons, fodders crops, fruits and berries, and grapes. Total area of agricultural crops exceeds 1.5 million ha, and a wide diversity of crops is grown (Table 2). Climatic and hydrological conditions are highly variable across the country. Agricultural crops are mainly produced using irrigation and rain-fed production systems.

Table 2. Trends in area of agricultural crops (all category of farms) (source: State Statistics Committee of the Republic of Azerbaijan, at stat.gov.az).

SOWN AREA OF AGRICULTURAL CROPS (1,000 ha)	2010	2013	2016
sown area of agricultural crops	1,583.9	1,684.2	1,628.3
sown area of cereals and dried pulses	968.0	1,074.1	997.5
sown area of fodder crops	384.5	396.4	394.1
sown area of fruits and berries	127.7	134.2	171.8
sown area of grapes	15.4	16.1	16.0

Agricultural production increased in the recent years, mainly through increase of yield. Production of cereals and dried pulses increased between 2010 and 2016 by about 50% (Table 3), while the sown area of cereals and dried pulses showed inter-annual variation of some 10%.

Table 3. Trends in production of agricultural crops (all categories of farms) (source: State Statistics Committee of the Republic of Azerbaijan, at stat.gov.az).

PRODUCTION OF AGRICULTURAL CROPS (1,000 TON)	2010	2013	2016
cereals and dried pulses	2,000.5	2,955.3	3,065.1
potatoes	953.7	992.8	902.4
vegetables	1,189.5	1,236.3	1,270.6
fruits and berries	729.5	853.8	882.8

Meat production (in slaughtered weight) increased from 0.24 million tons (2010) to 0.30 million tons (2016). Beef is the main type of meat produced in Azerbaijan (Table 4).

Table 4. Trends in animal production (all categories of farms) (source: State statistics Committee of the Republic of Azerbaijan, at stat.gov.az).

PRODUCTION OF ANIMAL PRODUCTS (1,000 TON)	2010	2013	2016
meat (in slaughtered weight)	244.9	286.9	302.2
milk	1,535.8	1.796.7	2,009.9

The production volumes of the main agricultural products (SSP2 scenario, MAGNET model; all prices relative to 2011 = 1) are presented in the following figures. Figure 1 presents the production volume of main agricultural products and figure 2 presents the production volume of main animal products. Production volume of wheat is estimated to increase by some 30%, and production volume of horticulture (vegetables, fruit and nuts) is estimated to increase by some 20% (Figure 18).

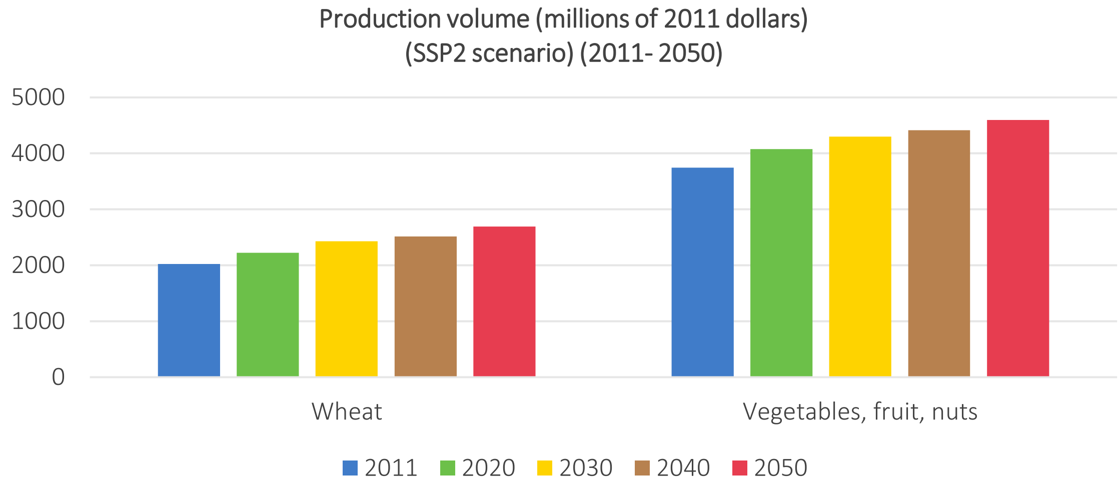

Figure 18. Production volume of main agricultural crops (millions of 2011 USD) for the SSP2 scenario and period 2011-2050.

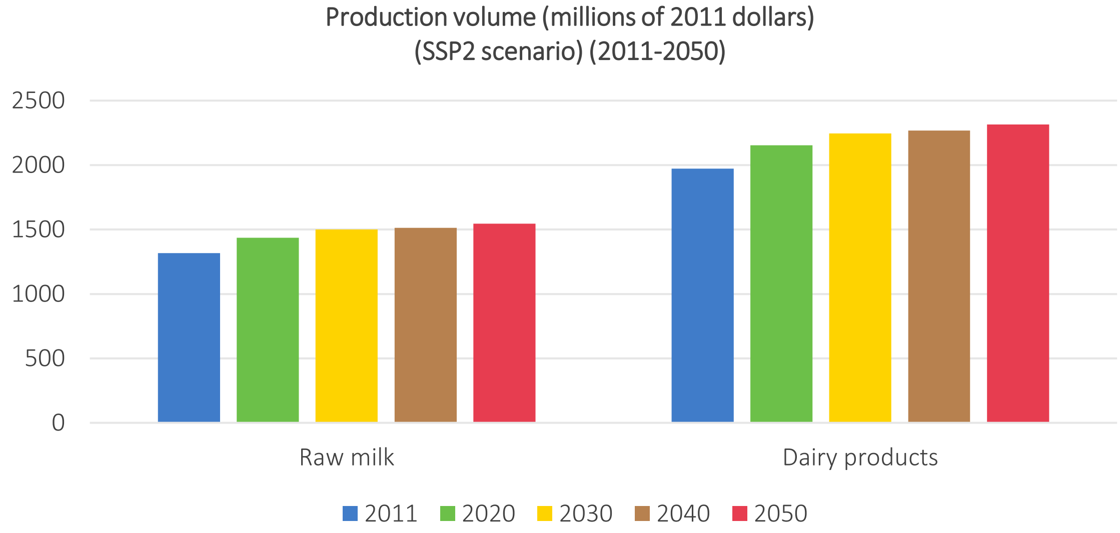

Figure 19. Production volume of main animal products (millions of 2011 USD) for the SSP2 scenario and period 2011-20150.

Energy and the macro economy

Gross Domestic Product (GDP) is estimated to increase from almost 66 billion US$ (2011) to reach 120 billion US$ in 2050. Note that all prices presented are relative to 2011 = 1. The production volume of crude oil is foreseen to increase by more than 40% (or the equivalent of 20 billion US$) during the period 2010 – 2050. It went over 31 billion US$ in 2011 and is estimated to increase by more than 30%, and reach close to 52 billion USD in 2050 (Figure 20).

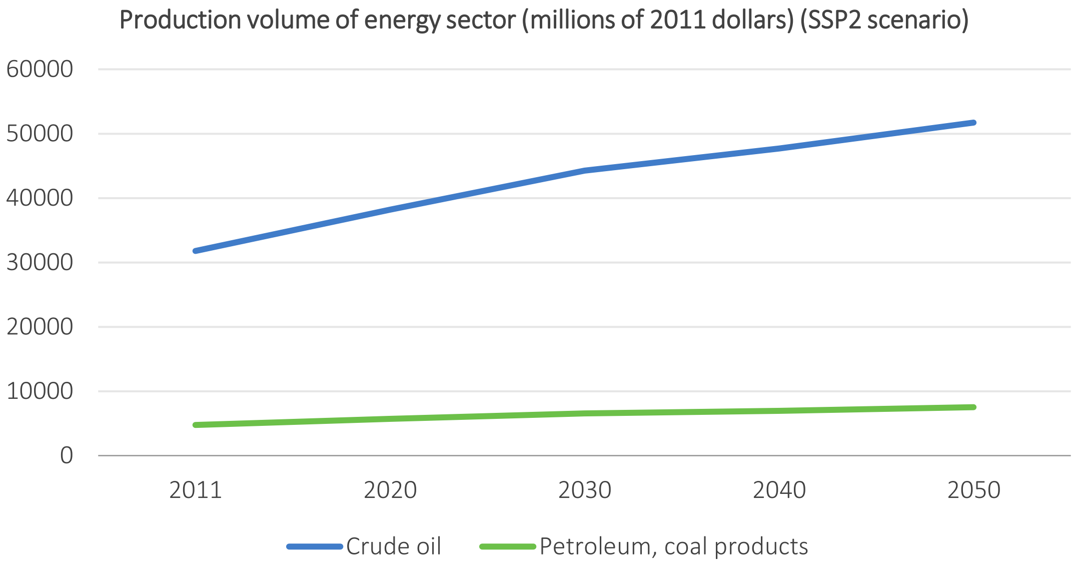

Figure 20. Production volume of the energy sector (crude oil, petroleum and coal products) in millions of 2011 dollars) for the SSP2 scenario for the period 2011 - 2050.

Production value of crude oil is expected to triple in 2050, in comparison to 2011 values and reach around 100 billion 2011-USD. In a similar trend, exports are foreseen to increase 3-fold from 13.4 billion 2011-USD to 56.2 billion USD in 2050, as shown in Figure 21.

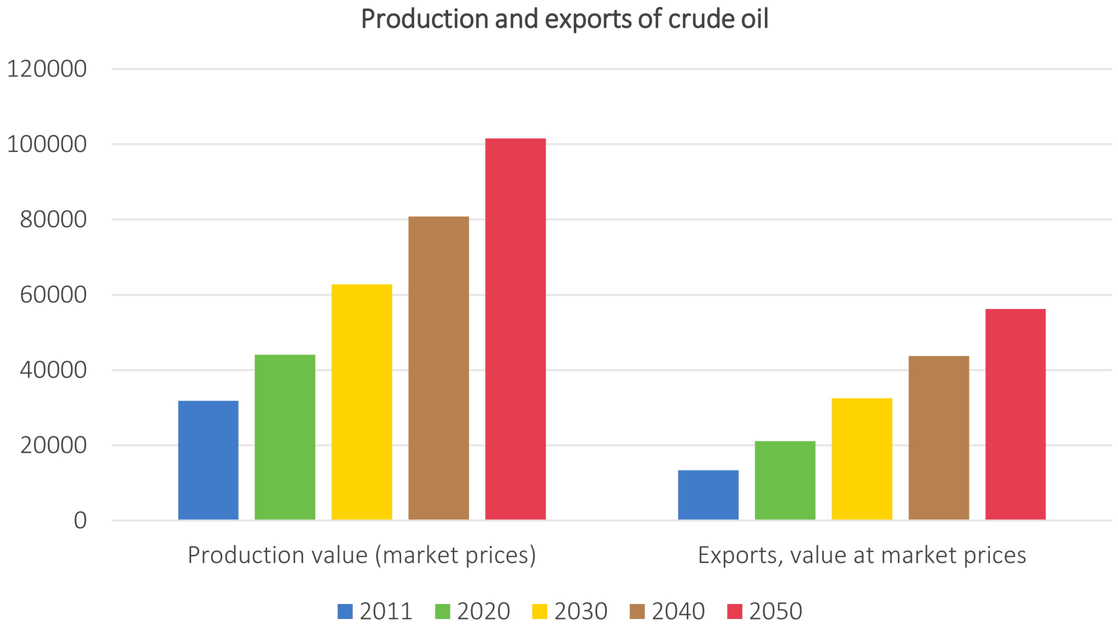

Figure 21. Production and exports of crude oil (millions of 2011 USD) for SSP2 and 2011 – 2050 period.

The service sector doubles between 2011 and 2050, to reach more than 60 billion USD (Figure 22). No major changes are evident in the production of other sectors throughout the period of analysis taking into consideration SSP2 input data.

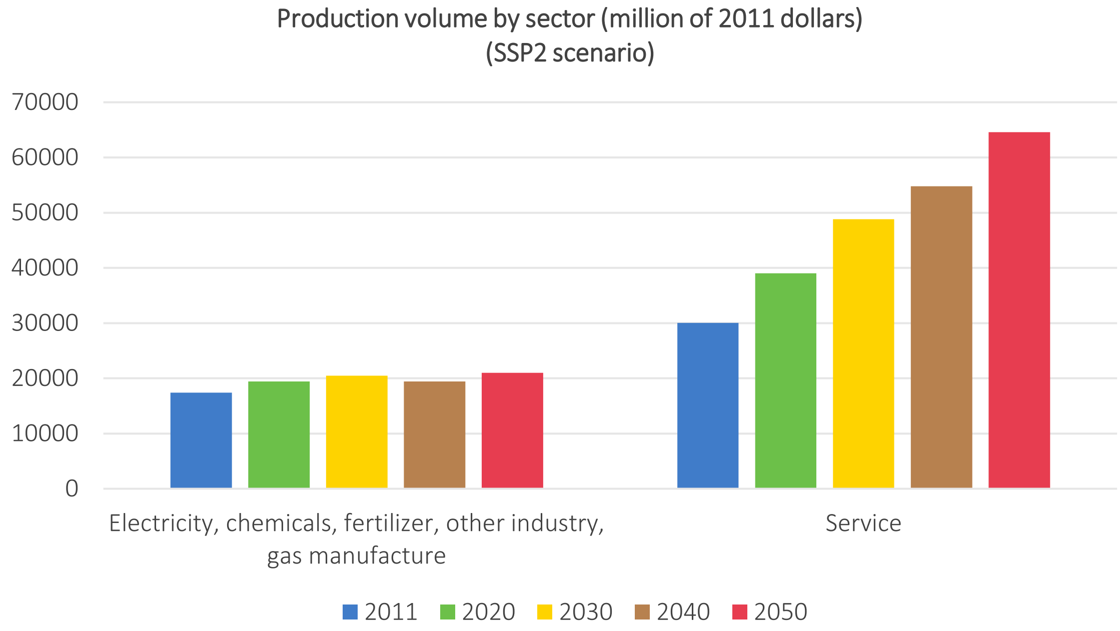

Figure 22. Production volume of the industrial sector and service sector (millions of 2011 USD) for the SSP2 scenario and 2011-2050 period.

1.4.4 CAPRI

In the case of the case study of Azerbaijan, only the global market model module was used for the analysis, as Azerbaijan is not an independent region in the full CAPRI model. It is, however, one of the ten countries that comprise the Former Soviet Union (FSU) region represented in the global market model, which is made up of 40 trade blocks[1].

The FSU region includes Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Turkmenistan, Uzbekistan and Tajikistan. Although the scale mismatch is not ideal, it creates the opportunity to explore the agricultural sector in more detail and to investigate potential implications of EU policies to the FSU region and, indirectly, to Azerbaijan. An assessment of the downscaling of FSU results will be further investigated. This will require the assessment of the agricultural production and consumption context of the country and of the other countries in the FSU region, so to identify the relevant agricultural products to analyze, and estimate their potential output in Azerbaijan.

Figure 16 shows the production of selected agricultural goods in 2010, for the Commonwealth of Independent States (CIS), with the exception of Russia and Ukraine. This selection includes 8 of the 10 countries in the FSU region – not represented are Georgia and Turkmenistan. It can be seen that the production profile and scale production varies across the countries. Azerbaijan's production, as represented in the figure, corresponds to 6.7% of the total and is dominated by the production of milk (22%), vegetables (17%), potatoes (14%) and cereals and pulses (28%). On the other hand, we have countries whose production is three or four times higher than the total of Azerbaijan, where the

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[1] http://www.capri-model.org/dokuwiki/doku.php?id=capri:concept:market

production of just one crop type can be higher than the total production of Azerbaijan – note for example the case of cereals and pulses of Belarus.

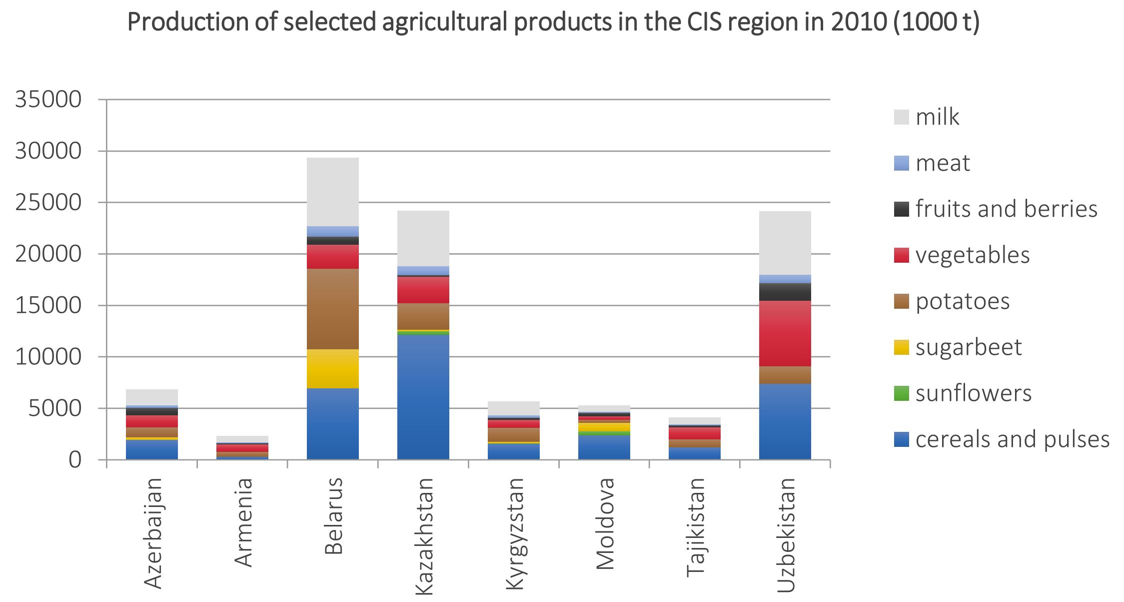

Figure 23. Production of selected crop-based agricultural products in the CIS region, excluding Russia and Ukraine (source: Statistical Committee of the Republic of Azerbaijan, at stats.gov.az).

In terms of temporal scope, the CAPRI model runs up to 2050 and shown in this report are results for 2010, 2030 and 2050; and main assumptions are aligned with the SSP2 scenario and consider a status quo policy setting.

CAPRI results for the FSU region

Production of cereals, including wheat, is expected to increase when until 2050 (Figure 24) by 18%. Domestic demand for cereals surpasses the production in 2010 and 2030, and it is only slightly higher than production levels in 2050. This indicates that the FSU region could supply its own demand and decrease its dependency on food imports. Overall agricultural consumption falls below the total production in 2050. The justification for this change needs to be further investigated.

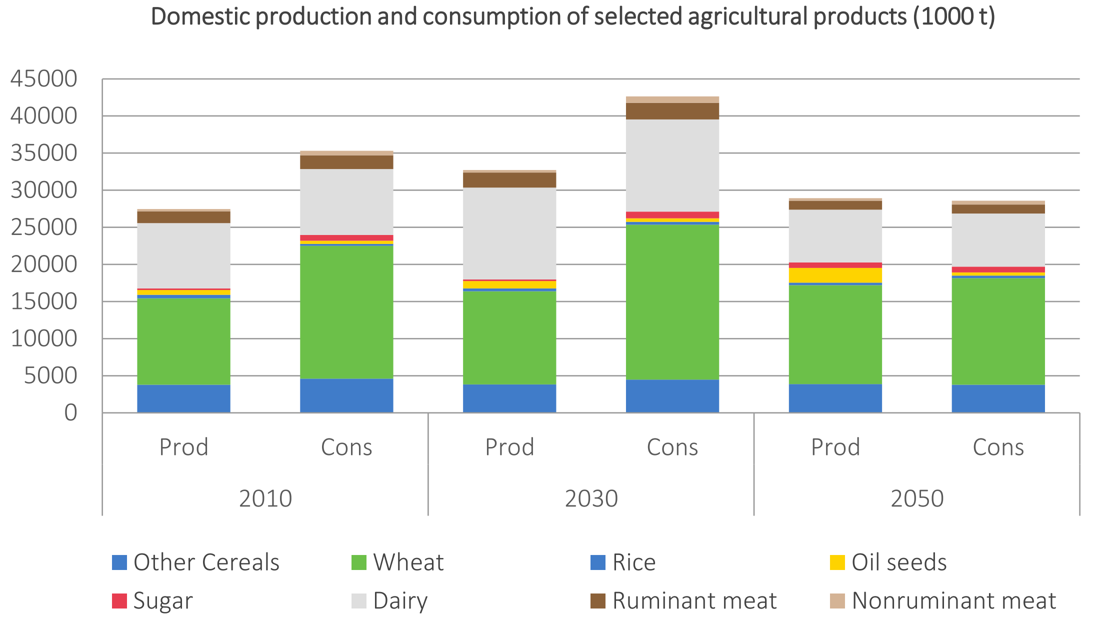

Figure 24. Domestic production and consumption of selected agricultural products for the FSU region in 2010, 2030 and 2050 (1000 t).

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

Considering the fact that the within the SIM4NEXUS consortium there is no Azeri native or someone with long experience in the area, networking in the country has been a challenging task. A number of people have been contacted but the list of stakeholders is not yet consolidated. In terms of workshops, a member from the SIM4NEXUS consortium participated in the Seventh International Forum on Energy for Sustainable Development[2] held by the United Nations Economic Commission for Europe (UNECE) in October 2016. This event provided an opportunity to establish contact with the State Agency of Alternative and Renewable Energy Sources who could potentially provide data on the energy sector.

On the side of that event, there was a meeting at the Baku State University to discuss their potential involvement in the project. As a result, a researcher from that institute has been subcontracted to provide consulting services. More specifically, they have been writing a large part of SIM4NEXUS Deliverable “D2.2 Nexus Nexus-relevant policies at national and regional scale” where they policies pertaining to different Nexus domains are analysed. Moreover, they help with the organisation of the first official, SIM4NEXUS workshop in Azerbaijan. The latter is expected to be held in spring/summer 2018 in Baku and the invitees will be mainly from the institutions identified in D2.2. Prior to the workshop, it is expected that some preliminary findings of the study will be shared with the invitees to help them get an understanding of the nexus concept. During the workshop, the participants are expected to share their views on the main nexus challenges and the importance of each. The findings

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[2] https://www.unece.org/index.php?id=42643

of the workshop will in turn assist the SIM4NEXUS consortium in further developing this case study, both on the modelling and the conceptual side.

The institutes involved in this case study are the Royal Institute of Technology – KTH, LEI Wageningen UR and Cambridge Econometrics. In October 2017, researchers from the three institutes convened in Stockholm where a case study workshop was organized. During this workshop, the different parties had the opportunity to discuss about the modelling exercise, potential interactions between the models, the conceptual framework and the next steps. A key decision of this workshop was that the SIM4NEXUS side would like to align their actions with the UNECE who has an ongoing project in the area looking into the interactions between energy and water. Therefore, the UNECE could potentially be a key stakeholder for the current case study.

Stakeholders have been and are expected to be involved in the following activities mainly through consultation workshops:

- Assess the relevance of the nexus interlinkages identified;
- Assess the relevance of/propose new scenarios to investigate;
- Provide data to further improve the models used in this study;
- Suggest key performance indicators to help convey the outcome of the analysis as well as weighting factors for multi-criteria analysis (MCA);
- Provide feedback on policy recommendations.

2 Conclusions and follow-up

The Azerbaijan case study is a very interesting case within the 12 case studies of SIM4NEXUS as it will provide a perspective of a oil based economy, with strong trade links to the EU. Both Azerbaijan and the EU countries aim at decarbonising their energy sectors and it is not clear what will be the impacts of the achievement of such goals. This is an important gap in research that will be combined with a nexus analysis, and therefore, turn into a comprehensive understanding of cross-sectoral implications of low carbon and resource efficient policies.

For the coming months, efforts will be focused on analysing the insights retrieved from the different thematic models used in the case study. This will be done in parallel with a more thorough identification of nexus interlinkages and associated challenges. Both these actions are required for the development of the conceptual model, the refinement and improvement of the modelling analysis and the identification of linking opportunities between modelling tools for the development of a wide-ranging analysis, within the limitations of model application and data availability. The second part of the year will be dedicated to stakeholder engagement and workshop preparation, along with the definition of potential scenarios in line with the policy analysis that could be of interest to discuss further with the to-de-involved stakeholders.

3 References

- Pirani, S. (2016). Azerbaijan’s gas supply squeeze and the consequences for the Southern Corridor. Oxford Institute for Energy Studies, NG 110.
- Mercure, J-F (2012), 'FTT:Power A global model of the power sector with induced technological change and natural resource depletion', *Energy Policy*, vol 48, pp 799–811.

- Mercure, J-F and P Salas (2012), 'An assessment of global energy resource economic potentials', *Energy*, vol 46(1), pp 322-336.
- IEA (2015). World Energy Outlook 2015. Paris: International Energy Agency / OECD.
- World Trade Organization (n.d.). "Country profile of the Republic of Azerbaijan". Available at: http://stat.wto.org/CountryProfile/WSDBCountryPFView.aspx?Language=E&Country=AZ
- UN Data (n.d.). "Country Profile of Azerbaijan". Available at: http://data.un.org/CountryProfile.aspx?crName=azerbaijan
- European Union External Action, EEAS (n.d.). "EU-Azerbaijan relations". Available at: https://eeas.europa.eu/headquarters/headquarters-homepage/4013/eu-azerbaijan-relations_en

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

D5.2: THE MAIN NEXUS CHALLENGES IN THE FRANCE-GERMANY TRANSBOUNDARY CASE STUDY

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Glossary / Acronyms

Term	EXPLANATION / MEANING
NGO	Non-Governmental Organisation
SDM	Systems Dynamic Modelling
SRADDET	*Schéma Régional d'Aménagement, de Développement Durable et d'Egalité des Territoires* Regional plan for land planning, sustainable development and territorial equality
UAA	Utilized Agriculture Area
USD	US Dollars
URR	Upper-Rhine Region
WFD	Water Framework Directive

1.1 Introduction

The France-Germany case study examines pathways to achieve the below +2°C targets on climate change, as set by the Paris Agreement. It also confronts the implementation of the European directives (Common Agricultural Policy, Water Framework Directive, Floods Directive) and the national legislations on energy transition in a transboundary region. The specificity of this case study, compared to the 11 other cases of the SIM4Nexus project, is to put the emphasis on the consequences for aquatic ecosystems and rivers functionalities. The case study focuses on the links and synergies between energy policy and the transition to a low-carbon economy on one side, and the management of natural resources (in particular water) and ecosystems on the other side.

Because of its transboundary character, it investigates also the links between policy development and implementation on both sides of the Rhine, and whether there would be opportunities for enhancing cooperation and policy coherence between France and Germany for achieving jointly set policy objectives in a more cost-effective manner. Stakeholders from both sides of the border, but also from transboundary organisations, have been met in order to present the SIM4Nexus project, understand their relations with the organisations of the neighbouring country and gather information about the main issues, present and future.

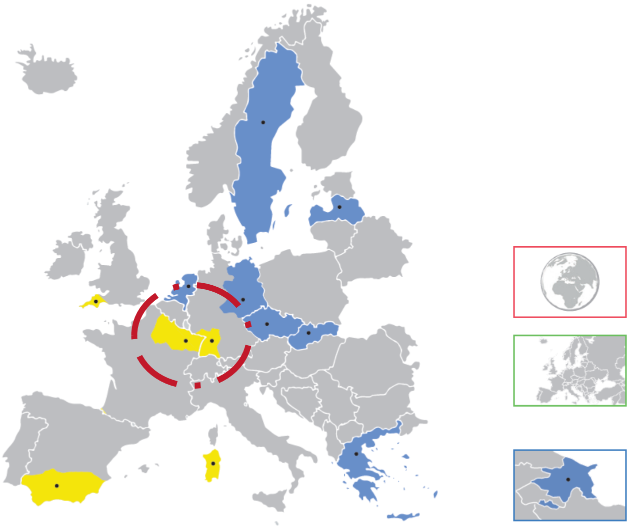

Figure 1: Situation of the France-Germany case study in Europe

The transboundary France-Germany case study is situated in the Upper Rhine region and covers the federal state of Baden-Württemberg (35 751 km^2) on the German side and the newly formed Grand Est Region[1] (57 800 km^2) on the French side, with the (Upper) Rhine playing the role of physical and administrative border in its middle[2]. The area along the Rhine is one of the most densely populated and highly industrialized area of the European continent.

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[1] Built from the former Alsace, Lorraine and Champagne administrative regions.

[2] The case study does not include the Swiss part of the territory which is usually included in the Upper Rhine in a water management context.

1.2 Description of the Nexus challenges

The following chapter describes, on the France-Germany transboundary case:

- The main trends for each of the nexus sectors: water, land, food, energy and climate;
- The interlinkages between the Nexus sectors;
- The trade-offs and synergies across the Nexus sectors.

The frameworks provided by WP1 (D1.1) and WP3 (D3.1) have supported this work.

1.2.1 The main trends

1.2.1.1 Energy

France

In 2010, the total final energy consumption in Région Grand Est was 18 550 ktoe[3]. There is a decreasing trend since 2005, in every former regions (Champagne-Ardenne, Lorraine and Alsace), as illustrated in Figure 2. The decrease is even more important than planned (objectives to achieve carbon neutrality by 2050), especially in Lorraine where the decrease objective was 4% and the real decrease was 30% over 10 years!

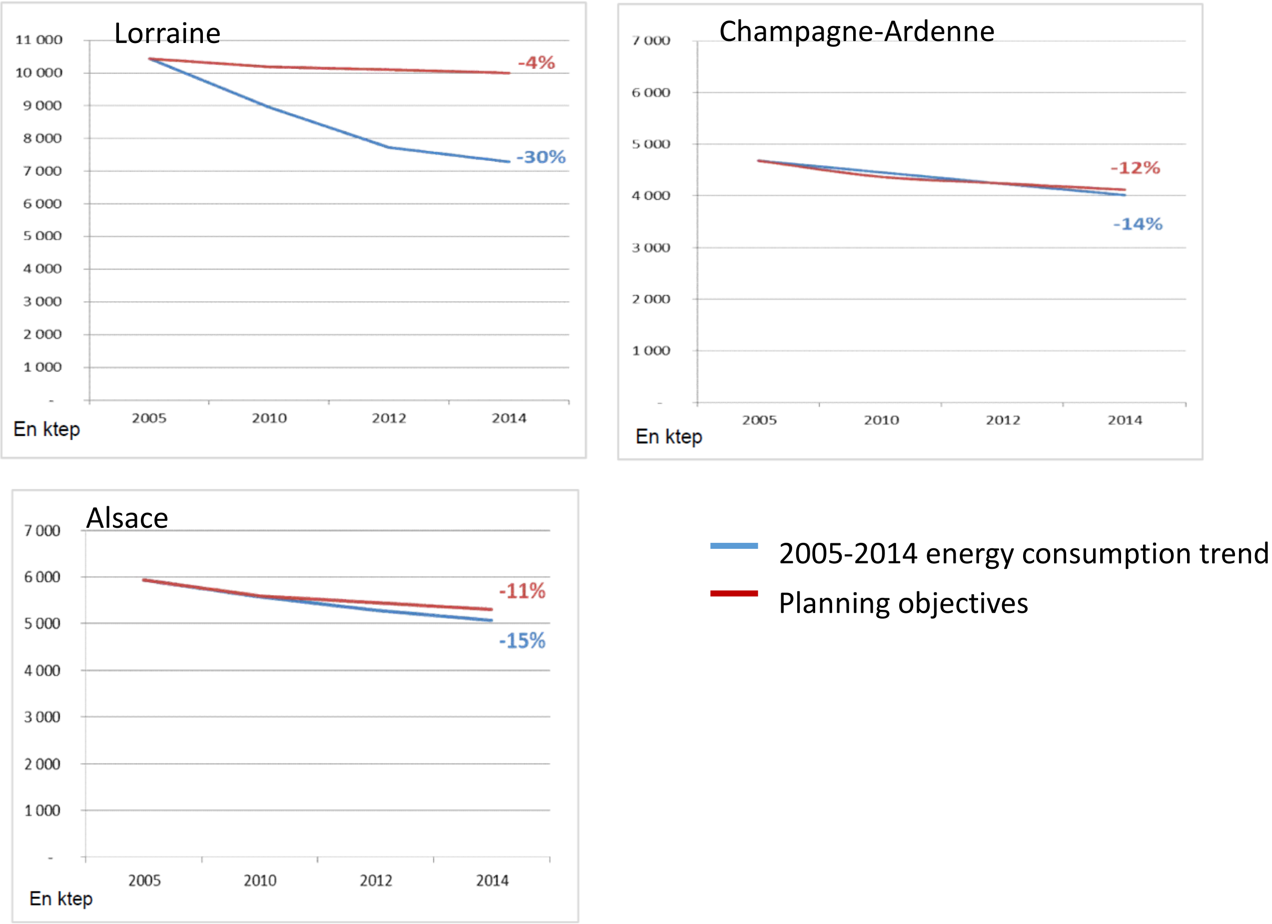

Figure 2: Final energy consumption 2005-2014 by former regions[4]

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[3] Ton of oil equivalent

[4] Source : Région Grand Est, SRADDET, Séminaire de co-construction Air-Energie-Climat, 5 juillet 2017

Energy was mainly consumed by four sectors as illustrated in

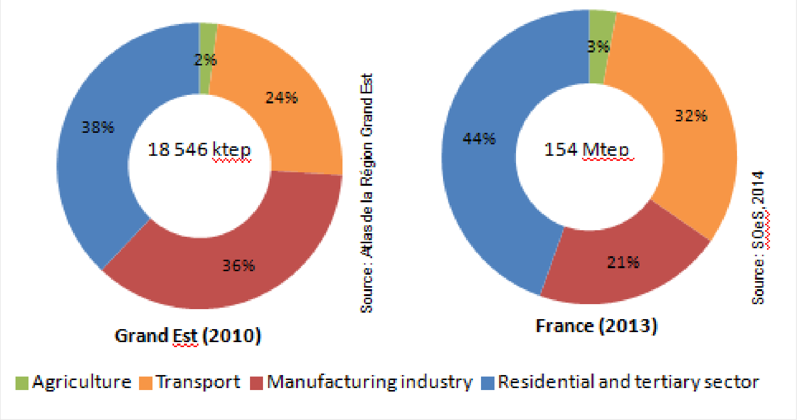

Figure 3. In 2010, the sector with the largest share of final energy consumption is the residential and service sector, which consumed 38% of the total amount of final energy consumption. The industry sector is second, consuming 36%. Transport is third with the consumption reaching 24% and last, the share of agriculture sector is 2%.

Consumption of industry sector is particularly important compares to national level (38% vs. 21%). Industry and residential-tertiary sector account for 75% of the total energy consumption.

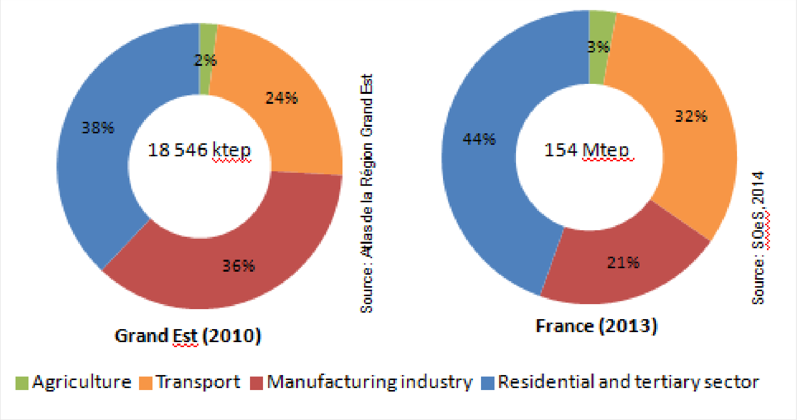

Figure 3: Final energy consumption by sector in the Région Grand Est and in France

The main energy fuels of final energy consumption are petroleum products, gas and electricity, which provide respectively 34%, 27% and 21% of the final energy consumption in 2010. Fuel wood, other renewable sources and derived heat, have a total share of around 9%. Solid fuels and others non renewable, have a total share of around 6% (Table 1). Renewable sources are mainly hydraulic power, fuelwood, agrofuel and wind power. Over the period 2005-2014, gas consumption decreased by 32%, petroleum products consumption decreased by 20%, and electricity consumption decreased by 10%.

Table 1: Final energy consumption per fuel types in Région Grand Est in 2010

unit: ktoe	Total	%
Electricity	3 909	21%
Natural Gas	5 008	27%
Total Petroleum Products	6 367	34%
Solid Fuels	1 002	5%
Fuel wood	1 054	6%
Other renewable energies	326	2%
Other Non renewable	683	4%
Derived heat	196	1%

Total	18 545	100%

Source : Atlas de la Région Grand Est

Germany

So far nearly one-third of the electricity supply in Germany comes from renewable sources such as wind, solar and biomass. Nuclear power will phase out completely by 2022.

The energy transition laws have set the following goals:

- 35% of energy consumption should be covered by renewable energy in 2020, 40-45% in 2025 and 80% by 2050;
- 20% less primary energy consumption by 2020;
- 40% less GHG emissions (baseline 1990) by 2020;
- 10% less energy consumption for transports by 2020.

1.2.1.2 Water

The Rhine river underwent heavy straightening of the watercourses in the 19th and 20th century which cut off of old meanders. In the late 1950ies, the Rhine canal was built between Basel and Breisach. The canal runs parallel to the Rhine, is 50km long and is used for the generation of electricity through hydropower. Over the years the straightening led to a lower groundwater table declining by two to seven meters in the lowlands on the both sides of the Upper Rhine since the establishment of the canal[5]. At the moment there are ten hydroelectric stations[6] and one nuclear power plant which receives cooling water from the canal[7], all are run by the French energy company EDF.

The Rhine aquifer is one of the biggest in Central Europe and an important source of drinking water, the area between Basel and Strasbourg receives three-quarters of its drinking water from this aquifer. Half of the industrial demand is also met in this highly industrialized region by the 45 billion m³ aquifer.

In spite of years of actions to protect these water resources, there is still concern on:

Water quality

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[5] http://www4.lubw.baden-wuerttemberg.de/servlet/is/21695/

[6] https://www.edf.fr/sites/default/files/Hydraulique/Alsace-Vosges/documents/les_amenagements_hydroelectriques_du_rhin_franco-allemand.pdf

[7] https://www.edf.fr/sites/default/files/contrib/groupe-edf/producteur-industriel/carte-des-implantations/centrale-fessenheim/actualites/Juin%202017/presseunterlagen_2017_de.pdf

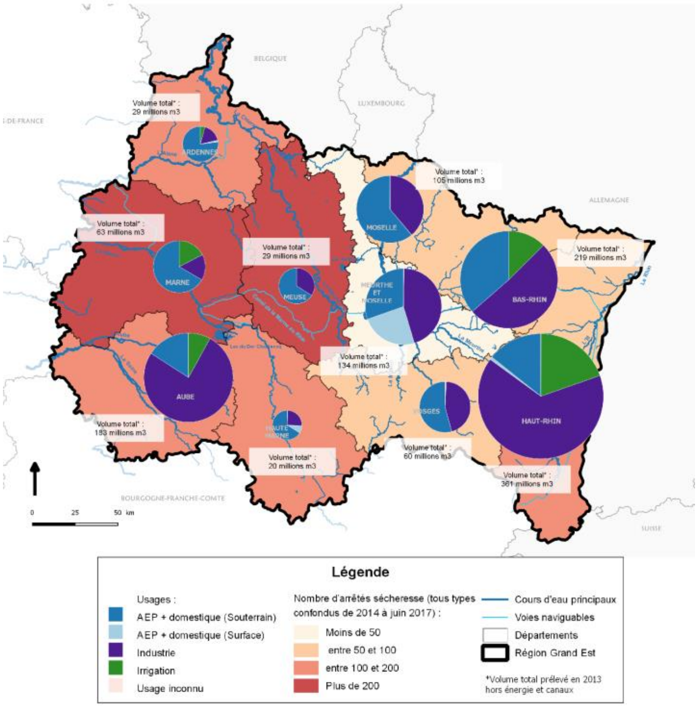
Pesticides and most importantly nutrients are still present in spite of stronger regulations (the good status thresholds have also been lowered and the detection levels have improved). Half of water bodies do not reach the good chemical status required by the WFD. Micro-pollutants are a new threat. A warning and alert plan has been established among countries in case of accidental pollution from the industries along the Rhine and tributaries.

Water quantity

Groundwater levels are decreasing in strategic areas due to the combined effects of increasing abstractions and decreasing infiltration.

Drought situations are occurring more frequently, putting a threat on aquatic life. Figure Figure 4: Water abstraction volumes for each user and number of water restriction orders from 2013 to 2017 in the Grand Est region shows, on the Grand Est region, the water needs for the different users (drinking water in blue, industries in violet, irrigation in green) as well as the number of water restriction orders (more than 200 orders in dark red) issued between 2013 and 2017.

Répartition par département des prélevements d'eau par usages (2013 hors énergie et canaux) confrontée au nombre d'arrêtés de restriction d'eau (2014 à juin 2017)



ACTeon - juillet 2017 - Données : BNPE; Propluvia; BDCarthage©IGN

Figure 4: Water abstraction volumes for each user and number of water restriction orders from 2013 to 2017 in the Grand Est region

Aquatic ecosystems and river morphology

Continuity of the river is still not reached due to large dams and sluices on the Rhine and its tributaries (10 000 obstacles reported on Grand Est region!). The migration of fish species is limited and efforts to reintroduce the Salmon fish are jeopardized.

Flood hazards

Expensive projects are implemented to recreate floodplains in order to mitigate the impacts from major floods and protect human settlements. 85% of the former alluvial area of the Rhine was lost to urbanisation and digging. In Région Grand Est, ¼ of cities and 10% of the population are located in flood prone areas. The floods in 1993 and 1995 caused severe damage (in Germany alone about 900 million USD[8]).The threat of climate change and its consequences on rainfall and snowmelt puts a high uncertainty on the frequency and magnitude of future flood events.

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[8] Kleinn, J., C. Frei, J. Gurtz, D. Lthi, P. L. Vidale, *and* C. Schär (2005), Hydrologic simulations in the Rhine basin driven by a regional climate model, J. Geophys. Res., 110, *D04102, doi:*10.1029/2004JD005143.

Navigability

Navigation is a particular sector to be considered in this case study, due to its importance in the economy of both French and German regions as well as for the associated infrastructures (ports, canals, sluices, etc).
Figure 5 presents the main ports (blue spots) and rivers as well as the quantities transported annually (more than 15 million tons in red, form 5 to 15 million tons in green, less than 5 million tons in blue).

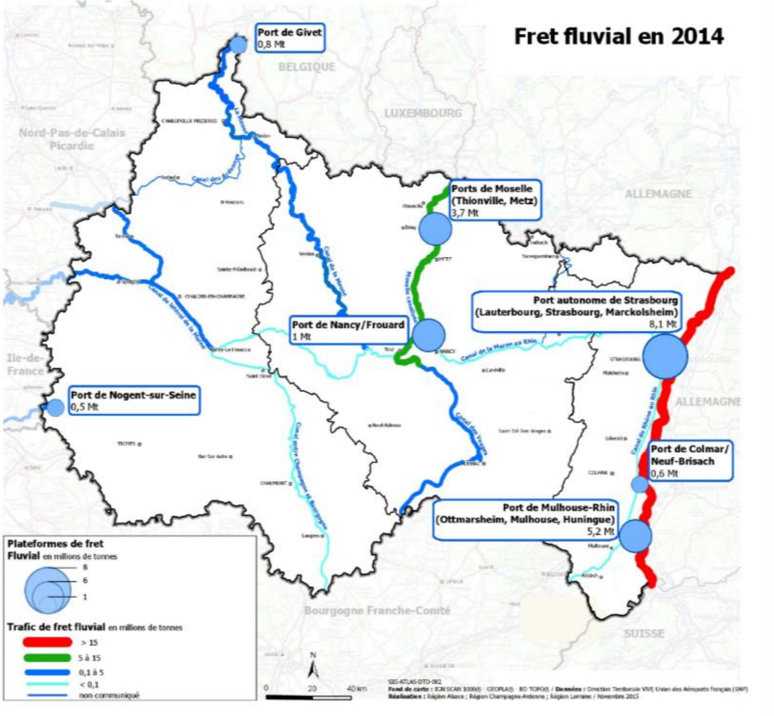

Figure 5: River transport in 2014 in the Région Grand Est

1.2.1.3 Climate

In the Rhine catchment, considerable knowledge[9] is available on the effects of climate change observed during the 20th century on the discharge pattern of the Rhine and the development of water temperatures since 1978. Furthermore, during the last years, and based on climate projections, water gauge related simulations of the development of the water balance and the water temperature in the river basin Rhine have been drafted for the near future (until 2050) and the distant future (2100). According to these projections, the development until 2050 is characterized by a continuous rise in temperatures which, for the period 2021 to 2050, compared to the period 1961-1990, will amount to an average of +1 to +2°C for the entire Rhine catchment.

For the winter, a moderate increase in precipitation is projected until 2050. Increased precipitation during the winter which, due to higher temperatures, will more often occur as rainfall than as snowfall, may lead to a moderate increase of medium and low flows.
Projections for the summer do not indicate any clear trend for precipitation until 2050. Compared to today's situation, runoff in summer will remain more or less unchanged.

Due to rising air temperatures, the results of the model chains considered seem to indicate that floods and extreme events will occur more often in the river basin district, that is, that the water balance will distinctly change, and this development might become more marked towards the end of the 21st century. Also, higher air temperatures (a rise by +2 °C to +4 °C is projected for 2100) will lead to higher water temperatures.

The direction of change for the water balance, which, in the near future (until 2050) will partly still be moderate, becomes clear when considering what is expected for the end of this century:
a. during the hydrologic winter:

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[9] https://www.iksr.org/en/topics/climate-change-in-the-rhine-catchment/

- Increased precipitation in winter
- Increased discharge
- Early melting of snow/ice/permafrost, shift of the line of snowfall

b. during the hydrologic summer:

- Decreasing precipitation (but possibly more often heavy rainfall in summer)
- Decreasing discharges
- Increasing periods of low flow.

c. Increase of smaller to medium floods, increase of peak flows of rare floods seem to be possible, but their extent cannot be quantified beyond doubt.

Simulations for the near future indicate that, compared to the reference situation and in periods of low flow, the number of days with water temperatures above 25 °C will increase up to the double. In the distant future, there will be a strong rise in the number of days with temperatures above 25 °C. For the distant future, this is also true of temperatures above 28 °C.

The International Commission for the Protection of the Rhine has published its adaptation strategy[10] in 2015.

1.2.1.4 Land

Population growth was strongly uneven between rural areas (population decrease) and urban areas (about +50% to +115% in the Rhine valley over 50 years. The main urban agglomerations are Karlsruhe, Strasbourg, Mulhouse, and Basel.

The land use categories[11] in the Upper-Rhine region (URR) show a distinctive spatial distribution following the specific topographic structure of the region.
Overall, around 37% of the URR area is used by agriculture. Arable land is concentrated on the flat of the Rhine valley. Permanent grassland is generally located in the mountainous regions and along the rivers. Between 2000 en 2010, the Région Grand Est lost 15% of permanent meadows surfaces (to urbanisation or crop land). Viticulture represents only 2% of the total surface, but remains an important economic sector for the URR. The main occurrences of viticulture are on the slopes of the Black Forest, the Vosges and the Kaiserstuhl.
Forests cover the highest percentage of the land, with about 43% of the total URR area. They are mainly located in mountainous areas such as Black Forest, Vosges and Jura. Broad-leaved forests are relatively rare in the Black Forest with 10% land cover, but more extensive in the Vosges with 19%. Conifer forests are inversely more important in the Black Forest (18%) than in the Vosges (9%).

Though heavily urbanised and populated, many initiatives have managed to secure natural habitats, reserves and protected wetlands on the Upper Rhine basin: 22 400ha on French side and 25 100ha on German side. These areas play vital roles for human settlements (flood mitigation, social value of riparian landscapes, recreation, etc) and wild species (in particular migrating fish species and birds).

1.2.1.5 Food

The agricultural productions' focus is distinctively different in the two countries. Crop production from arable land is dominant in Alsace with around 70% arable land of total French UAA. In comparison, the lowest share of permanent grassland has Alsace with only around 23%. Permanent cultures such as

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[10] https://www.iksr.org/fileadmin/user_upload/Dokumente_en/Reports/219_en.pdf

[11] European Environmental Agency 2015

wine and fruit-growing orchards are quite important in the German URR part (11% of German UAA), also important in Alsace (around 5% of French UAA).

1.2.2 The interlinkages

The table below shows the links between the 5 Nexus components that are most relevant for the France-Germany case study. It is built from Deliverable D1.1.

	Water	Energy	Land Use	Food	Climate
Water		Water is required for biofuel cultivation and processing. Water is used in the transportation sector. Water is used in electricity generation. Water is used in hydropower generation. Water is used in thermal power generation (fossil fuel and nuclear). Water is used by non-hydro renewable energy technologies.	Irregular flooding of rivers threatens human settlements and croplands. The amount of available water controls the existence of forests and semi-natural areas. Wetlands are vital for maintaining water availability and increasing the resilience of agriculture to survive extreme water events. Natural water purification is served by inland water bodies and wetlands.	Crops require water for photosynthesis. The water requirements of crops vary considerably, as do irrigation efficiencies. Animals need water to drink (and indirectly for the production of feed). Fish need water as habitat. Reaching food security targets depends highly on the physical access to water and on water quality. Sufficient water, in combination with well-maintained and organized irrigation systems, can be a huge boost to food production. Water quality is an essential issue for food production.	Due to the relatively high heat capacity, water bodies dampen temperature extremes in their vicinity. Local climate optimization can be favored by water for minimizing temperatures extremes.
Energy	Energy, commonly electricity, is needed for pumping (extraction and distribution). Energy for the operation of pump storage power plants. Energy used for irrigation/pumping in agriculture. Implications to water quality from thermal power operation, hydropower generation, thermal power generation, hydropower production and storage. Environmental flows' regulation, due to energy generation.		The extraction, generation, production and transmission infrastructures associated with all energy technologies have implications for land use. Biofuels production will result in indirect land use change (ILUC), increasing the price of agricultural land which will induce the conversion of non-agricultural land that tends to be carbon-rich into relatively carbon-poor agricultural land. Large hydro schemes, for both generation and storage, have the potential to alter land considerably both upstream and downstream.	Pumping or desalinating water for irrigation purposes, lead to more energy intensive food products. Biofuels take land from food for human consumption. Energy is needed in agriculture and livestock sections and therefore for the production of corresponding goods.	Massive fossil fuel combustion causes climate change. UHI affects the dominance of impervious surfaces and comparably sparse vegetation in urban areas, leading to lower evapotranspiration rates and upheating. All human activities related to energy are responsible for gasses emissions leading to the greenhouse effect and correspondingly to climate change.

Land Use	Urban subsector is responsible for high water usage, sewage and waste disposal, increased runoff, and runoff from lawn fertilizers and pesticides. Industrial subsector is a large water consumer, disposes industrial waste on surface and underground water resources and creates high runoff. Agricultural subsector has enormous irrigation needs, is responsible for chemical and nutrient inputs from fertilizers, pesticides etc., and creates high runoff. Forests effectively cycle water with very small losses to surface and groundwater, while evapotranspiration consumes a great part of water. Wetlands act as a retention buffer for water, conserve water, moderate runoff, function as a natural purifier, reduce flood risks at downstream locations, and improve water quality.	Artificial surfaces (urban and industrial) require a continuous supply of energy to support infrastructure, transport, buildings, water supply, food production and industrial-commercial activities. The increasing demand for industrial land require even larger amounts of energy and reduces the availability of forest and energy crops as resources for the production of bioenergy. Agriculture areas use energy as an input to production, but can also provide renewable fuel feedstock for the energy sector. Forests and semi-natural areas provide resources that can be made available for use in the bioenergy sector for the production of both heat and electricity. Inland water bodies regulated by artificial dams allow for hydropower production in regions with sufficient water supply.		Pastures have a food production role as grazing ground for different animals, important for dairy farming. Cropland has a food production role for direct human consumption and for feed. Forests have a food production role as provider of non-timber products (e.g. bush meat, nuts, and seeds).	Urban land use affects microclimate of urban regions with the creation of heat islands. Agriculture also contributes to CO2 sequestration, by absorbing CO2 through specific crops and by reduced use of fertilizers, pesticides, mechanical work. Vegetation and forestry have a direct impact on the microclimate, by affecting the albedo, providing cooling and lowering the air temperature of the region. Forestry affects the climate by absorbing CO2, thus reducing GHG emissions.
Food	Crop based food production needs irrigation through rainfall plus withdrawal of (ground-) water resources. Animal based food production has direct water requirements for animal drinking and indirect through water required in plant-based production as animal feed. Agro-chemicals (crop protection products) will impact water quality. Antibiotics and possibly hormones will have an impact on water quality. Certain food products and its waste impact water quality.	Anaerobic decomposition of food waste produces methane, which can be converted to electrical power or heat. Another end product of anaerobic digestion of food waste is a residual digestate, that can be used as fertilizer. Food processing waste that has high contents of oil and grease can produce biodiesel. Food processing waste that has high contents of hydrocarbon can produce ethanol. Food prices are intimately linked to global energy prices. Biofuels can be produced from crops used for energy production (biocrops/biofuel/biodiesel).	The growing demand for food, as well as non-food biomass, will lead to an expansion of global cropland.		Soil management (N2O and C changes). Fertilizer production and application. Liming of agricultural soils (carbon dioxide). Other emissions (e.g. machinery). Loss of climate regulation services of converted forests, peatlands and wetlands. Change of surface albedo for agriculture and food-system related infrastructure.

Climate	Global warming includes changes in seasonal patterns of precipitation and evapotranspiration and increased frequency and intensification of extreme events lead to general acceleration of the hydrological cycle. The seasonal changes expected under progressing climate change will lead to alterations in precipitation and thus will affect water. The increasing air temperatures will increase evaporation globally. Climate change-driven river runoff changes broadly resemble the pattern of precipitation alterations. Seasonal streamflow patterns of rivers depend on climate. Floods and droughts are likely to become more frequent and severe, affecting the water regime. Higher average air temperatures will inevitably lead to a rise in water temperature in all types of water bodies. More frequent rain events will increase the load of suspended matter and nutrients to lakes and rivers.	Meteorological conditions directly govern the actual output of thermal solar panels, photovoltaics and wind turbines. Hydropower installations and bioenergy plants depend on climate conditions via river discharge and biomass production. Extreme temperatures lead to increased usage of heating and cooling systems. Thermal power plants need cooling water to operate, the resources of which are affected by climate. Climate change will lead to more air-conditioning in summer and less heating in winter; as heating is usually provided by fuel burning and while air conditioning is operated by electricity, the demand would shift towards electrical energy.	Floods have strong impact on urban and industrial areas, where they can be devastating, causing economic losses (housing, infrastructure), health hazards and loss of human life. Climate change intensifies the intensity and increases the frequency of flooding events, either as flash floods, or as floodplain/river flooding. Flooding affects agriculture, especially animal husbandry, by imposing severe economic losses. Landslides are related to intense precipitation and can affect any type of land use, with the strongest and most devastating consequences in urban areas. Landslides can also cause severe disruptions to the infrastructure (e.g. transport, roads). Hailstorms can cause damages to both agricultural and urban areas. Increased frequency and intensity of heatwaves may affect urban land use, by decreasing the comfort index of the area and thus reducing tourism.	Climate change is expected to bring about higher temperature, higher concentration of carbon dioxide in the atmosphere, and a different regional pattern of precipitation, affecting crop yields and agricultural productivity. Decreased water supply and increased water demand by livestock under climate change could also lead to lower production. River and lake temperatures are expected to increase; this could impact the health and development of species, in addition to preventing migration.	

1.2.3 The trade-offs and synergies

Below are a few trade-offs and synergies that were reported by the stakeholders and/or covered in the policy documents analysed.

The morphological integrity of rivers and aquatic ecosystems are influenced through various factors. Straightening of the riverbanks of the Rhine (to protect human settlements from floods, to produce hydroelectricity or to improve navigation) changed the flow rate of the water thus affecting the natural dynamics of sediments erosion and deposits in the river and the floodplain.
The renaturation of riparian distributaries along the Upper Rhine (Ramsar site / Integrated Rhine Programme) balances the higher flow rate and brings back meanders and various habitat niches for key species of flora and fauna to foster the ecological integrity of the aquatic and riparian ecosystems. Human activities are however often limited on these areas (extensive grazing or recreational activities only).

Hydroelectric power generation plants influence the river discharge and therefore flooding (Integrated Rhine Programme) through regulated flows up- and downstream of the plants. Climate change also affects river discharge and temperature, potentially creating disruptions in the energy power generation or navigation.

For the production of biofuel, agricultural land is used. This land can no longer be used to produce food. In some cases fertilizers are used to increase the yield of energy crops, which may increase eutrophication and therefore indirectly affect water quality and life.

Burning fossil fuels for electricity production, transport or food production emits greenhouse gases. The gases contribute to global climate change and lead to more extreme weather events on a regional scale. This includes more storms, which could foster energy generation through wind turbines but also lead to flooding of agricultural land or settlements through heavy rains. Extreme temperature and evapotranspiration increases the water demand from plants and the water consumption for agriculture (either for food production or energy production). Extreme temperature also threatens aquatic ecosystems and favors eutrophication. Drought events contribute to low water discharges with consequences for navigation, energy production, pollutants dilution and aquatic life.

Nuclear power plants use stream water for cooling purposes; but the process may shift the thermal status of river discharge.

Former potash salt mining increased salination of the groundwater and indirectly alters the ecological integrity of groundwater fed ecosystems.

1.3 Description of the pathways

So far, no pathway has been identified nor developed with the stakeholders.

However, the following research questions have been agreed upon:

- What are today’s policies put in place in France and in Germany for achieving **transition to a low-carbon economy**? What are the **similarities and differences between France (Grand Est) and Germany (Baden-Württenberg)**? And what are current mechanisms and initiatives made (and at which decision making level) for establishing **synergies and coherence** (if these already exist) between the two countries?
-
- What are (visible or foreseen) **impacts, positive and negative**, of these policies on the management of **natural resources**, in particular **water, ecosystems and biodiversity**? Which sectors targeted by a transition to a low-carbon economy are mainly responsible for these impacts? What are the mechanisms and instruments put in place (be it in the policies aiming at transition to a low-carbon economy, or in water/ecosystem policies) that limit, or enhance, these impacts? How do these impacts affect indirectly other economic activities and sectors of the Upper Rhine economy? Would the foreseen impacts on natural resources and ecosystems, and also on activities benefiting from these ecosystems, be aggravated, or reduced, under scenarios of climate change? If yes, how – and by how much?
-
- Which changes in policies could **enhance the coherence between both policy domains** – in France (Grand Est) and in Germany (Baden-Württenberg) considered as separate entities? What would be the **social, economic and environmental impacts of such policy changes**? What are the pre-conditions for ensuring such policy changes take place and are effective?
-
- How could **cooperation** between France (Grand Est) and Germany (Baden-Württenberg) **be strengthened** so as to reach jointly the policy objectives of transition to a low carbon economy in a more **cost-effective** (optimal) manner? Would such cooperation modify significantly the impacts on natural resources and ecosystems as compared to policies been implemented independently in both countries? More generally, what would be the social, economic and environmental impacts of such cooperation? And what are the pre-conditions for ensuring such cooperation takes place and is effective?
-
- How should cooperation be designed, accounting for today’s situation and for climate change, so as negative impacts on natural resources and ecosystems are minimized, and positive impacts on natural resources and ecosystems are maximised? What would be the pre-conditions for proposed mechanisms to take place and be effective?

1.4 Develop a conceptual model

According to the schedule developed by WP3 and WP4, the France-Germany transboundary case will undergo the following steps:

- From February 2018 onwards: build the conceptual model;
- From March 2018 onwards: run the thematic models;
- From May 2018 onwards: develop the System Dynamics Model;
- From July 2018 onwards: implement policies in the SDM;
- From end 2018 onwards: adapt the Serious Game.

Figure 6 below shows the first draft of the conceptual model for the France-Germany transboundary case study as of December 1st, 2017.

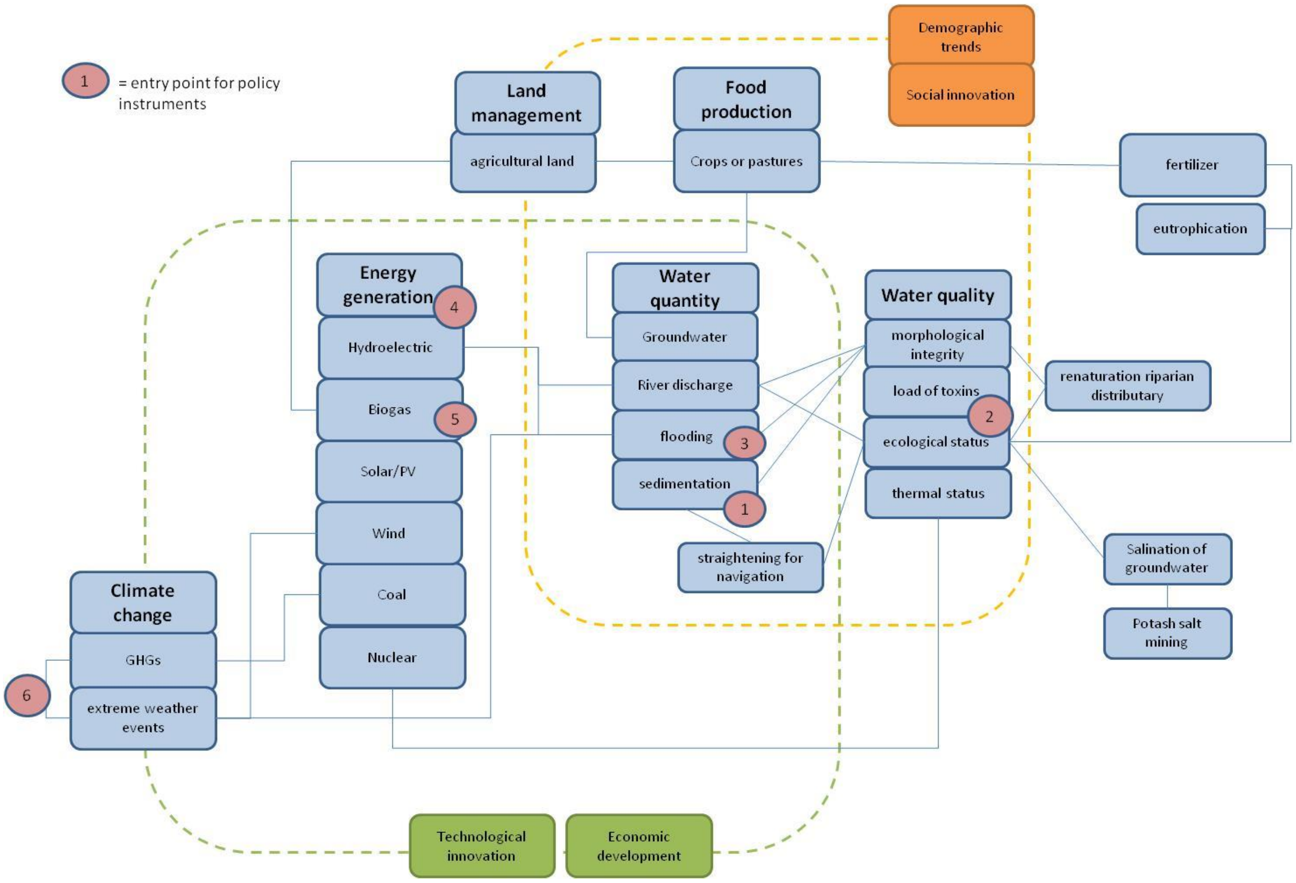

Figure 6: First draft of the conceptual model of the Nexus for the France-Germany transboundary case study (dec. 2017)

All five Nexus sectors are covered: Water and Energy are the two central nexus domains relevant for the case study. Land, Food and Climate are influencing or being influenced by the goals set on Energy and Water systems.

Resource efficiency is at the core of the transboundary case study, though it may not be obvious from the figure (to be improved). The goals relate to a more efficient and balanced use of energy resources as well as an optimised use of water resources for human activities in order to reduce negative impacts on water ecosystems. The policies to be tested in the case study will also focus on measures contributing to a more efficient use of natural resources (especially water and energy).

Some entry points for policy instruments or improved governance have been highlighted : these relate to climate policies (mitigation or adaptation), to energy policies on the balance between the different energy sources – especially biogas and biofuels – to water policies related to flood management, navigation and achieving good water status (transboundary agreements to be enforced).

The conceptual model is still at a very preliminary stage. So far, there is no difference between the German side and the French side of the Rhine river basin: some interactions may however be specific to one country only.
This has not yet been investigated if the conceptual model is relevant for the two time horizons (2030 and 2050).
The conceptual model has not yet been confronted with the stakeholders' points of view. This will be an essential step to understand better how policies influence the system but also to better qualify the relations with the demography trends and the economic development.
The links are not yet qualified. We still need to confront this graphic with the input / output parameters from the models.

1.5 Use of thematic models in understanding the Nexus

The France-Germany transboundary case has hardly started working on thematic models. This part will be fully developed in 2018 according to the schedule agreed upon (see 1.3.). However, a few elements can already be communicated.

The France-Germany transboundary case plans to use three thematic models to cover the Nexus challenges identified:

- E3ME: Energy-Environment-Economy Macro-Econometric model
- CAPRI: Common Agricultural Policy Regional Impact model
- SWIM: Soil and Water Integrated Model

As regards E3ME, a downscaling exercise will be required to produce data at the regional level for both sides of the Rhine region. Indeed the energy sectors and the economies of the Grand Est region and Baden-Württemberg are very specific and cannot be considered similar to the national level (both France and Germany are large countries with major differences between their regions or Landers). A similar exercise was performed for Sardinia so there are high chances the same can be achieved for the Upper Rhine basin.
No difficulty is foreseen in applying the CAPRI model to the France-Germany transboundary case study.
SWIM has already been used on the Rhine catchment. However, contacts still need be taken with the model developers to provide additional input data relevant for the case study. This part will start in January 2018.

Probably one of the main gaps will be on modelling ecosystems' responses or evolutions under a set of drivers.

1.6 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

This chapter summarises the stakeholders' process in the case study. We describe the steps taken, the lessons learnt, the way stakeholders inputs were integrated in the case study, as well as the next steps.

This case study has been chosen in SIM4Nexus because both sides of the river are historically intertwined and cooperation beyond borders, be it between France and Germany or between all riparian countries of the Rhine River, is the norm. This statement is particularly true in the field of water management as illustrated by the activities of the International Commission for the Protection of the Rhine (ICPR)[12]. At a more local level, urban development around its main cities are today truly transboundary, as illustrated by the growth and planning of the Eurodistric (around the city of Basel) and the Eurométropole (around the city of Strasbourg).

The most important actor on French side is the Région Grand Est (regional government) as it deals with all Nexus components as well as economic development, innovation and social issues. The representatives of the Nexus sectors on French side have also been identified and interviewed.
On German side, the most influential stakeholders are the Ministries of the Lander and their underlying executive bodies. There are some respected NGOs, like the BUND, or research networks that have observer status or are asked for professional opinion regarding policy crafting or revision.
At transnational level, the international Commission for the Protection of the Rhine and the Upper Rhine Commission are the most important stakeholders. Moreover, there are various networks, clusters, NGOs and associations on a lower level (e.g. enterprise level, community level…) holding up strong transnational cooperation between their members (such as TRION on energy and innovation issues).

ACTeon has developed several projects in the Upper Rhine area and could rely upon a significant list of potential stakeholders covering all five Nexus dimensions and a diversity of organizations (administrations, research institutes, universities, private companies, NGOs and professional networks). ACTeon staff speaks both French and German: the SIM4Nexus documents were soon translated into the two languages to help-out the first contacts. However, reaching interested persons in the Ministries of the Land Baden-Württenberg was unsuccessful up to now.

Interviews with relevant stakeholders on French and German side were held during the 1st semester of 2017. These interviews helped frame the case study questions, provided understanding of the Nexus challenges and the sectoral policies.

Sadly, it was not possible to organise Workshop 1 during the 2nd semester of 2017, as initially planned. Several reasons justify this situation:

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[12] Transnational cooperation along the Rhine started effectively after the Sandoz (chemical plant near Basel) accident in 1986 which polluted the entire downstream aquatic ecosystems and affected all adjacent countries and their economies. In 1994, most of the pollution reduction levels set were achieved. Cooperation also addresses issues of fish (Salmon in particular) migration, flood protection and more generally the coordinated implementation of the EU water policies (the Water Framework Directive and the Floods Directive in particular).
http://www.archive.riversymposium.com/index.php?element=09_SculteWL_Paper

- All efforts were put on the policy analysis – already a challenge since the policy documents from two countries and the international bodies have to be reviewed. One person was hired over a 6-months period to work on the case study's policy analysis.
- We looked for opportunities to co-organise a joint event and rely on a well-known stakeholder to kick-start the case study, but none was identified during this period. Nonetheless, contacts with stakeholders was continued in order to mobilise a larger group.
- Lack of administrative staff to support the organisation of Workshop 1 was a serious difficulty, especially since translation has to be taken care of. This situation is now overcome.
- Finally, we felt the need to be more confident about what SIM4Nexus and the transboundary case can deliver, which requires the team to progress first on the conceptual model, to contact the modelling teams and to understand better the Serious Game. During the interviews, we also felt the need to offer more contents to the stakeholders, especially on policy analysis, in order to point-out better the trade-offs between the Nexus components.

The list of stakeholders identified and contacted is provided in Table 1.

Country	Nexus Sector	Type of Organization	Name of Organization	Contribution to the case study definition	Involvement in the case study development
FR	Multiple sectors	Regional governmental organisation	Région Grand Est	Nexus concept is somehow similar to SRADDET (regional integration of all policies and strategic planning). Concerns on the sustainable development of biomass. Biomass plan under discussion. Concerns on climate change adaptation in a time of budget constraints.	Potentially interested in the results of the policy analysis and the modelling. Interested in transboundary comparisons.
FR	Energy, Environment	National governmental organisation	ADEME Agence de l'environnement et de la maîtrise de l'énergie	Since 2013 : implementation of the transboundary strategy on climate and energy.	
FR	Multiple sectors	Trade union	CCI Alsace		Through the Clim'Ability consortium, combine efforts on communication and stakeholders mobilisation. Share results.
FR	Water	Regional governmental organisation	Agence de l'eau Rhine-Meuse	Concerns on impacts from biomass development on agriculture practices and water (quantity and quality). Concerns on impacts from climate change and optimized adaptation strategies. Concerns on the right balance between water policies and energy policies.	Climate change adaptation plan being written (ddl June 2018). Opportunities to present results from SIM4Nexus in workshops.
FR	Agriculture	Trade union	Chambre d'agriculture d'Alsace		
FR	Agriculture	Research	INRA Colmar - Institut National de la Recherche Agronomique		
FR	Agriculture	Business	Coopérative Agricole de Céréale		
FR	Agriculture	Business	Le Comptoir Agricole		
FR	Agriculture, Land	Business	SAFER Sociétés d'aménagement foncier et d'établissement rural		
FR	Environment	National organisation	Office National des Forêts		

FR	Agriculture, Environment	Regional governmental organisation	DRAAF Grand Est - Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt		
FR	Water, Environment	Research	ENGEES École national du génie de l'eau et de l'environnement de Strasbourg	On-going research projects on renaturation of the Upper Rhine	Using the Serious Game for education purposes.
FR	Environment, Land	Regional governmental organisation	DREAL Direction régionale de l'environnement, de l'aménagement et du logement		
FR	Environment	National governmental organisation	ONCFS Office National de la Chasse et de la Faune Sauvage		
FR	Water	Network	APRONA Association pour la Protection de la Nappe Phréatique de la Plaine d'Alsace		
Inter-national	Water	Research	CHR Commission Internationale pour l'Hydrologie du bassin du Rhin		
FR	Environment	NGO	Alsace nature		
FR	Energy, Water	Business	EDF		
GER	Energy	Business	EnBW		
GER	Agriculture	Trade Union	BLHV Badischer Landwirtschaftlicher Hauptverband		
GER	Environment, Water, Energy	NGO	BUND Mittlerer Oberrhein		
GER	Water	Regional organisation	Regierungspräsidium Freiburg Integriertes Rheinprogramm		
GER	Multiple sectors	Business	IHK Südlicher Oberrhein		
GER	Energy	Network	Strategische Partner Klimaschutz am Oberrhein e.V.		
GER	Energy, Climate, Environment	Regional organisation	Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg		
GER	Agriculture, Land	Regional governmental organisation	Ministerium für Ländlichen Raum und Verbraucherschutz Baden-Württemberg		
FR, GER	Energy	Research	EIFER European institute for Energy Research		
FR, GER	Energy, Environment	Network	Upper Rhine Cluster for Sustainability Research		
FR, GER	Multiple sectors	Network	Eurodistrict Strasbourg-Kehl-Offenburg		
FR, GER	Multiple sectors	Network	Eurodistrict Freiburg-Alsace		

FR, GER	Multiple sectors	NGO	ICLEI Local Governments for Sustainability		
FR,GER	Energy	Network	TRION Climate e.V. Netzwerk für Energie und Klima der Trinationalen Metropolregion Oberrhein	Looking for business and innovation opportunities in adressing climate change adaptation and energy transition. Interested in Serious Games.	Through the Clim'Ability consortium or Annual conference. Provide access to private companies.
FR,GER	Water	Network	logar Länderübergreifende Organisation für Grundwasserschutz am Rhein		
FR, GER, CH	Multiple sectors	Transnational governmental organisation	Upper Rhine Commission		
Inter-national	Water	Transnational governmental organisation	ICPR International Commission for the Protection of the Rhine	Fish migration and hydropower are top concerns, followed by water quality issues.	Results from SIM4Nexus project

1.7 Conclusions and follow-up

The France-Germany transboundary case study had a slow start related to the complexity of the area to be studied (two countries) and the wide span of potential Nexus challenges to be studied.

Preliminary interviews with local stakeholders helped narrow-down the research questions:

- What are the similarities and differences between France (Grand Est) and Germany (Baden-Württenberg policies for achieving transition to a low-carbon economy?
- What are (visible or foreseen) impacts, positive and negative, of these policies on the management of natural resources, in particular water, ecosystems and biodiversity?
- Which changes in policies could enhance the coherence between both policy domains? What would be the social, economic and environmental impacts of such policy changes?
- How could cooperation between France (Grand Est) and Germany (Baden-Württenberg) be strengthened so as to reach jointly the policy objectives of transition to a low carbon economy in a more cost-effective (optimal) manner?
- How should cooperation be designed, accounting for today's situation and for climate change, so as negative impacts on natural resources and ecosystems are minimized, and positive impacts on natural resources and ecosystems are maximised?

In order to answer these questions, 3 thematic models (E3ME, CAPRI and SWIM) were confirmed and a first draft of conceptual model was elaborated in order to represent the links between all five Nexus components.

Relevant stakeholders for the case study focus have been identified and contacted. Workshop 1 could not be organised. More efforts are now required to communicate more actively our progresses and to build a core team of active persons contributing to the case study on a regular basis.

The policy analysis of the case study is on-going, following instructions from the WP2 leaders (PBL).

The 1st semester of 2018 will be dedicated to:

- Integrating one more person into the SIM4Nexus team at ACTeon in order to take care of the stakeholders' engagement process (French and German speaker);
- Getting ready for Workshop 2;
- Following-up on the policy coherence evaluation;
- Working further on the conceptual model with the help from UNEXE;
- Contacting the modelling teams to discuss input / output parameters and get results for the case study.

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

D5.2: THE MAIN NEXUS CHALLENGES IN THE TRANSBOUNDARY CASE STUDY DE-CZ-SK

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Glossary / Acronyms

TERM	EXPLANATION / MEANING
CZ	TWO-LETTER ISO CODE FOR THE CZECH REPUBLIC
DE	TWO-LETTER ISO CODE FOR GERMANY
GDR	THE FORMER GERMAN DEMOCRATIC REPUBLIC, EAST GERMANY
GHG	GREENHOUSE GASES (CO2, CH4, NOX, AND OTHERS)
PV	PHOTOVOLTAICS
SK	TWO-LETTER ISO CODE FOR SLOVAKIA

1 Introduction

The case study covers the eastern part of Germany most of which had been the domain of the GDR until 1990[1] and both the Czech Republic and Slovakia. This area (236,736 km², 32.1 million inhabitants on 1 January 2016; EUROSTAT 2017) shares the common history of socialist rule which is still visible in the agricultural landscape: Average farm sizes, measured in total (agricultural) area in the year 2013, are 130 (81) ha in Slovakia, 193 (133) ha in the Czech Republic, and 241 (229) ha in Eastern Germany – about five times larger than average farms in Western Europe (EUROSTAT 2017); see also Fig. 1. In Slovakia, there are historically small farms (1–5 ha) which in total cover only approximately 10% of the farmland. This is reflected in the lower average size of Slovak farms albeit most of Slovak farmland is managed by large enterprises.

Regarding the time frame, the study will look both at developments during the past decades as well as scenarios up to the middle of the 21st century.

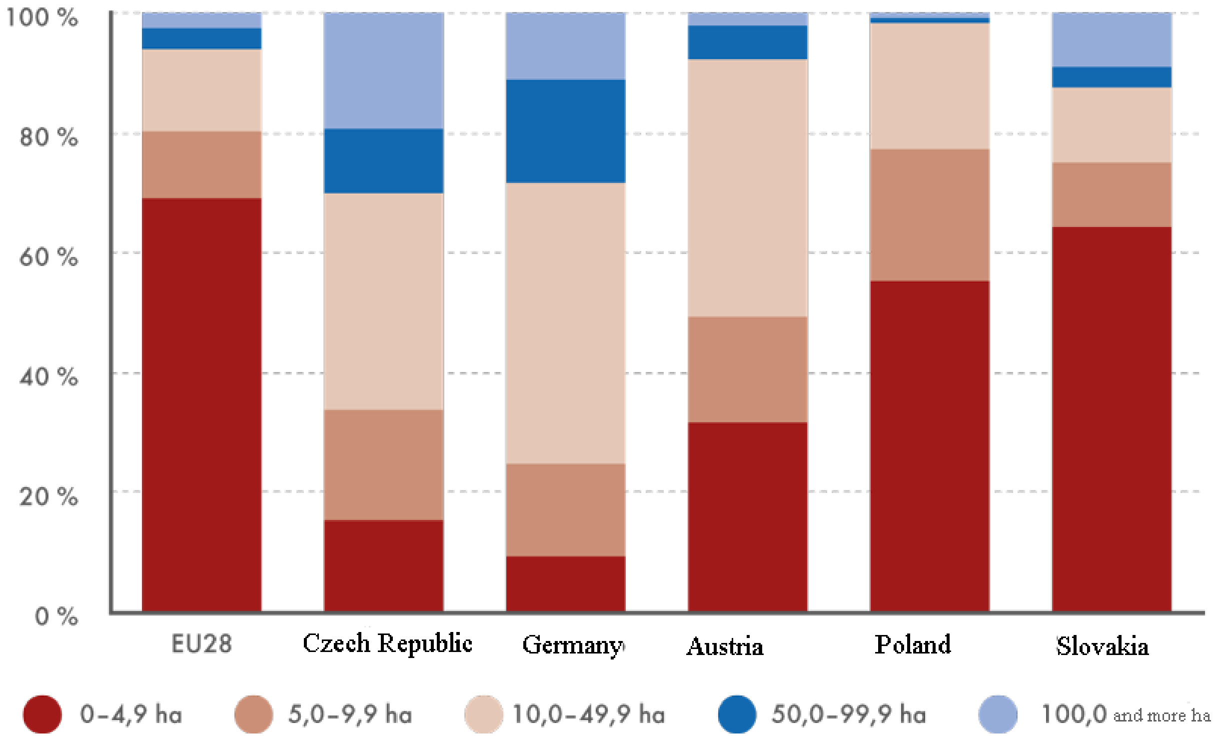

Figure 1: Size of farm subjects and their representation in selected EU countries (adapted from http://www.statistikaamy.cz/2014/07/v-cem-je-ceske-zemedelstvi-jine/)

In several German and Czech locations there are still active open cast lignite mining sites where farmland, forests, and small settlements are converted to giant industrial pits. Excessive amounts of groundwater have to be pumped out of these places during the excavation phase. Then there are many disused lignite mining areas being filled by river runoff and receding groundwater whose "renaturation" process is projected to extend past the middle of the century. Both the active mining as well as the renaturation phases massively impact the regional hydrological regime.

Another issue between land, energy, and food is the recently extended production and use of bioenergy crops like rape and silage maize, contributing to the landscape effects on the regional

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[1] Included is also the city/federal state of Berlin that was split between the Four Powers during the Cold War. The German part of the case study is actually defined by the current federal state boundaries that differ only slightly from the former GDR border.

climate. During the last decades decreasing precipitation could be observed for the Czech and Slovak lowlands while the Slovak mountains received more water, however this was connected to more frequent thunderstorms. A shift of precipitation from agriculture lowland to near mountains (where the dew point is reached) is considered to be more general and deserves more attention. It should not be neglected as well that more land devoted to bioenergy production means less land for food production.

Photovoltaics (PV) and wind power are problematic, too. Valuable crop land has been lost to PV installations which are sealed surfaces contributing to sensible heat emissions. PV subsidies in the Czech Republic were adjusted too high discrediting PV in the public opinion. Wind power requires huge installations with negative impacts on the amenity quality of the landscape – in Germany, this led to a big movement of NGOs protesting against new wind power projects. Finally, PV and wind cause big pressures on grid stability, because there are hardly any storage possibilities for electrical energy, and the strong natural fluctuations in radiation and wind have to be buffered by fossil fuel power plants. There are only two double-line connections between Germany and the Czech Republic in the continental electricity grid (ENTSO-E 2017), and the general direction of electricity exchange between these countries has been swapped in the recent years: Historically, the Czech delivered (cheap nuclear) power in a one-way relation to Germany, but during the last years more and more renewable energy (especially wind) pushed the balance into the opposite direction; this is illustrated in Fig. 2.

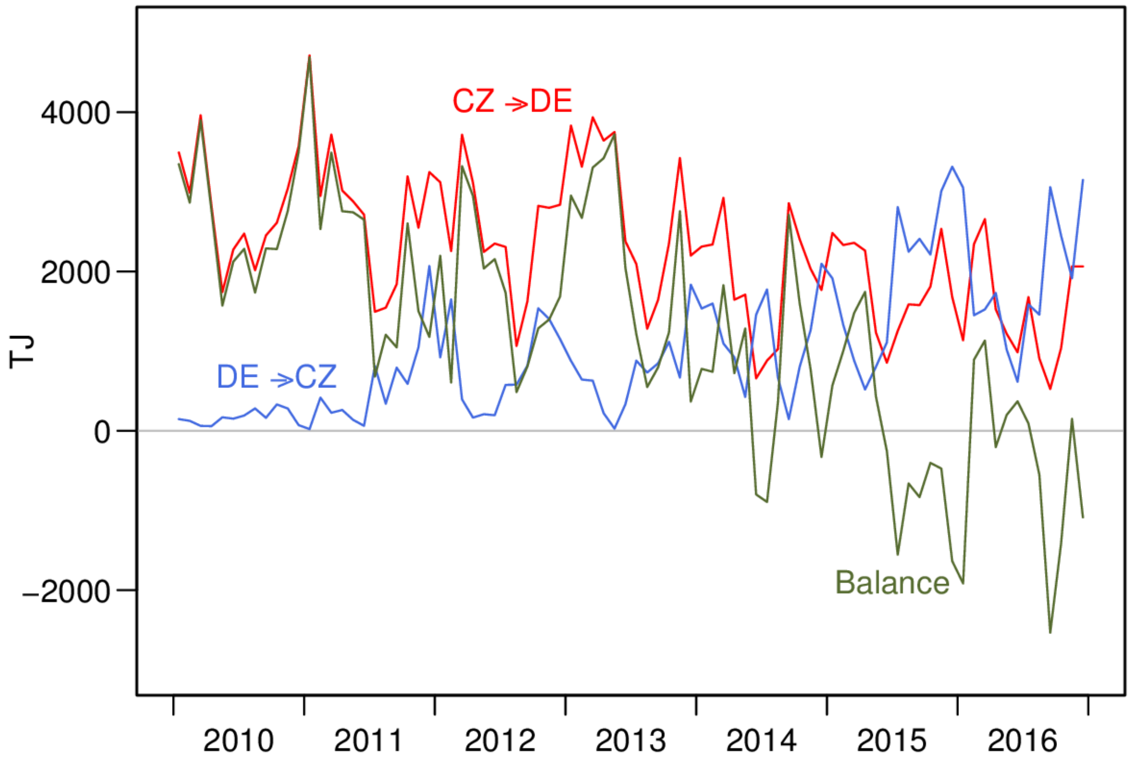

Figure 2: Monthly electricity transfers between Germany and the Czech Republic in Terajoule (1 TJ = 0.278 GWh). Data source: DESTATIS 2017.

There are neither more hydropower nor more wind power potentials in the Czech Republic, therefore biomass production (biofuel, biogas) is supported. Fast growing woods are cultivated only on 3000 ha in CZ; agroforestry has a potential in drained agricultural landscape for its ecological functions.

The main question of this case study is whether the landscape structure dominated by monoculture-like crop areas in some of the lower parts and its alterations by energy production affects the water cycle in an unfavourable way: The principal societal challenge is the resource-efficient and socially compatible decarbonisation of the energy sector.

1.1 Description of the Nexus challenges

1.1.1 Main trends for the nexus sectors

Climate

The global warming trend caused by greenhouse gas emissions is also observed in the case study region. Since the end of the 19th century, average temperatures have risen about one Kelvin with most of the increases taking place after the Second World War. Although there has recently been a hiatus decade of a stagnant temperature trend it is very likely that the region will experience another Kelvin of warming within the next three to four decades. Droughts are more pronounced in agricultural lowlands with large drained fields. Regional studies show a decrease of small precipitation events and longer periods without rain during the vegetation period. The number of so-called tropical days (temperature maximum exceeding 30°C and remaining over 20°C during night) is increasing. Except of the general trend of global warming, spring frosts occurs and results in losses of crop, fruits and vegetables and even traditional local products like blueberries.

Precipitation has not changed very much regarding the long-term trend of annual averages. However, Germany and the Czech Republic experienced major flood events in the Elbe River basin in 2002 and 2013, and there are increasing numbers of heavy thunderstorms causing flash floods, hail storms, and tornadoes. In Slovakia, decreasing precipitation trends have been observed in the lowlands during summer while respective increases – connected to higher thunderstorm frequencies – have been reported for the mountainous areas.

Water

As already mentioned, river runoff has been massively impacted where open-cast lignite mining landscapes emerged. On the other hand 2.5 billion m^3 of water have been accumulated in former open cast mines. The water developed high quality (transparency several meters) owing to water depth and targeted fish stock management and can be considered as a strategic reserve. Apart from that, there are many reservoirs in the case study area, these are partly used for drinking water supplies, generally contribute to reduce flood waves, and increase runoff during drought phases.

Two severe floods struck the Elbe River in 2002 and 2013, and there were several locally extreme precipitation events during the last decade causing flash floods – the climatic trend towards more extremes is seen in the discharge as well. The average level of river runoff decreased around 1990, the year of the political and economical system change. This might have been an effect of the so-called re-dimming: Many old industries with massive aerosol emissions were shut down, the skies became brighter, evapotranspiration increased driven by the surplus radiation reaching the ground, and river discharge consequently decreased (Conradt et al. 2012, Wild 2012, Vetter & Wechsung 2015).

The effect of increased sensible heat released from drained areas (spoil heaps, harvested fields, urban areas and stores) of heat islands should be also taken into account as drought phases seem to occur more frequently also due to climate change, see Fig. 3. Scenario projections indicate ongoing increases in evapotranspiration. In summer, small streams in agricultural regions have low water flow and many of them even dry out. In many regions underground water level decreased which results in water shortage of local rural sources.

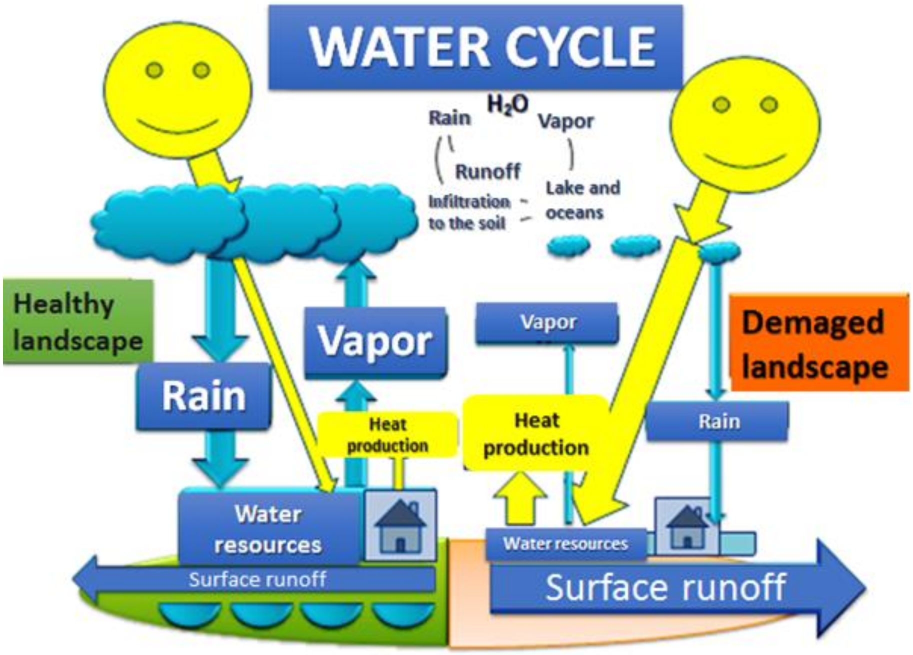

Figure 3: The water cycle in a healthy and in a damaged landscape

Energy

The former dominance of fossil energy sources, especially the lignite from within the area has already been confined by political decisions in favour of renewables. It remains however unclear which development path will be taken when the last fossil fuel power plants are being phased out: the hydropower potential is small and already largely tapped, but other options are possible. Bioenergy, which is currently stabilizing on an already high level may be further pushed at the expense of food production. Photovoltaics and wind seem to continue their massive development in recent years, but this sets the stability of the grid at stake. More wind machines and high-voltage pylons are also about to cause protests from opinion groups. Either route seems to cause problems and conflict, but nuclear energy seems no sustainable alternative given the inherent risks of this technology, too. All three countries have negative energy balances when we consider the import of primary energy sources, especially crude oil and natural gas.

Land

There is no trend of reversing the big block structure of the agricultural areas inherited from the collectivisation period. The socialist co-operatives had just been taken over by larger companies. Persistent trends can be found in urbanisation – each day, the area of several football fields is sacrificed to urban development, usually involving sealing. The integration and drainage of vast agricultural lands lead to the following negative events:

Soil loses organic substances. The decomposition of organic substances (mineralization and release of carbon dioxide) in the soil is accelerated by repeated drying up and rewetting accompanied by soil acidification linked with the outflow of nutrients and alkaline cations as well as the release of aluminium and heavy metals in the soil solution. Soil acidification and decreasing fertility on the one hand and the high nutrient content and water eutrophication on the other are two connected effects of poor landscape management. Thus the soil loses its water sorption ability and is more prone to erosion. The surface overheats in sunny weather which leads to decomposition of organic matter in the soil (carbon dioxide release); the top soil horizon often disappears. See Fig. 4 for the effects about the carbon cycle.

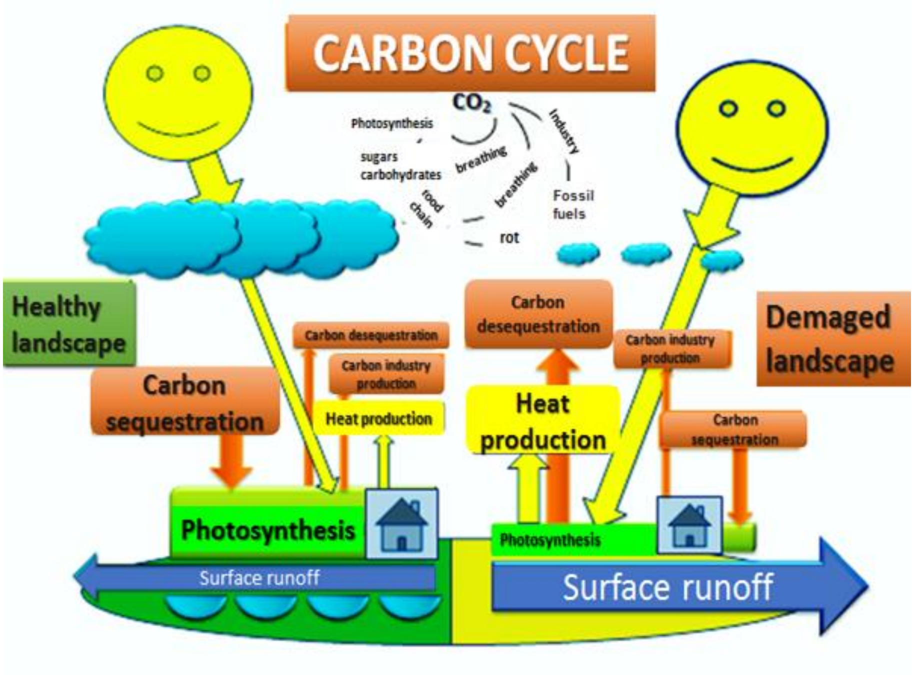

Figure 4: The carbon cycle in a healthy and in a damaged landscape

Thermal and satellite images show high surface temperatures of harvested agricultural fields, comparable to surface temperatures of drained impermeable areas (Figs 5 and 6). In precipitation-free periods the agricultural landscape becomes a heat island similar to cities lacking vegetation: The solar radiation on the top of the Earth´s atmosphere is 1320 to 1410 W/m², on the surface it reaches 1000 W/m² on a sunny day. Only where water is abundantly available it evaporates and stores the solar energy as latent heat in form of water vapour (1 litre of evaporated water equal 2.4 MJ). On drier surfaces, incoming solar energy is transferred into sensible heat, warm air moves fast up (together with the evaporated remains of water), and the landscape dries up. From each km² of dry harvested fields several hundred MW sensible heat are released during sunny days. In this way convective potentials are created which realise as strong winds, thunderstorms, and torrential rains.

Periods without small rains and regional droughts and lack of water became more frequent (Kovářová & Pokorný 2010). Most vulnerable to drought are drained agricultural areas on sandy soils in all three countries.

Figure 5: Surface temperature (ST) measurements on 26 August 2017, incoming solar energy approx. 700W/m². The ST of a harvested field (48°C) nearly equals that of an asphalt surface (49°C).

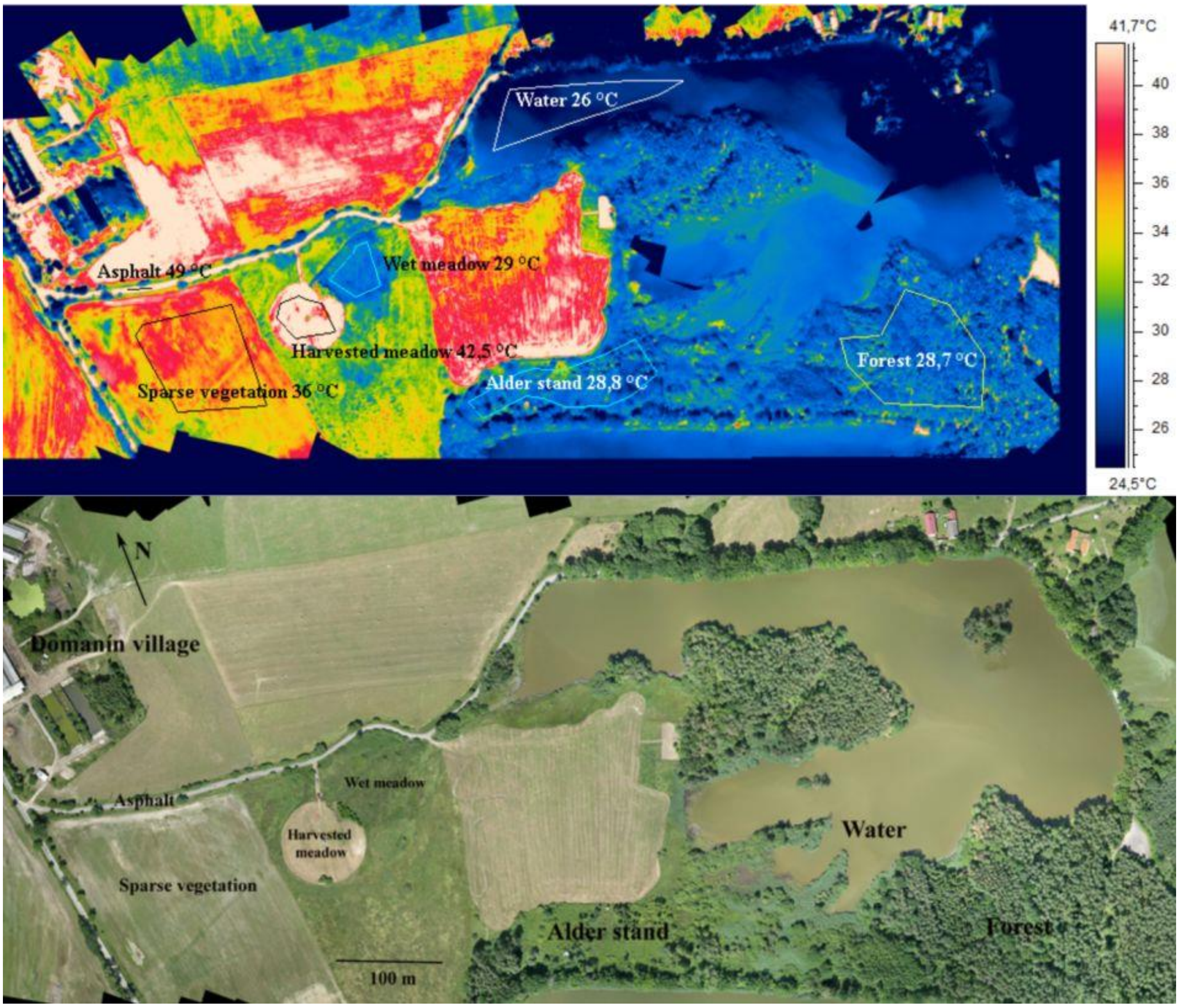

Figure 6: Average surface temperatures of different land cover types calculated from aerial thermal images on 9 July 2010 at 12:00 GMT. Air temperature measured in the screen in 2 meters was 32°C. (ENKI, o.p.s. published in: "Drought impacts prevention for the territory of the Czech Republic".

Document proofed by the CZ Government on 28 July 2017). For the data see: Hesslerová et al. (2011) and Ellison et al (2016).

Food

The agricultural primary production (everything grown on the fields, without cattle breeding) includes approximately 32 million tons of grain production – which equals more or less one ton per inhabitant and year (EUROSTAT 2017). Approximately 45,000 km² of the agricultural land (approx. 82,000 km² in total) are currently used for this output, however approx. 22,000 km² are used for growing silage maize and rape, both typical bioenergy crops. There is an overproduction of plant biomass in the Czech Republic and Slovakia whereas pork, beef, milk, cheese, and vegetables are imported for about 50% of the internal consumption of these countries.

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

1.1.2 Interlinkages of the Nexus sectors

We see water as the natural hub between the Nexus sectors. Michal Kravčík's "water rotor" (Fig. 7) gives an iconic illustration for this – everything depends on water which is kept in motion through the hydrological cycle powered by the sun:

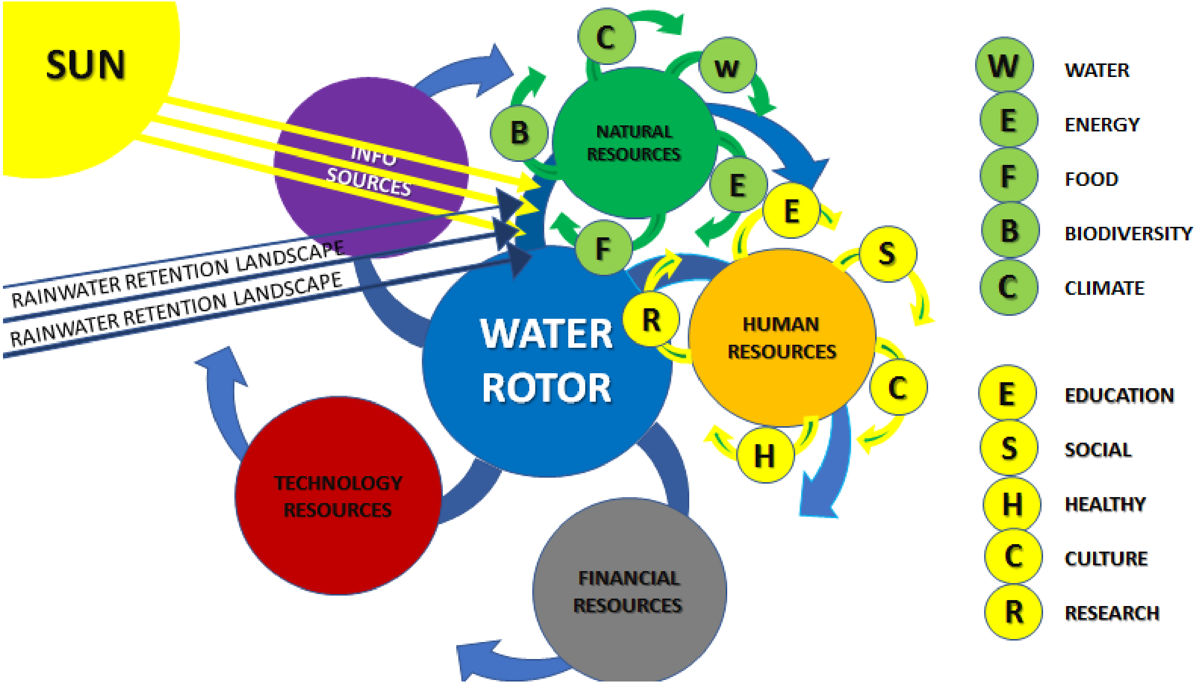

Figure 7: The Water Rotor

Not only from this perspective food production depends on water: The primary production of crops needs fertile soils to grow, and water is the main factor of fertility, soil quality is primarily ranked by the water storage capacity. The opposite link, the meaning of food for water, is defined by water consumption of the crops – for instance, the usual cereals die when they are ripe which leads to reduced evapotranspiration and respectively increased sensible heat, a negative side-effect especially in the heat of the summer.

Possible trade-offs emerge wherever water is redirected towards other purposes, e.g. maintaining minimum water levels in rivers or the flooding of lakes in post-mining landscapes. These activities may cause drought events harming cereal growth and food production. There is also a concurrence in growing/harvesting area between food and bioenergy crops. Increased generation of electrical energy from solar radiation and wind requires a powerful grid with many nodes capable of absorbing short-term input variations caused by cloud shadows or wind gusts.

Synergies, on the other hand, can be expected from the re-establishment of a more compartmented landscape with numerous installations keeping the (rain)water in place: This would very much improve the local climate through evaporative cooling in summer and attenuate diurnal heat extremes (water has got a very high specific heat capacity). Plants (crops, fruits, and vegetables) would suffer less during drought phases; they could also help increasing water quality through nutrient uptake.

Water supply is a precondition for plant growth (primary production) i.e. sequestration of carbon dioxide via photosynthetic process into plant biomass above- and underground. Organic matter accumulates and carbon is kept in soils under such conditions, also contributing to the water storage capacity of the soil.

1.2 Description of the pathways

Regarding the greenhouse gas emission scenarios, pre-defined as RCPs, we follow the recommendation given in D3.3 (Downscaling Report) to treat the different input climate scenarios based on all four RCPs (2.6, 4.5, 6.0, and 8.0) just as different realisations of one and the same climate scenario, because they do not significantly depart from each other until the middle of the 21st century which is the time horizon of this case study.

Pathways are therefore exclusively defined by the Shared Socio-economic Pathways (SSP) as detailed in Riahi & van Vuuren (2017). Besides the baseline – SSP2 “Middle of the road” – which is the obligatory start in SIM4NEXUS, we will estimate the consequences of SSP3 “Regional rivalry – A rocky road”, motivated by current threats to the stability of the European Union like the recent emergence of right-wing nationalist parties in a couple of member states.

The narratives of SSP2 and SSP3 shall be repeated here for clarity, they are quoted from O’Neill et al. (2017; emphasis kept from the original):

SSP2: Middle of the road

> The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns. Development and income growth proceeds unevenly, with some countries making relatively good progress while others fall short of expectations. Most economies are politically stable. Globally connected markets function imperfectly. Global and national institutions work toward but make slow progress in achieving sustainable development goals, including improved living conditions and access to education, safe water, and health care. Technological development proceeds apace, but without fundamental breakthroughs. Environmental systems experience degradation, although there are some improvements and overall the intensity of resource and energy use declines. Even though

> fossil fuel dependency decreases slowly, there is no reluctance to use unconventional fossil resources. Global population growth is moderate and levels off in the second half of the century as a consequence of completion of the demographic transition. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and to rapidly slow population growth. This growth, along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, maintain challenges to reducing vulnerability to societal and environmental changes and constrain significant advances in sustainable development. These moderate development trends leave the world, on average, facing **moderate challenges to mitigation and adaptation**, but with significant heterogeneities across and within countries.

SSP3: Regional rivalry – A rocky road

> A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues. This trend is reinforced by the limited number of comparatively weak global institutions, with uneven coordination and cooperation for addressing environmental and other global concerns. Policies shift over time to become increasingly oriented toward national and regional security issues, including barriers to trade, particularly in the energy resource and agricultural markets. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development, and in several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time, especially in developing countries. There are pockets of extreme poverty alongside pockets of moderate wealth, with many countries struggling to maintain living standards and provide access to safe water, improved sanitation, and health care for disadvantaged populations. A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions. The combination of impeded development and limited environmental concern results in poor progress toward sustainability. Population growth is low in industrialized and high in developing countries. Growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation and slow technological change imply **high challenges to mitigation**. The limited progress on human development, slow income growth, and lack of effective institutions, especially those that can act across regions, implies **high challenges to adaptation** for many groups in all regions.

As we see the goal of our case study in identifying those policy/management options that would lead to i) better microclimates and higher biodiversity from a water-preserving landscape, ii) the secured provision of (electrical) energy in an environmentally sustainable way, and iii) strengthening the regional food production for higher self-sufficiency (avoiding unnecessary transports), implementing SSP3 – how to enable this with limited transboundary exchange of goods and services – will be a real challenge. Showing the drawbacks and potential losses under SSP3 conditions will highlight the value of a strong cooperation among our and other European countries.

It was suggested that we should also look into the other direction: a pathway with enhanced cooperation between the countries. We do however already observe a strong cooperation in land, energy, and water-related policies implemented by the EU, e.g. through the agricultural subsidies or the Water Framework Directive. Therefore, the effects of a stronger cooperation are implicitly covered as the opposite of SSP3 effects.

A central question regarding SSP implementations for case study regions are of course the quantitative regional ramifications of the global narratives. This is currently a hot topic in the socio-economic sciences. There are already some scenarios available, and the International Institute for Applied Systems Analysis (IIASA) runs a database where respective time series for world regions, groups of countries, and even single countries are gathered. Figs 8 and 9 provide examples of GDP and population projections for the Czech Republic and Slovakia.

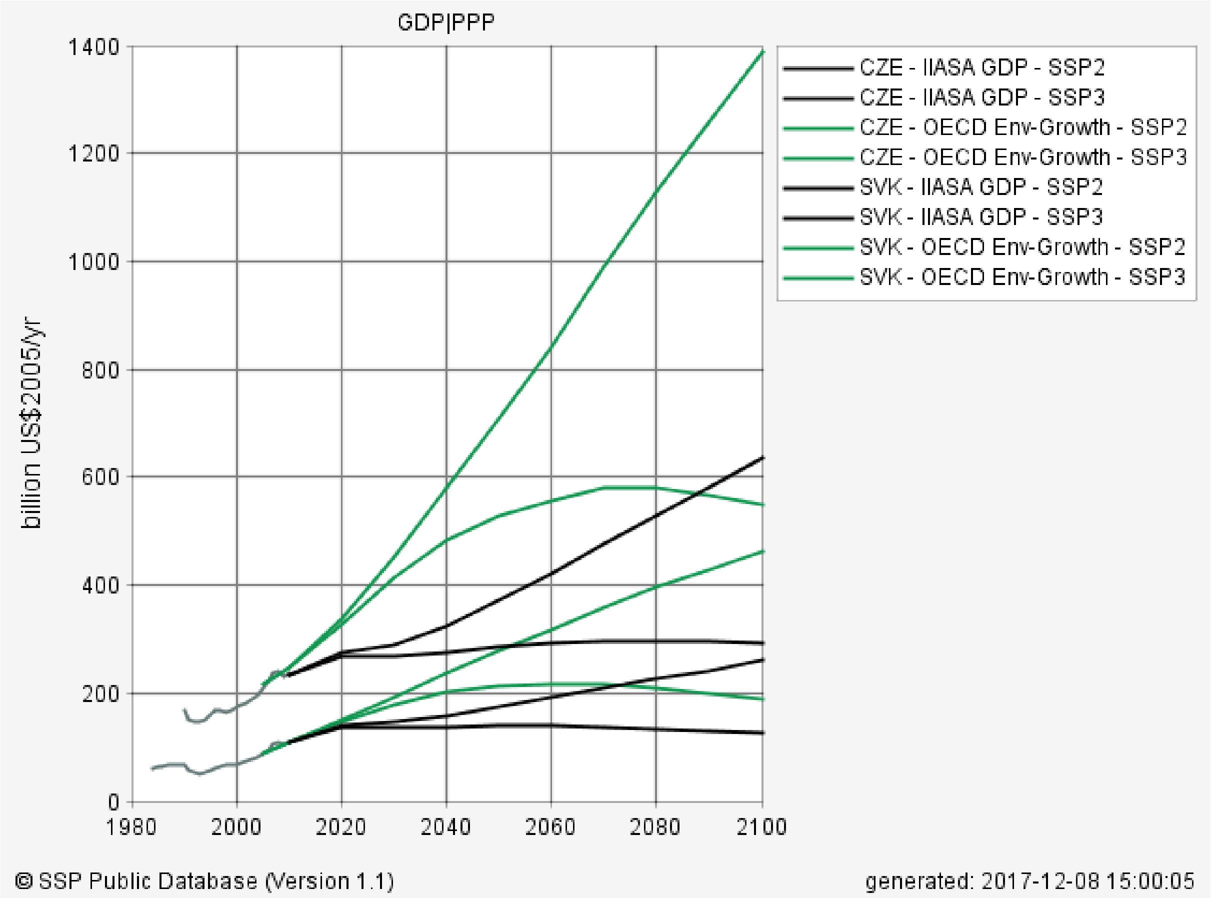

Figure 8: GDP development in the Czech Republic (CZE) and Slovakia (SVK) under SSP2 and SSP3 conditions. Scenarios courtesy of the SSP Public Database V1.1 hosted by IIASA.

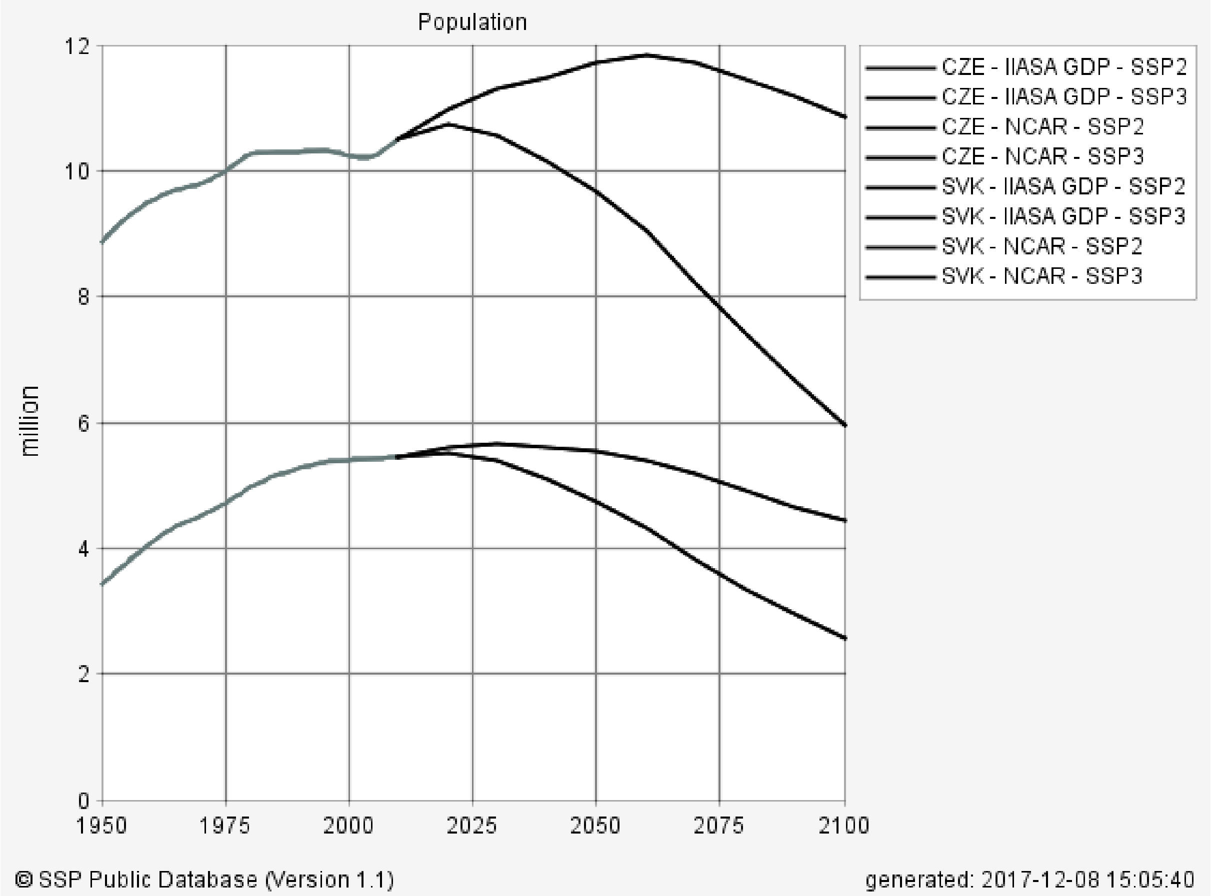

Figure 9: Population projections for the Czech Republic (CZE) and Slovakia (SVK) under SSP2 and SSP3 conditions. Scenarios courtesy of the SSP Public Database V1.1 hosted by IIASA.

1.3 Develop a conceptual model

Following the above considerations we conceived our conceptual model with water in the centre; this is just the domain of PIK's eco-hydrological model SWIM. Figure 10 shows the results in graphical form. Within this graphic, nodes representing SWIM's model domain are coloured in blue.

One important design point are "Nexus services", positive effects for each of the five Nexus sectors to be maintained and furthered by intelligent policy making and wise behaviour of the relevant actors. These are shown as yellow ellipses in Fig. 10. While individual actor's decisions cannot be controlled very closely, the policy framework can be shaped to some extent. The policy making must correspond to the buttons and levers in the SIM4NEXUS serious game; in our conceptual model the respective nodes of influence are coloured in pink.

The model network can be explained from the perspective of each sector: Climate is top-left, driven by the global greenhouse gas emissions. Climate itself governs the local weather. This can take good or bad qualities for life on earth, the best service for human health, ecosystems and the economy would be the complete avoidance or at least very low probability of extreme events (torrential rain events, wind storms, etc.). Weather directly influences crop growth and the landscape hydrology, these are the blue elements covered by the SWIM modelling. Even more so, weather directs the power output of photovoltaics and wind energy. But weather is not only determined by large-scale climate: the landscape structure and its water content shape the energy balance at the ground and provide strong feedbacks into the atmosphere; alternating warm and cold spots (e.g. open-cast mining areas and lake surfaces) can trigger thunderstorms (and hence locally extreme precipitation).

There are some links from the water sector towards the energy sector: Crops may be used as biofuel, either directly or through the stage of cattle breeding, and both are producing food as well which means a direct hard tradeoff, because cropland cannot easily be extended. Beyond biofuel and hydropower – direct outputs of the water-land system – there may be negative long-term consequences for all thermal power production (fossil plus nuclear) from losses of cooling water. This is however not included in the conceptual model, because it had already been researched and seems not to be the biggest concern in the case study region. As the region's contribution to the global greenhouse gas (GHG) emissions is negligible, the arrows towards the GHG pool could also have been omitted. But as GHG from all sources over the world need to be cut down substantially, these must be monitored and should be used as a negative success metric within the Serious Game.

The energy sector shown in the bottom left corner is also heavily policy controlled: If there still were nuclear power plants in the German part of the case study region, they would have to be shut down until 2022. Installations for renewables had been massively subventioned during the last decade – leading to massive alterations in the landscape structure as indicated by the very long collector arrow »tunnelling« the sketch from left to right.

The major policy-controlled actors to the right of Fig. 10 are the farms (and to a lesser extent also the forestry). Farmers' decisions and activities directly shape the landscape especially through the crop types sown, determine the nutrient input into water bodies through fertilisation, and closely affect local weather, water quality, and biodiversity.

This model is to be built on and around the core component SWIM covering the blue boxes. SWIM will initially be driven by the downscaled climate without local feedbacks on the weather, but this will be done on a daily timestep both for the past as well as for the future scenario decades until 2050. Thus, summary outputs for each decade can be easily compiled. Missing feedbacks should be approached as quantitatively as possible, and we intend to orient our research activities accordingly.

For representing the cropping decisions of the farmers, we will use scenario data from the CAPRI model: SWIM's crop module will work on spatial units representing the crop type shares of the given scenario in a regionalised way. This will directly show the impacts of agricultural policies on the water cycle, because different crops have, depending on their growth stages, different water needs and seasonal patterns of transpiration.

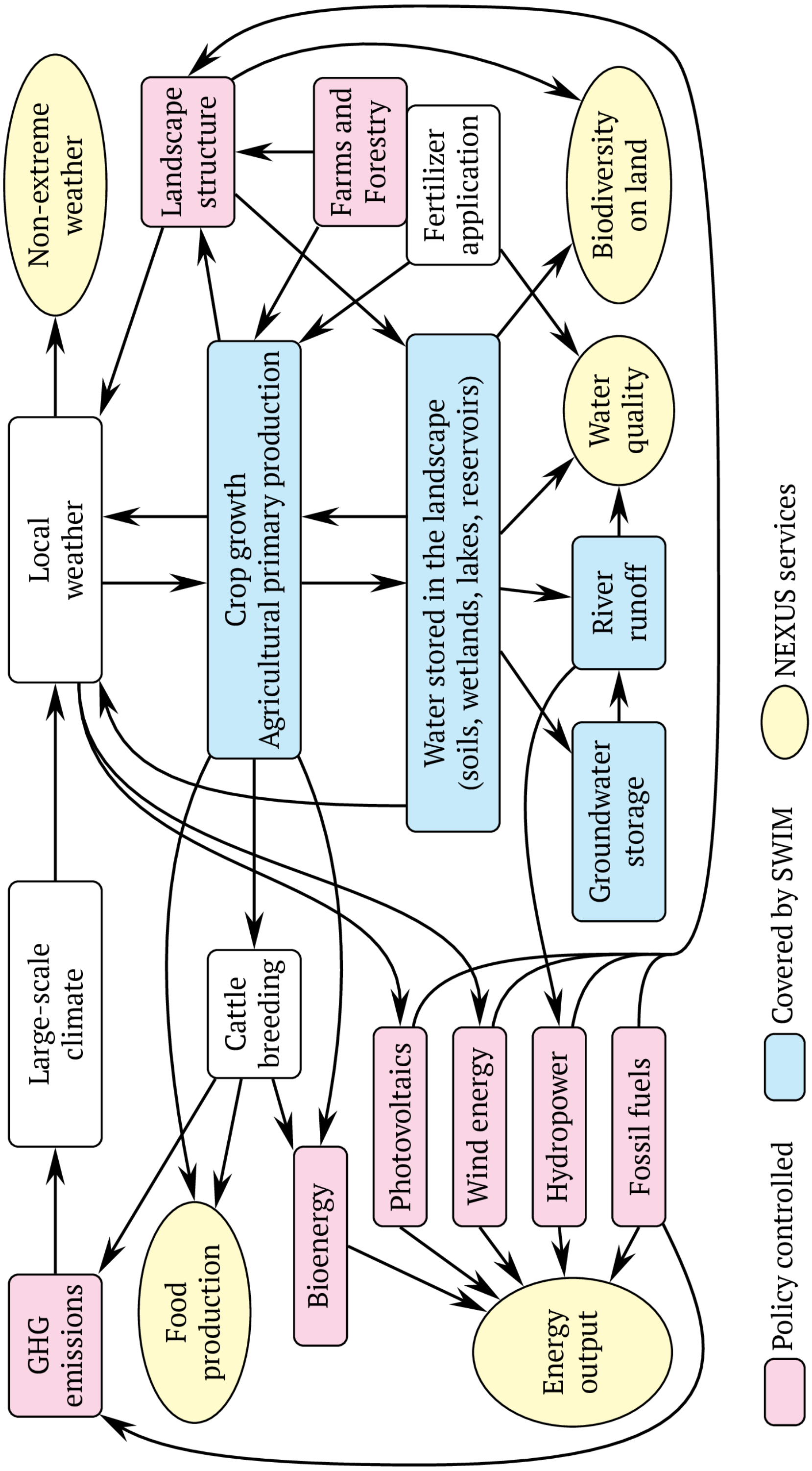

Figure 10: The conceptual model for the transboundary case study DE-CZ-SK

1.4 Use of thematic models in understanding the Nexus

Our specific Nexus questions about the land and water sectors are largely covered by SWIM, a spatially distributed eco-hydrological model. SWIM is working on a model landscape consisting of detailed land use and soil maps and a relatively detailed representation of the drainage system by sub-basins including reservoirs. Agricultural management (which plants to grow where and when plus respective details on fertilisation) has to be provided, too. The model is driven by daily weather data spatially discretized or interpolated to the sub-basin units. The SWIM outputs include runoff time series for each sub-basin outlet, respective local water balances, as well as biomass production and crop yields; the latter can be spatially aggregated for arbitrary regions, e.g. NUTS units. Combining the local water balance data with demand scenarios, possible deficit areas or drought periods can be quickly projected. Hydropower production or respective projections can be easily derived from the runoff calculations.

It is planned that SWIM will be set up for the Elbe and Danube River basin parts of the case study region in March 2018. For making a first version of the baseline scenario – consisting of water balance and crop yield data in NUTS-2 regions – three more months should be considered, because the model always needs a thorough calibration. The model projections will be used as soon as they are available; what we can present at the first stakeholder workshop in March 2018 will however be more a roadshow of possible outcomes. This needn't be a disadvantage, because the stakeholders will definitely give their feedback about what exact data they would be most interested which could trigger some efforts to get exactly these outputs (if possible).

Guidances about the model output will be produced as necessary in form of "instruction leaflets" for all cases where such data shall be released. However, we do not intend to generally release raw outputs from the model. Other users will usually be provided with maps and graphs illustrating the SWIM output in the framework of research articles and project deliverables where detailed explanations are obligatory.

The nexus challenges addressed by the model are both land use and climate change related impacts on the water sector and agricultural (food) production. Crop share alterations will be considered from respective CAPRI scenarios. Not covered, except from hydro-energy, is the energy sector. The atmospheric feedbacks of land cover as well as regional climate change are also to be provided as input to SWIM and are not dynamically modelled. We will however do some assessments for covering this important point of our reasoning; see Conradt et al. (2007) for an example study about the effects of new lakes on regional precipitation.

Regarding the energy sector, there are a lot of data available about production and consumption pathways and trends, many of them also spatially discretized (EUROSTAT 2017). There is also a considerable amount of literature on grid stability (e.g. Flynn et al. 2017, van Meerwijk et al. 2016, Pierri et al. 2017). We will review the available information and can probably answer many of our nexus-related research questions through this kind of meta-analysis.

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

Meetings with stakeholders take place consistently on the national level in form of workshops and conferences, but in the first place through personal consultations. In several conferences on which researchers of SIM4NEXUS lectured there were more than 100 participants from local communities, regional governments, landscape planners, or mayors of villages and small cities. Slovak participants joined events in the Czech Republic (Dačice and Třeboň [two times]), Czech participants came to Slovakia (Zvolen [two times] and Bratislava), and both Slovak and Czech lecturers took part in an event in Germany (Berlin).

Germany is the most important commerce partner of the Czech Republic: 32% of the Czech exports (in total amounting to 142 bn EUR in 2015) go to Germany, and 30% of the Czech imports (totalling 127 bn EUR in 2015) originate from there. Slovakia is the second partner for exports (9%) and takes the fourth place after Germany, Poland, and China in the import ranking (6.5%).

On the national level, the number of meetings about Nexus issues is roughly 30 in the Czech Republic and Slovakia. A list of stakeholders was elaborated and delivered by ENKI.

Our transboundary case study workshop will be held at Třeboň (CZ) from 7 to 9 March 2017. ENKI, o.p.s. organizes the workshop and will cover the stay of invited stakeholders and their travel costs from their SIM4NEXUS budget. Details of the reimbursement are currently being discussed with Marianne Selten.

Some stakeholders will travel about 700 km, our aim is therefore to deal with stakeholders also before the event to make it more effective. The following stakeholder groups are being addressed for the workshop from Czech Republic: landscape and urban planners active in the governmental commission of sustainable development, a leading research scientist from the Research Institute of Soil Management (soil erosion expert), a representative of Povodí Labe (state administration of river management), and representatives of “small” farmers (Bitek, Kajan, Marada), municipalities cooperating long term with ENKI (towns Třeboň, Dačice), further forest managers or forest researchers, biogas/biofuels producers, owners of agricultural land, as well as energy strategists/planners. From Germany and Slovakia, similar mixtures of representatives are being invited.

About seven stakeholders from each country plus organising staff from ENKI, P&W, and PIK will participate. More than seven stakeholders from the Czech Republic can take part from practical reasons; respectively more representatives from Slovakia can take part in the follow-up case study workshop in Slovakia.

2 Conclusions and follow-up

The achievements in preparing this Deliverable can be summarised as follows:

Common issues of the transboundary study (Germany–Czech Republic–Slovakia) were defined:

- Germany and Slovakia are the most important commerce partners of the Czech Republic.
- East Germany (former GDR), the Czech Republic, and Slovakia (former Czechoslovakia) share the common history of socialist rule which is still visible in the agricultural landscape: Average farm sizes are about five times larger than average farms in Western Europe. The areas of drained field blocks are largest in the EU. Our study will look both at developments during the past decades as well as scenarios up to the middle of the 21st century.
- The ramified hydrological web of the original agricultural landscape disappeared.
- EU subsidies do not support restructuring of the agricultural landscape.
- To fulfil the EU aim of 20% of energy provided from renewable sources until 2020, governments in CZ and SK support plant biomass production: rape for biofuel, maize for biogas, and straw for direct combustion, the latter are used for heat and electrical energy production.
- Overheated land amplifies soil erosion, its acidification, decomposition of organic matter (carbon release), loss of water capacity causing higher flood risk and drying-up tendencies, and it enhances convection leading to thunderstorms.
- Release of huge flows of sensible heat (several GWh per km^2 during a sunny day) has serious consequences for local climate and hydrology. Droughts namely in agriculture areas limit crop and vegetable production, early morning frosts in spring damage fruit production.
- In several German and Czech locations there are still active open cast lignite mining sites where farmland, forests, and small settlements are converted to giant industrial pits. Excessive amounts of groundwater have to be pumped out of these places during the excavation phase. Then there are many disused lignite mining areas being filled by river runoff and receding groundwater.

Both droughts (ongoing water shortage) and policies supporting biofuels linked to soil degradation are discussed on regional and governmental levels. There is a need to quantify the negative effects of large drained fields on runoff, distribution of solar energy, the regional water cycle, carbon sequestration, and the local climate.

There are programmes under preparation and local activities aimed at restoration of drained agriculture landscapes. Guiding questions are:

- What effect could be achieved by greening in the drained fields and by landscape restoration based on seepage grass strips, wetlands and ponds for water retention which also stimulate sequestration of carbon and reduce water and nutrient losses?
- To which extent can the direct effects of permanent vegetation on local climate, carbon balance and hydrology be covered by the thematic models SWIM and CAPRI? (SWIM can not model the atmospheric feedbacks, but water balance shifts from different land use and cropping; Crop share scenarios can in turn be provided from CAPRI.)

Concerning energy, the former dominance of fossil energy sources (lignite) was confined by political decisions in favour of renewables. Hydropower has no more unused potentials but PV and Wind are being further developed with negative feedbacks to electrical grid stability. Wind power installations cause protests of civic groups. Bioenergy may be supported on account of food production. A second category of bioenergy (non-food) might be an option for the future because it can provide important ecological functions of permanent vegetation. There are programmes for effective use of energy from sludge of waste water treatment plants. All three countries have negative energy balances when we consider the imports of fossil fuels.

Interlinkages between the Nexus sectors are understood through water as the natural hub: The conceptual “water rotor” development is kept in motion through the hydrological cycle powered by the sun.

Development pathways were defined by the Shared Socio-economic Pathways (SSP): Besides the baseline – SSP2 “Middle of the road” – which is the obligatory start in SIM4NEXUS, we will estimate the consequences of SSP3 “Regional rivalry – A rocky road”, motivated by current threats to the stability of the European Union like the recent emergence of right-wing nationalist parties in a couple of member states.

The conceptual model for the DE-CZ-SK transboundary case study was developed. The model distinguishes policy controlled and SWIM covered entities and simulates Nexus services as its value outputs.

As SWIM needs lots of geo and time series data, besides others daily meteorological data in spatial discretisation, respective grid data (1961–2016) from several regions of the Czech Republic are being purchased. These will also be used for statistical evaluation of local climate changes associated with land cover alterations.

Finally, venue and date of the workshop with stakeholders from all three countries of transboundary study was set. Consultations with stakeholders on national level take place in form of workshops, conferences, individual meetings, questionnaires, cooperation in projects, professional bodies etc., and invitations to the upcoming stakeholder workshop are being distributed.

3 References

- Anonymus (2017) Koncepce ochrany před následky sucha pro území České republiky. Schváleno Vládou ČR 28. července 2017, in Czech. (“Drought impacts prevention for the territory of the Czech Republic”). Document proofed by the CZ Government on 28 July 2017)
- Conradt, T., Z. W. Kundzewicz, F. Hattermann & F. Wechsung (2007) Measured effects of new lake surfaces on regional precipitation. Hydrological Sciences Journal 52 (5) 936–955. doi:10.1623/hysj.52.5.936
- Conradt, T., H. Koch, F. F. Hattermann & F. Wechsung (2012) Spatially differentiated management-revised discharge scenarios for an integrated analysis of multi-realisation climate and land use scenarios for the Elbe River basin. Regional Environmental Change 12 (3) 633–648. doi:10.1007/s10113-012-0279-4
- DESTATIS (2017) GENESIS database of the statistical office of Germany, Wiesbaden, as of December 2017. URL https://www-genesis.destatis.de/genesis/online – last accessed in December 2017.
- Ellison, D. et al. (2016), Trees,forests and water: Cool insights for a hot world, Global Environmental Change http://dx.doi.org/10.1016/j.gloenvcha.2017.01.002
- ENTSO-E (2017) European network of transmission system operators for electricity: ENTSO-E Online Grid Map. URL: https://www.entsoe.eu/map/Pages/default.aspx, see also https://www.sepsas.sk/images/schemasiete/Central_Europe_2017_04_30.png – last accessed in December 2017.

- EUROSTAT (2017) Database of Eurostat, the statistical office of the European Union, Luxemburg, as of December 2017. URL http://ec.europa.eu/eurostat/data/database – last accessed in December 2017.
- Flynn, D., Z. Rather, A. Ardal, S. D'Arco, A. D. Hansen, N. A. Cutululis, P. Sorensen, A. Estanquiero, E. Gomez, N. Menemenlis, C. Smith & Y. Wang (2017) Technical impacts of high penetration levels of wind power on power system stability. Wiley Interdisciplinary Reviews – Energy and Environment 6 (2) e216. doi:10.1002/wene.216
- Hesslerová, P., Pokorný, Brom J. & Rejšková A. (2013) Daily dynamics of radiation surface temperature of different land cover types in a temperature cultural landscape: Consequences for the local climate. Ecological Engineering 54, 145–154.
- Kovářová, M. & J. Pokorný (2010) Comparison of long-term monitoring of temperature and precipitation between wetland and other ecosystems. Ecohydrology. 2010, vol. 3, no. 4, s.445-456. ISSN 1936-0584.
- van Meerwijk, A. J. H., R. M. J. Benders, A. Davila-Martinez & G. A. H. Laugs (2016) Swiss pumped hydro storage potential for Germany's electricity system under high penetration of intermittent renewable energy. Journal of Modern Power Systems and Clean Energy 4 (4) 542–553. doi:10.1007/s40565-016-0239-y
- O'Neill, B. C., E. Kriegler, K. L. Ebi, E. Kemp-Benedict, K. Riahi, D. S. Rothman, B. J. van Ruijven, D. P. van Vuuren, J. Birkmann, K. Kok, M. Levy & W. Solecki (2017) The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Global Environmental Change 42 169–180. doi:10.1016/j.gloenvcha.2015.01.004
- Pierri, E., O. Binder, N. G. A. Hemdan & M. Kurrat (2017) Challenges and opportunities for a European HVDC grid. Renewable and Sustainable Energy Reviews 70 427–456 doi:10.1016/j.rser.2016.11.233
- Riahi, K. & D. P. van Vuuren (eds) (2017) Special Section "Quantification of the Shared Socio-economic Pathways". Global Environmental Change 42 148–358. – Editorial plus fifteen research papers with individual doi references.
- Vetter, T. & F. Wechsung (2015) Direct aerosol effects during periods of solar dimming and brightening hidden in the regression residuals: Evidence from Potsdam measurements. Journal of Geophysical Research – Atmospheres 120 (21) 11299–11305. doi:10.1002/2015JD023669
- Wild, M. (2012) Enlightening Global Dimming and Brightening. Bulletin of the American Meteorological Society 93 (1) 27–37. doi:10.1175/BAMS-D-11-00074.1

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

D5.2: THE MAIN NEXUS CHALLENGES IN THE EUROPEAN CASE STUDY

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Glossary / Acronyms

CAP	COMMON AGRICULTURAL POLICY
EAFRD	EUROPEAN AGRICULTURAL FUND FOR RURAL DEVELOPMENT
EAGF	EUROPEAN AGRICULTURAL GUARANTEE FUND
EED	ENERGY EFFICIENCY DIRECTIVE
EPBD	ENERGY PERFORMANCE OF BUILDINGS DIRECTIVE
ESD	EFFORT SHARING DECISION
ETS	ENERGY TRADING SYSTEM
EU	EUROPEAN UNION
GHG	GREEN HOUSE GASES
IAM	INTEGRATED ASSESSMENT MODELS
ILUC	INDIRECT LAND USE CHANGE
LULUCF	LAND USE, LAND USE CHANGE AND FORESTRY
MSA	MEAN SPECIES ABUNDANCE
RCP	REPRESENTATIVE CONCENTRATION PATHWAY
SSP	SHARED SOCIO-ECONOMIC PATHWAY
WHO	WORLD HEALTH ORGANIZATION

1 Introduction

The Continental European case study examines the impact of a transition to a low carbon economy in Europe on the five elements of the Nexus: Climate, Energy, Land, Water and Food. The spatial scale is the entire European continent, however for the sake of policy analysis and interpretation a division is made between the EU (European Union) and the rest of the European continent. The time frame for the analysis is until 2050, with future projections reported in 10 year periods. The case study will examine economic incentives, such as carbon prices and renewable energy subsidies, as well as regulatory policies on, for example, land use or transport emissions such as biofuel mandates, as possible pathways for the transition to a low carbon economy in Europe as a mitigation strategy to combat climate change. The case study will assess the impacts of this transition on water demand for hydro-power and for irrigation of bioenergy crops resulting from policies that stimulate these sectors, and how this change in water demand will affect environmental flows and biodiversity. Further the impacts of the transition to a low carbon economy on European and global food security and nutrition will be examined as agricultural land could be used for growing energy crops and forests instead of food.

Unlike the national and regional case studies the Continental European case study is initially driven by the thematic models and will engage the stakeholders once the preliminary analysis of the energy transition pathways is completed. The thematic models involved in the European case study are: E3ME-FTT, MAGNET, CAPRI, IMAGE-GLOBIO, and MAgPIE. The organizations involved either directly or as anticipated end users of the analysis and results of the European case study include: various departments of the European commission including DG Energy, Agriculture, Climate and environment, the European parliament, the water supply and sanitation technology platform (WssTP) and Copa-Cogeca (an organization representing farmers and their cooperatives). The transition pathways developed in this case study would then help to inform the stakeholders in developing an integrated Europe wide energy, climate, water and agricultural policy as well as provide a framework of possible future scenarios for national level decision makers in these policy arenas.

The aim of this deliverable is to present an overview of the nexus challenges until 2050 at the European scale. This overview is informed by the first run scenario results of the thematic models as they were developed in the case study workshop in The Hague in October 2017, as well as a summary of the European policy pathways relevant to the five Nexus elements. Further a conceptual model is proposed to highlight the main Nexus interactions that will be the focus of the case study. This deliverable also proposes several Nexus policy options highlighted by the conceptual model and give a short analysis of which thematic models can provide insight into these policy options and Nexus elements in the conceptual model.

The deliverable is structured as follows. Section **Error! Reference source not found.** presents an overview of the Nexus challenges based on the scenario data that were shared between the modelling groups. Section **Error! Reference source not found.** provides a summary of the European policy and climate pathways relevant to the five Nexus elements. Section **Error! Reference source not found.** presents the first version of the conceptual model of the European case. Section **Error! Reference source not found.** Explores the ability of the thematic models to investigate the nexus relationships highlighted in the conceptual model. Section 1.5 Describes the planned interaction with the stakeholders and summarizes the results of the work case study. Section 2 summarizes the proposed next steps in the case study and concludes.

1.1 Description of the Nexus challenges

1.1.1 Introduction

Each thematic model has developed a baseline projection for continental Europe until 2050 according to the Shared Socio-economic Pathway (SSP) 2, business as usual narrative (O'Neill et al., 2013). With the exception of population and GDP growth the exact implementation of the SSP2 scenario in the models is flexible. Therefore in this section the baseline model results for selected Nexus indicators from each thematic model have been compared, both in order to give a preliminary analysis of the development of the Nexus elements in Europe until 2050 and in order to facility harmonization in the interpretation and implementation of the of the SSP2 narrative.

Furthermore, several models have submitted results from a 2 degree mitigation scenario. These mitigation scenarios were developed independently by the thematic models and therefore the mitigation polices vary across the models. The results of the mitigation scenarios are compared in this section as well in order to gain an understanding of the variation of the possible impacts on the Nexus elements.

1.1.2 Food

Europe has already in 2010 reached a food supply of more than 3000 kcal per capita per day, which indicates sufficient food availability and a substantial share of food being wasted in households. The food supply in calories consists approximately of one quarter of animal-based products and three quarters of plant-based products.
Four SIM4NEXUS models have projected future food availability in Europe (see Fig 1). There are some differences in 2010, as the harmonization with respect to the regional aggregation and the calibration on the base year is still an ongoing process. For the future development of per-capita food demand, the models come to different conclusions. CAPRI, MAGNET and IMAGE project a further increase of the animal-based products in the diet; in contrast, MAgPIE estimates a decline in both total calories and animal-based calories, as the demand is income-saturated and per-capita intake requirements decline with an ageing population. The effect of a climate mitigation policy on food demand has been estimated by MAGNET, MAgPIE and IMAGE. In MAgPIE this policy has hardly any impact on food demand. MAGNET and IMAGE are more elastic in terms of food demand.

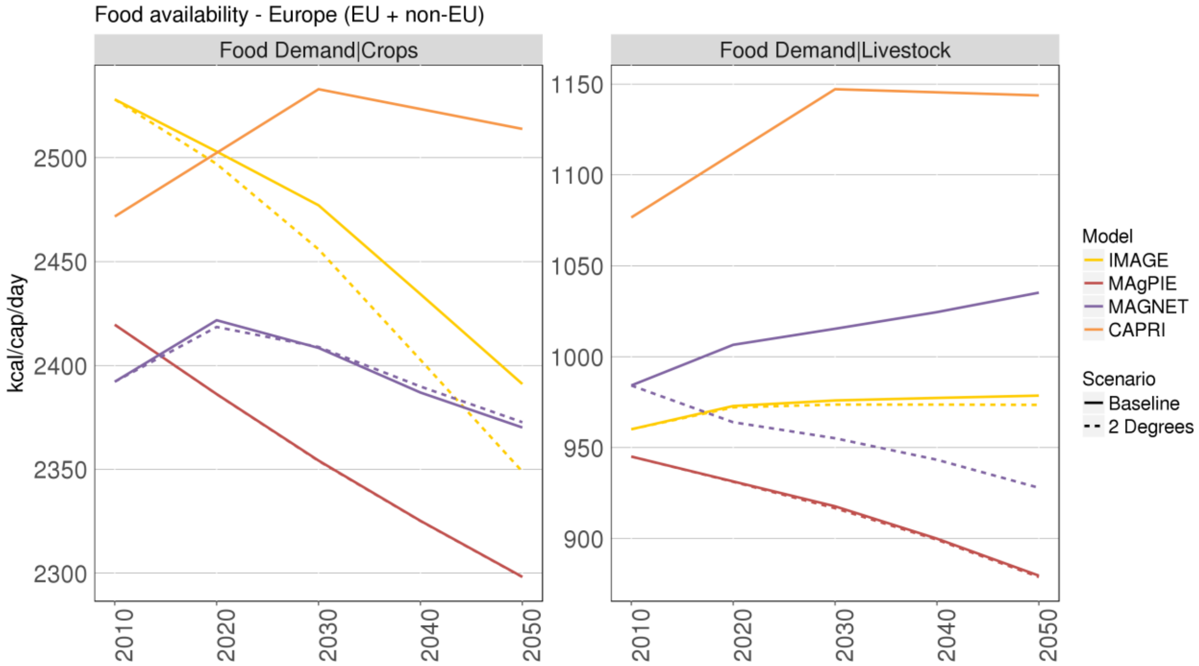

Figure 1: Per-capita food supply in Europe (EU+nonEU) in a SSP2 baseline scenario without climate change mitigation and in a SSP2 scenario with a carbon price to reach RCP2.6, simulated by different models.

The per-capita demand is one of the main drivers of the agro-food system. Beyond, European agricultural production is also driven by population growth, feed demand, bioenergy demand and material demand, and it is strongly determined by international trade. The projections of agricultural production can therefore also strongly differ from the development of per-capita demand. In the baseline scenario, the projections of IMAGE, MAgPIE and MAGNET foresee a small increase in cropland and livestock production in Europe, while crop production stays merely constant in CAPRI (see figure 2). Bioenergy production remains marginal if no climate policy is implemented. In case of a 2° policy target, the cultivation of bioenergy makes up a larger share of agricultural production, ranging up to 30% in the year 2050 in MAgPIE.

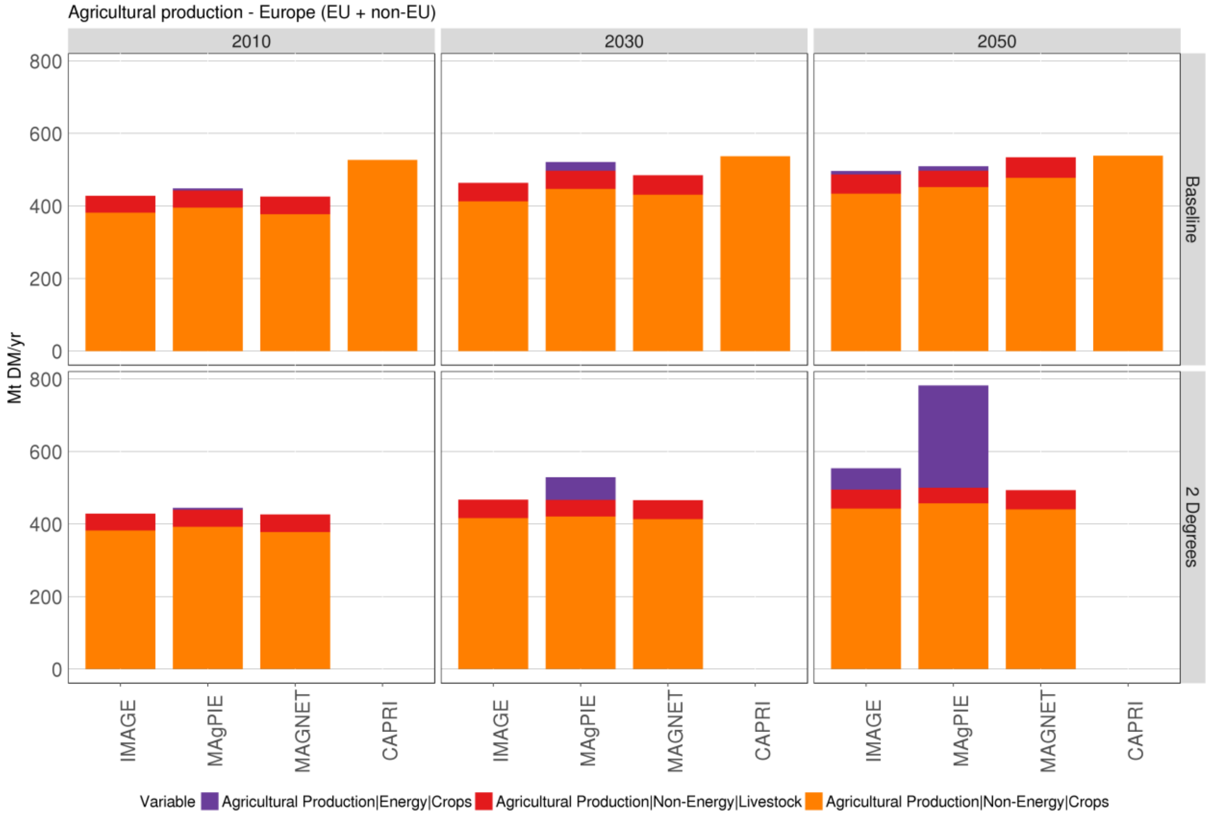

Figure 1: Agricultural production in 2010, 2030 and 2050 in the reference and 2 degree scenarios

1.1.3 Water

Water problems in Europe include water scarcity, water quality and flood risks. Various environmental assessments have indicated that a key environmental problem in the next decades will be increasing water scarcity (Marchal et al., 2011, Bijl et al., 2016). Water scarcity can be a threat to ecosystems, food production, rural livelihoods and electricity production. Agriculture is the dominant sector in water demand, most importantly through large-scale irrigation. In addition, the electricity, industry and municipal sectors have a substantial water demand. Especially in more arid regions, like Southern Europe, and during dry periods of the year, overall demand and competition between different sectors can cause scarcity. The occurrence of dry periods is expected to increase as a result of climate change, increasing the gap between demand and supply. Water scarcity in turn will have effects in other parts of the water-land-food-energy-climate nexus. Apart from water quantity, water quality is an important issue. While the deterioration of water quality has been stabilized or turned into some improvement especially in Western Europe, in Eastern Europe eutrophication is expected to increase due to agricultural intensification. Water quality often reacts to diffuse emission reductions with a time delay. Urban nutrient emissions will further decrease in Europe (as opposed to other continents) if current policies for water treatment are met. With respect to flood risks, these are expected to increase in several parts of Europe due to sea level rise and more irregular rainfall patterns leading to river floods.

From the thematic models considered in the European case, IMAGE and MAgPIE calculate water demand from irrigated agriculture (Figure *3*). In IMAGE, water demand in Europe is stable due to limited increases in irrigation area and due to CO_2 fertilization which reduces the water requirement of crops. In the mitigation scenario, CO_2 concentrations are lower leading to slightly higher water demand. In MAgPIE, water demand from irrigated agriculture in Europe increases from 2010-2050 both in the baseline and the mitigation scenario due to increasing irrigated area.

IMAGE also calculates water demand from the electricity, industry and municipal sectors. It is shown that water withdrawal for electricity generation decreases substantially in Europe due to reduced need for cooling water as the number of traditional coal-fired power plants goes down. In the mitigation scenario this process is even faster leading to much lower water withdrawal by the year 2050. In contrast, water use for hydropower (not yet included in the model calculations) is expected to increase. Water withdrawal for industry and the municipal sector is roughly stable as Europe is already at a high level and because population is projected to remain stable as well.

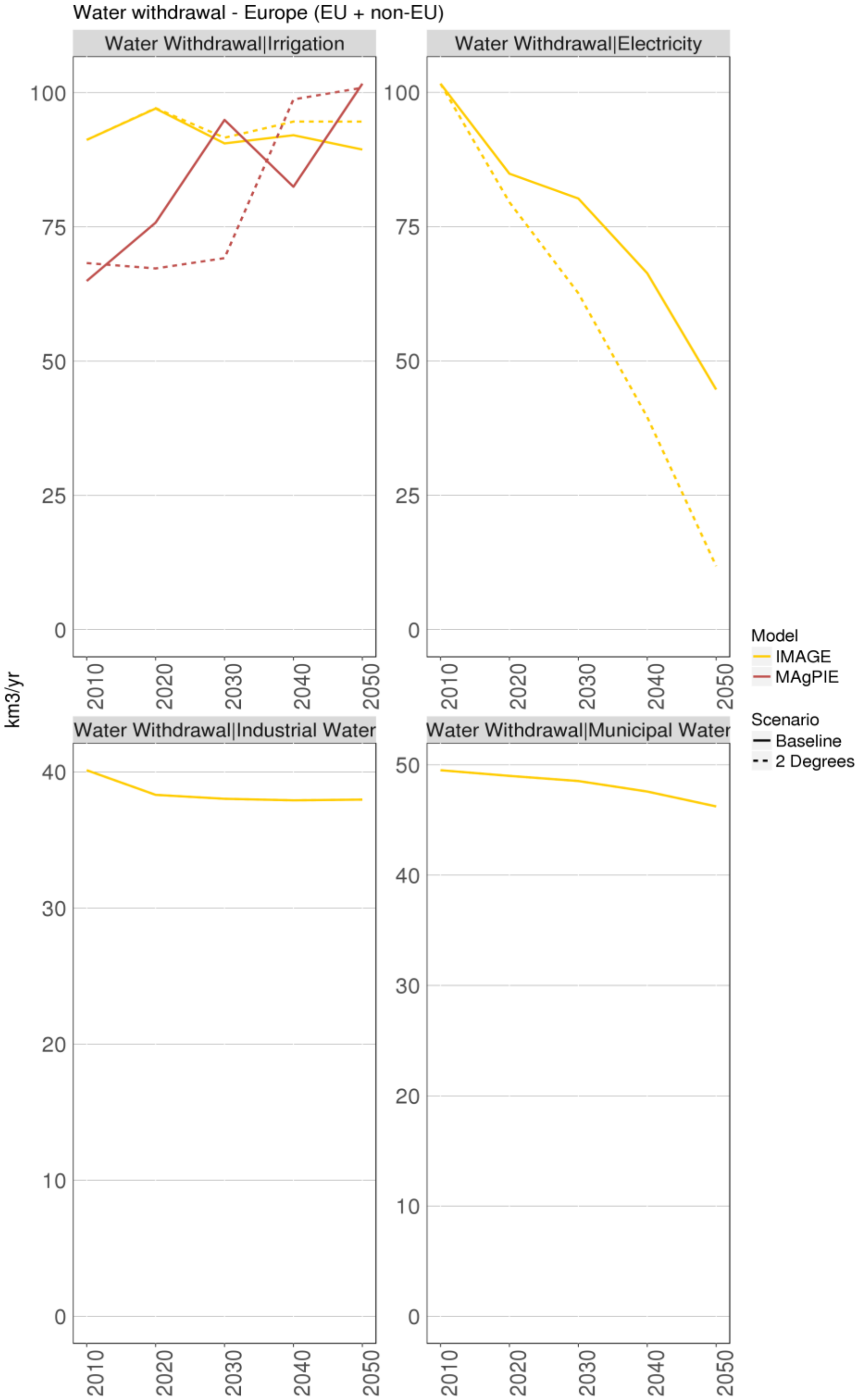

Figure 2: water withdrawal for four sectors: irrigation for agriculture, electricity, industry and municipal water use

Besides these trends in water demand, there is an expected negative trend in water availability due to climate change, especially in Southern Europe. According to the IMAGE projections, the number of people living in river basins with (varying degrees of) water stress (water scarcity) will increase from 146 million to 274 million in the described period.

Water quality and ecological quality of aquatic systems are covered by the IMAGE-GLOBIO model. Just over 50% of European water bodies have remained a high biodiversity intactness and this will change only little according to the SSP2 scenario. This figure is likely to be too optimistic as not all pressures were as yet included in the model. The number of lake cells being at risk of harmful algal blooms above the WHO standard will increase from about 50 to 55% according to these model projections, due to increased nutrient emissions in the eastern part of Europe and due to higher water temperatures.

1.1.4 Land

Figure 5 summarizes the change in land use in million Hectares (Mha) between 2010 and 2030 as well as between 2010 and 2050 for the SSP2 baseline scenario and also for the 2 degree mitigation scenario. Four thematic models have been able to provide results on land use change for the baseline scenario IMAGE, MAgPIE, MAGNET and CAPRI and the first three models have also provided results for the 2 degree mitigation scenario. IMAGE and MAgPIE report changes to multiple types of land use, while MAGNET and CAPRI report changes in land use strictly as it relates to Agriculture.

All models are in agreement that total agricultural land area in Europe decreases by 2030 and further decreases by 2050 for the baseline scenario. MAgPIE and MAGNET report that this decrease in agricultural land is almost entirely explained by a decrease in pasture land, while IMAGE estimates that cropland and pasture land decrease by approximately the same amount. The decrease in agricultural land is mirrored by a corresponding increase in forested areas. MAgPIE in particular reports an increase in forested areas on former pasture areas, as livestock production in Europe shifts from ruminants to chickens. A reason for this could be that MAgPIE does not take into account policies that support pasture areas for landscape or biodiversity preservation. IMAGE reports a smaller increase in forested area and also a modest increase in the built up area. Even through MAGNET does not model forest cover, the exogenously assumed increase in forest cover is used to calibrate the reduction in available agricultural land.

In MAGNET, pasture land is less intensively used compared with crop lands. Therefore the value, per hectare, of land is relatively higher in the crop activities compared with pasture, which is why the reduction in agricultural land primarily comes from pasture land. In MAgPIE, a shift from ruminant to chicken production is the main driver of pasture abandonment in Europe; globally, the demand for meat from monogastric animals increases disproportionally, and livestock production intensifies, which results in lower grass and higher concentrate feed rations for animals.

Despite implementing different mitigation scenarios, IMAGE, MAgPIE, MAGNET report similar trends for Europe, namely that agricultural land is either almost unaffected (MAGNET) or increases compared to the baseline scenario, (IMAGE, MAgPIE). In MAGNET the mitigation scenario is driven by a global carbon price on agricultural emissions. Europe has relatively low emissions per unit of agricultural output in the baseline, so the burden of the carbon tax falls primarily on the rest of the world giving a competitive advantage to European agriculture. In MAgPIE, mitigation causes two opposing dynamics: while the pricing of carbon stocks leads to reduced deforestation and afforestation and thereby to reduced agricultural area, an increasing demand for bioenergy drives for increasing agricultural areas. As in the mitigation scenario, afforestation mainly takes place in other world regions while Europe provides large amounts of bioenergy, the reforestation in Europe is even slower in the mitigation case than in the baseline run.

The impacts on biodiversity are calculated by the IMAGE-GLOBIO model. Opposing trends in the baseline - increase in forest but also in energy crops and urban area, at the expense of cropland and pasture – lead to a limited negative effect on overall terrestrial mean species abundance (MSA).

Combined with other drivers such as increased infrastructure and climate change, however, the MSA will substantially decrease from 0.37 to 0.29 in the SSP2 scenario.

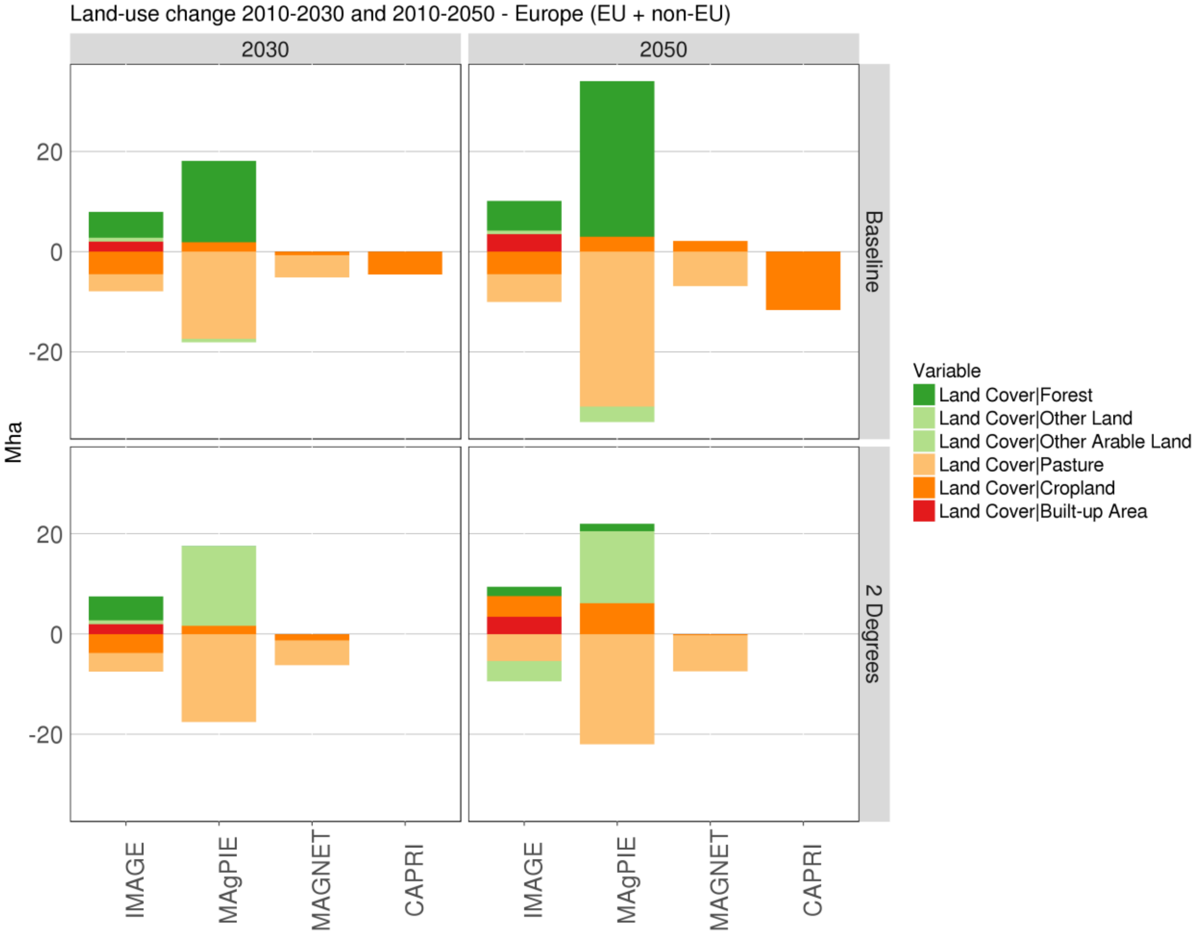

Figure 3: land-use change for periods 2010-2030 and 2010-2050

1.1.5 Energy

Figure 6 below summarises the total primary energy demand results for E3ME, IMAGE and MAgPIE. As the MAGNET model has results for secondary energy only,not primary, it was left out of this comparison. It is important to note the historical primary energy demand values vary considerably between models. Both IMAGE and E3ME are reporting similar primary energy demand levels for coal, oil, gas and biomass. E3ME did not report primary energy demand for nuclear and renewable energy. Both IMAGE forecasts and increase in primary energy demand by 2050, while E3ME project a decrease in primary energy demand. The E3ME results are mainly driven by policies implemented in the EU, such as the EU-ETS, the Energy Efficiency Directive and the Renewables Directive. These policies are expected to lead both to lower energy-intensity in the economic sectors targeted as well as a decrease in demand for coal in the power generation sector in the EU. On the other hand, the IMAGE model results highlight an increase in primary energy demand for coal in the baseline.
When examining the 2-degree scenario results we see that results from the two thematic models show a decrease in primary energy demand as expected. Primary energy demand for both coal and oil are expected to decrease considerably by 2050 in the 2-degree scenario. Furthermore, both E3ME and IMAGE results show an increase in bioenergy use in the 2-degree scenario, which may raise challenges with regard to land-use, food production, biodiversity and water use in the energy crop areas, either

inside or outside Europe. Please note that E3ME did not report primary energy demand for nuclear and renewable energy.

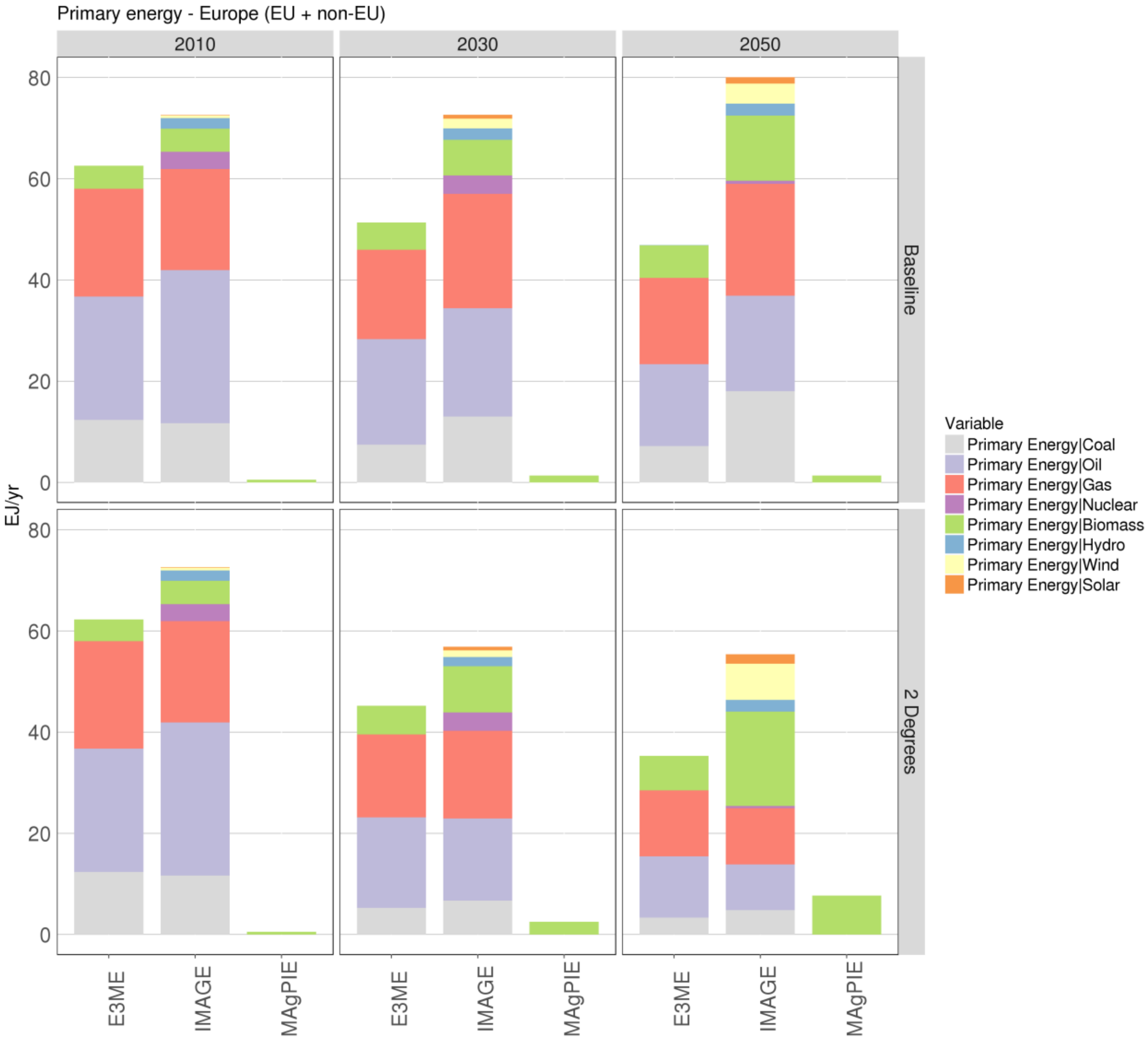

Figure 4: primary energy production per energy carrier in 2010, 2030 and 2050

1.1.6 Climate

Figure 7 summarises the European CO_2 emission results in the baseline and 2-degree scenario. E3ME, IMAGE, MAGNET and MAgPIE were able to provide results for the baseline; E3ME, IMAGE and MAgPIE also provided results for the 2-degree scenario. MAgPIE provides emissions for land-use only, MAGNET only for energy emissions, the other models provided both; IMAGE also included industrial process emissions.

Historical energy-related CO_2 emission results are very similar across the different models used. The future baseline CO_2 emission trends are also very similar when looking at the IMAGE and MAGNET results; both models show an increase in CO_2 emissions over the projection period. On the other hand, E3ME results show a decrease in CO_2 emission levels between 2010 and 2050. The reason for the decrease of CO_2 emissions in E3ME is a result of recent policies implemented in the EU, such as the provisions of the EU-ETS, the RES Directive, the Effort Sharing Decision and the Energy Efficiency Directive. These policies are expected to lead to reduced energy intensity of activities in parallel with reduced carbon intensity of power generation and reduced energy demand. MAGNET energy-related CO_2 emission projections in 2050 are somewhat higher compared to both the E3ME and IMAGE results.

Looking at the 2-degree scenario results, we see that the energy-related CO_2 emission reduction is at a similar level in E3ME and IMAGE. IMAGE also estimates a reduction of CO_2 emissions from land-use. This is not the case in E3ME, where changes in land-use emissions cannot be captured in the modelling yet, and in MAgPIE where bioenergy cultivation even reduces the negative emissions that were estimated for the baseline scenario.

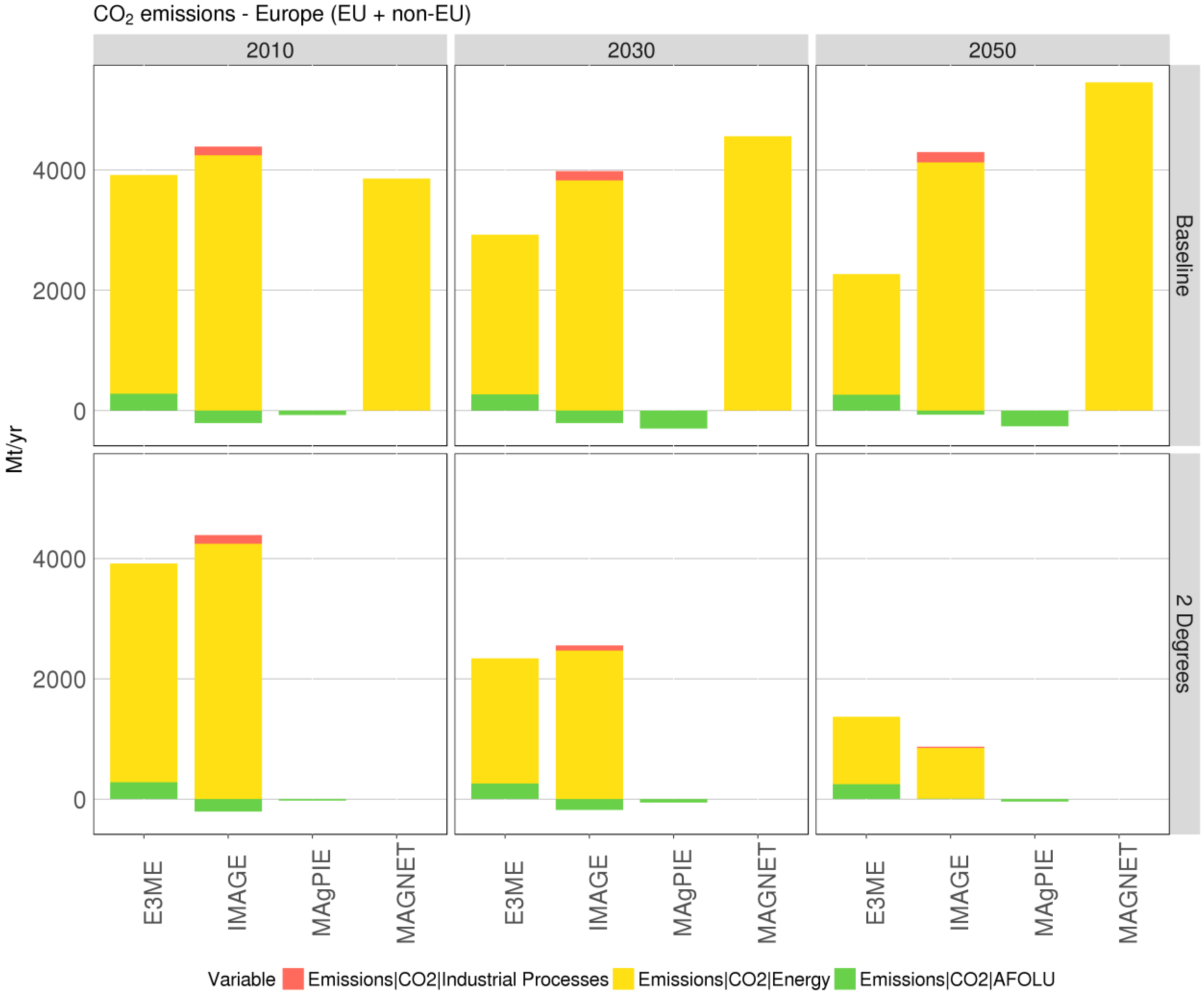

Figure 5: CO_2 emissions per source in 2010, 2030 and 2050

Figure 8 summarises the methane (CH4) and nitrous dioxide (N2O) emission results for the baseline and 2-degree scenario. E3ME CH4 emission results are slightly lower in the baseline compared to IMAGE results, with E3ME CH4 levels decreasing slightly between 2020 and 2040. On the other hand, IMAGE CH4 remissions remain at a relatively stable level over the projection period. MAGNET CH4 baseline emissions increase considerably over the period to 2050.
Baseline N2O emission results vary somewhat between the models. Both IMAGE and MAGNET N2O emission results increase over the projection period. While the N2O emission levels are different in the two models, with IMAGE levels starting higher in the historical period compared to MAGNET, the rate of emission increase in both models is quite similar. On the other hand, E3ME N2O projections are expected to decrease considerably by 2050. In contrast to the other models, MAGNET does not include exogenous emission savings technology in the baseline. Therefore the change in emissions is due solely to the change in the production or use of the commodity responsible for the emissions. Further the preliminary mitigation scenario implemented in MAGNET only examine mitigation policies that target agriculture even through the model includes emissions from the entire economy. Agriculture is only responsible for 23 percent and 83 percent respectively of total CH4 and N20 emissions, so the emission reduction from agriculture small compared to the total European CH4 and N20 emissions.

IMAGE highlights a considerable decrease in CH4 emissions in the 2-degree scenario, due to emission saving technologies in the agricultural sector which for example reduce emissions from manure and enteric fermentation in the livestock sector. However, the CH4 emission reduction in E3ME appears significantly smaller. A similar pattern can be observed when looking at the N2O emission results.

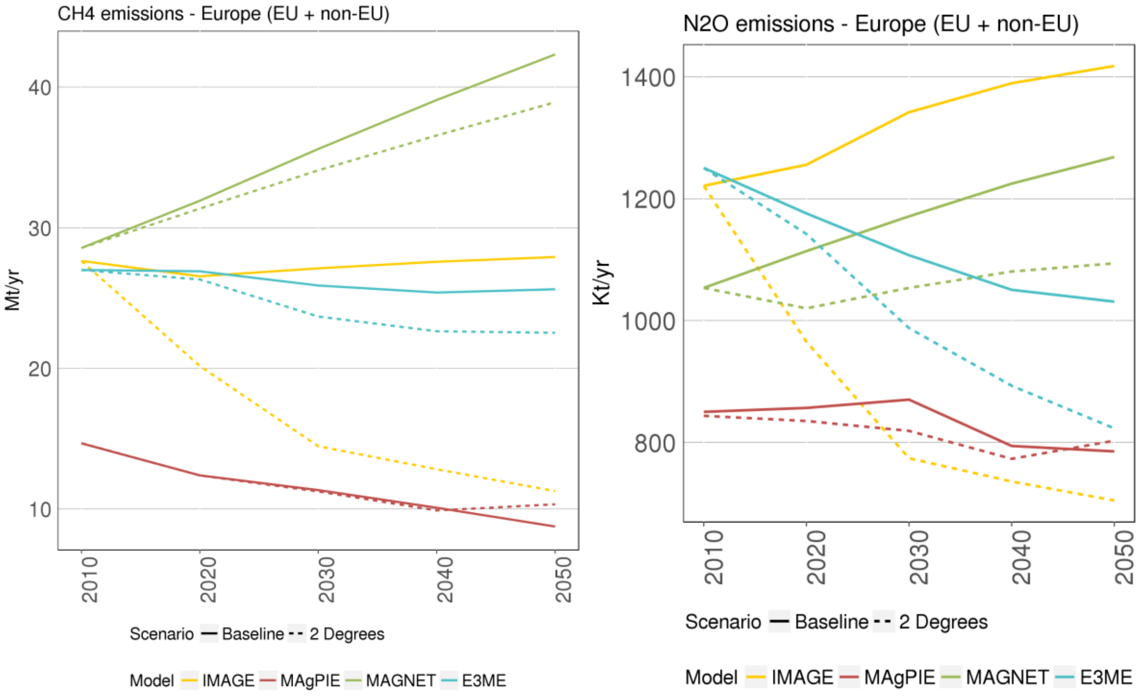

Figure 6: CH$_4$ and N$_2$O emissions from 2010 to 2050 for four models: E3ME, IMAGE, MAgPIE and MAGNET

1.2 Description of the pathways

1.2.1 Introduction

As mentioned in section 1.1 each thematic model has independently developed a baseline projection for continental Europe until 2050 according to the Shared Socio-economic Pathway (SSP) 2, business as usual narrative (O'Neill et al., 2013). For the European case study a consistent implementation of European policies across all thematic models as they relate to the Nexus is critical for comparing results across models and for exploiting synergies between them.

As the thematic models differ in focus and in structure, the exact implementation of the polices is different in the various models. However, the decision about which policies are relevant as well as the interpretation of those policies should be uniform across all thematic models involved. Therefore to facilitate further harmonization among the thematic models in this case study and to ensure a consistent policy narrative, this section provides an overview of the climate pathways and the various European policies that will be included in the case study scenarios.

The policies described in the rest of section 1.2 are not yet uniformly implemented in the thematic models, this will be one of the primary tasks for early 2018. This further harmonization will most likely have an effect on the results on the Nexus indicators reported in section 1.1.

1.2.2 RCP pathways considered in the European case study

The representative concentration pathways (RCPs) are a set of harmonized emission trajectories that aim to improve harmonization between integrated assessment models (IAMs) and climate models (van Vuuren et al., 2011). They have been used extensively in the fifth IPCC assessment report where they served as a basis for many experiments thus improving comparability across different fields of science.

The RCPs have been defined to cover the range of radiative forcing outcomes (and as a consequence temperature) that are available in the literature. The highest radiative forcing outcome is 8.5 W/m^2 in the year 2100 in RCP8.5, implying a temperature increase of >4°C. The lowest radiative forcing target is 2.6 W/m^2 in RCP2.6, which results in a 66% chance of limiting global warming to 2°C by the end of the century. In response to the Paris climate agreement where the parties agreed to 'aim to limit climate warming to 1.5°C' RCP1.9 was created which aims to limit radiative forcing to 1.9 W/m^2 in order to keep global temperature change below 1.5°C.

For the SIM4NEXUS project, two RCPs are selected. First, the RCP6.0 which leads to a radiative forcing of 6.0 W/m^2 by the end of the century which implies a temperature increase of 3°C -4°C. This RCP is consistent with the SSP2 scenario without climate change mitigation as projected by IAMs (Riahi et al., 2017). Second, the RCP2.6 which leads to a radiative forcing of 2.6 W/m^2 and a 66% chance of keeping temperature change below 2°C. The latter scenario represents ambitious climate change mitigation.

1.2.3 Energy policy pathways

The purpose of this section is to outline the main energy-related policies and measures that should be included in the thematic models' baseline for the European case study. The key policy and areas cover: renewable energy, energy efficiency, internal market and competitiveness and energy security. The future transformation of the EU energy system is linked to the legally binding targets on renewables (RES) (20% share of gross final energy consumption from RES by 2020 and 10% specifically in the transport sector). The baseline should also cover any national support schemes that promotes the use of energy from renewable sources, including feed-in-tariffs, investment aid, tax exemptions or reductions, tax refunds, renewable energy obligation. For biofuels, national blending obligations should be included in the baseline, as well as the ILUC amendment[1] for the RES and Fuel Quality Directives.

Beyond 2020, no additional RES targets are set and therefore no additional specific RES policy support should be included. It is important to note that even with the direct phase-out of RES support, we would still expect to see a continuance of RES investments because of:

- continued learning-by-doing, which makes some RES technologies economically competitive
- the expected increase in the EU-ETS carbon price
- extensions in the grid and improvement in market-based balancing of RES as well as maintaining priority dispatch

In recent years there have been several policies adopted with respect to energy efficiency in the EU The main ones are: Ecodesign and labelling, the Energy Efficiency Directive (EED) and the Energy Performance of Buildings Directive (EPBD). There are also some policies and measures that do not target energy efficiency directly, both lead to significant additional energy efficiency benefits. Among these policies are the EU-ETS Directive, the Effort Sharing Decision (ESD), and the CO2 standards for cars and vans.

The ESD is a legally binding national GHG emission targets in 2020 compared with 2005 for sectors not covered by the EU-ETS, but excluding LULUCF. The ESD is expected to lead to an EU-wide emission reduction of 10%. To achieve the targets the directive defines for each country a linear emission path between 2013 and 2020 which has to be satisfied each year but is subject to a number of important flexibility mechanisms, such as carry-forward of emission allocations, transfers between Member States and use of international credits.

For the CO2 standards for cars and vans the Regulations sets the following standards: for cars 95gCO2/km by 2021, for vans 147gCO2/km by 2020. Complementary to this Regulation there is a Directive on alternative fuels which supports infrastructure development for electro-mobility and the uptake of other alternative fuels (e.g. liquefied natural gas in road freight and shipping).

The internal market and competitiveness sub-system essentially establishes common rules for the completion and competitiveness of the EU energy market and it prioritizes important energy infrastructure projects including those that will lead to achieve an electricity interconnection target of 15% between EU countries by 2030.

Energy security is pursued with actions in the gas, oil and electricity areas and through general rules to ensure a stable and abundant supply of energy for European citizens and the economy.

1.2.4 Food policy pathways

This section describes the common Agricultural Policy (CAP) and the assumptions made on its future development. All policies described are considered as part of the business as usual reference scenario. We do not consider additional food related policies connected to a low carbon mitigation scenario.

CAP 2014-2020 objectives

The objectives of Common Agricultural Policy (CAP) 2014-2020 are (EC, 2013):

1. viable food production
    a. to contribute to farm incomes and limit farm income variability;
    b. to improve the competitiveness of the agricultural sector and to enhance its value share in the food chain;
    c. to compensate for production difficulties in areas with specific natural constraints.

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[1] The ILUC directive is linked to as being EU sustainability criteria for biofuels.

2. agricultural nature management and climate action
    a. to guarantee sustainable production practices and secure the enhanced provision of environmental public goods;
    b. to foster green growth through innovation;
    c. to pursue climate change mitigation and adaptation actions.
3. territorial balance
    a. to support rural employment and maintaining the social fabric of rural areas;
    b. to improve the rural economy and promote diversification;
    c. to allow for structural diversity in the farming systems.

Unlike some other EU policies, the CAP objectives are given in qualitative terms without quantitative specification.

Budget for the first and second pillar of the CAP

The CAP is composed of a first pillar (including market and income policy measures) and a second pillar (focussed on rural development measures). Measures in the first pillar of the CAP are financed by the European Agricultural Guarantee Fund (EAGF). For this purpose, Member States receive an annual national envelope.

The measures of the second pillar are financed by an EU contribution and a national contribution by Member States. The European financial contribution to the second pillar measures originates from the European Agricultural Fund for Rural Development (EAFRD). Member States are allowed to shift part of their national envelop for the first pillar to the second pillar or vice versa. This resulted in a net budgetary transfer of about 4 billion euro from the first to the second pillar of the CAP in the period 2014-2020 (EC, 2017). Finally, Member States can include a national top-up in the budget for rural development.

The end year of the NEXUS scenarios is 2050. As it is yet unknown how the CAP would look like in 2050, we assume for the time being that CAP2050 is similar to CAP 2014-2020 and that the share of the budget for financing the CAP in 2050 in the total EU budget equals that in the period 2014-2020. The total EU budget is based on the same Member State contribution rules as in the period in 2014-2020; its net size in 2050 has grown by the GDP growth in the EU28 between 2020-2050 (Table 1).

First pillar 2050	Similar to first pillar 2014-2020
Second pillar	Similar to second pillar 2014-2020
Share CAP in total EU budget 2050	Similar to current multi-annual framework (i.e. 39%)
Total EU budget 2050	EU budget (2014-2020)/7 * GDP annual growth rate (2020-2050)
Distribution of CAP budget over Member States 2050	Similar to 2014-2020
Contribution of Member States to EU budget 2050	Similar to 2014-2020

Table 1: Proposed Nexus design of CAP2050

1.2.5 Land use policy pathways

There are three major instruments to regulate land-use and land-based mitigation in the EU.
Natura 2000 is a network of nature protection areas protecting currently 18% of the land in the EU countries. It is an important component of the EU Biodiversity Strategy, aiming at halting further biodiversity loss in Europe. Other components are the maintenance of ecosystems and their services by establishing green infrastructure and the restoration of degraded ecosystems. The EU renewable energy directive sets a binding target for renewable energy production of 20% final energy consumption by

2020, and more than 27% by 2030. All countries also agreed to provide 10% of their transport fuels from renewable sources by 2020. Below the EU level target, each member state has a specific action plan. In Germany, the action plan e.g. specifies that 12% of the transport energy shall come from biofuels.
The nationally determined contributions to climate change mitigation have been set out according to article 4 paragraph 2 of the Paris Agreement. For Europe, they state that domestic greenhouse gases shall be reduced by 40% until 2030.

Greenhouse gas emissions and removal from land use, land-use change and forestry (LULUCF) has been part of climate action policy of the European Union since the start of the Kyoto Protocol (European Commission, 2017). The principle is known as the so-called “no debit rule” under which emissions from LULUCF must be compensated by an equivalent absorption of CO_2 within the sector. Up to 2020, this commitment was undertaken as part of the Kyoto Protocol, however for the period 2021-2030 the European Commission aims to integrate this into the 2030 climate and energy framework.

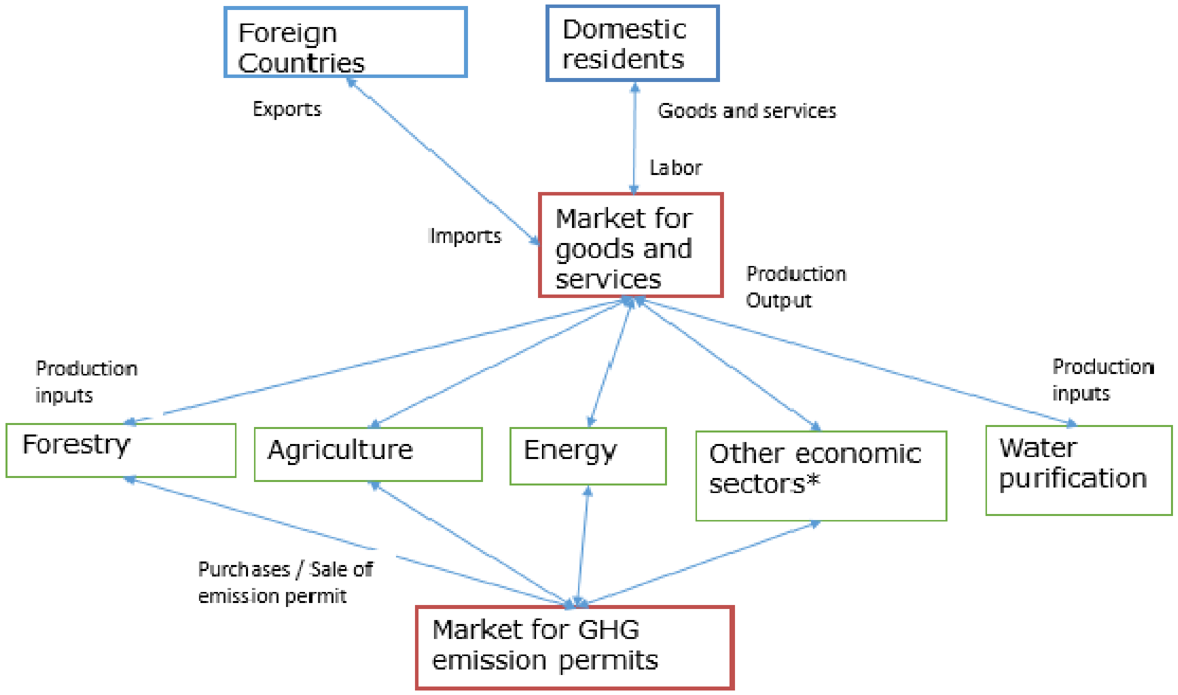
1.2.6 Water policy pathways

The broad aim of European water policy is sustainable water management in a green economy (EEA, 2012). The EU strives for resilient and healthy aquatic ecosystems that are able to provide both provisioning and regulating ecosystem services to humans. This translates into improving the ecological status of water bodies (currently 50% inadequate) by further reducing point sources and diffuse pollution, restoring hydromorphology and environmental flow, and reducing water abstraction. A key integrative policy instrument is the Water Framework Directive (2000). Recent evaluations of the WFD specifically point to the responsibility of the agricultural sector to achieve the water quality and quantity goals. This relates also to policies in the land domain like the Nitrate Directive, the Common Agricultural Policy and the EU Biodiversity Strategy mentioned above. They can contribute to land-use systems where water retention is improved or restored. Other water policy instruments are the Urban Wastewater Treatment Directive, which has already resulted in considerable progress in water purification, the Drinking Water Directive, and the Floods Directive, aiming at reducing the risks of harmful floods by increasing the resilience of river systems to climate change. The EU Roadmap to Resource Efficiency also includes several policy goals in the water domain, such as irrigation efficiency and improved water retention and purification methods in cities that are also less energy-intensive.

1.3 Conceptual model for the case study

The preliminary conceptual model for the European case study is shown in Figures 9, 10 and 11. Figures 9 and 10 show all of the relationships and entities considered in the conceptual model for the European case study. While figure 11 highlights a selection of these relationships as they relate to the energy transition to a low carbon economy.

Figure 9 shows the economic relationships between the various Nexus related entities. The arrows represent quantity flows, for example Imports flow from Foreign countries to the European market for goods and services.



*E.g. Chemicals, Industry, Services, transport etc...

Figure 9: Economic relationships between entities in the European case study

Figure 10 shows the interactions between the nexus elements that are not included in the economic interactions. These are represented in physical flows and the direction of the arrows shows the direction of the physical flow. For example water volumes flow from the “Water” nexus element to the water purification sector. The water purification sector provides water to the rest of the economic sectors and domestic residents but this is an economic relationship and so it is captured in Figure 9 and not included in Figure 10

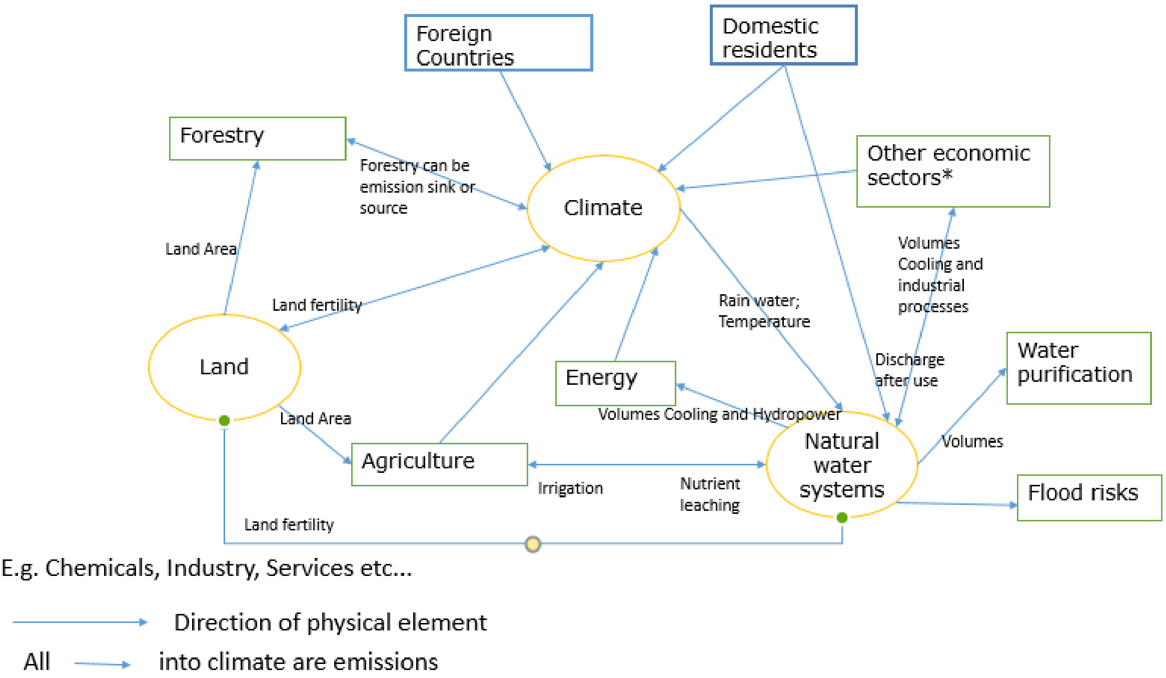


Figure 10: Physical flows and relationships between entities in the European case study that are not captured in Figure 9 above.

Figure 11 highlights the relationships shown in Figures 9 and 10 focusing in more detail on the aspects of the model that are key to the transition to a low carbon economy. Figure 11 highlights both the economic linkages to markets for the various energy products as well as the dependence on bio-mass and water as critical inputs for a cleaner energy supply.

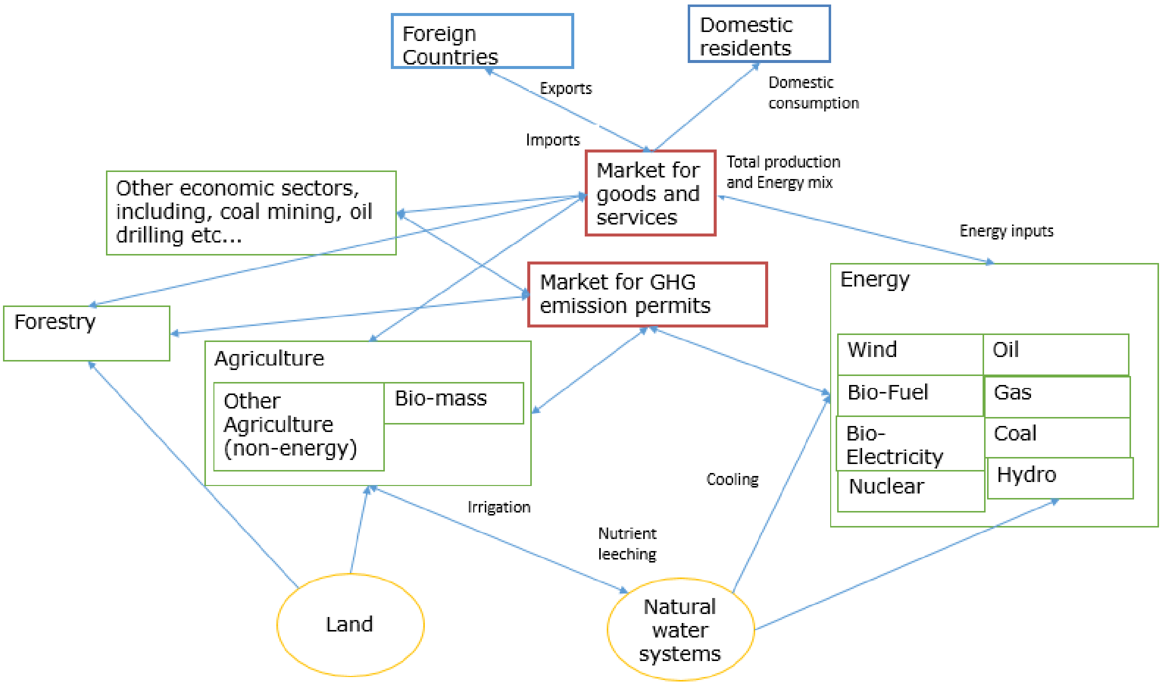


Figure 11: Both economic and physical flow as they relate to energy and emissions. All entities in figure 11 are also GHG emitters (with the exception of the markets and Raw Water), however the arrows to climate have been removed for clarity.

1.4 Use of thematic models in understanding the Nexus

1.4.1 Coverage of the Thematic models of the main Nexus interactions and challenges

All thematic models used in the European case study have a record of publishing results related to Nexus interactions at the various spatial scales, for examples please see section 3.2 of Sim4Nexus deliverable 1.3 as well as section on the global case study of the this report. Further an example of this nexus research from the CAPRI model at the on the EU 28 is included as appendix A.

Table 2 gives an indication of the possible policy interventions that could be analysed in the European case study to facilitate the transition to a low carbon economy in Europe and to ensure a relatively positive outcome from that transition for the other nexus elements, land, water and food. The policy possibilities are described through the lens of the conceptual model from section 1.3 and they form a preliminary overview of the actions (policy options) that a player might take in the serious game as well as the information (indicators) that the player receives on the outcome of the policy.

The first column on the left in table 2 is the element of the conceptual model affected by the policy, the second column is the policy option itself. The third column is the indicators i.e. information that the policy maker can receive on the effectiveness or impact of the policy. The fourth column indicates which thematic models can analysis this relationship between policy option and indicator. The fifth column shows which Nexus elements are directly affected by the policy option in column two and the final column on the right indicates which European Nexus policy objectives are affected by this policy . The Nexus policy objectives are described in Sim4Nexus deliverable 2.1 in table 7 and which has been reproduced as appendix B in this report.

Element from conceptual model	Policy options	Indicators	Included in Thematic models	Directly affects Nexus element	Related to Nexus policy objectives
Markets for goods and services	Taxes, quota	Prices, volumes	MN, E3, CP	Food, Energy	E1-6,8,10 F2,F7
Land	Land allocation policies (e.g. conservation, afforestation),	Land prices, land area	MN, IM, MP, GL	Land	L3,L4 C1,C5 W5
Water	Regulations (abstraction, discharge, emissions)	Water quality, environmental flows	GL, MP	Water	W1,W2,W6
Water	Water pricing	Volumes abstracted	GL,IM, MP	Water, Food, Energy	W3,W4 F1,F3
GHG emissions Market	Carbon price/quota	Emission Volume/carbon price	MN, CP, E3, MP	Climate	C1,C2,C5
Climate	Direct emissions regulations	Emission volume	MN, E3, CP, GL,IM, MP	Climate, Energy, Food	C1, C5
Energy	Blending Mandates	Emission volume, bioenergy production	MN, IM, MP	Energy, Climate	E1-E4,E7 C1-C3

Table 2: The policy options and indicators considered in the European case study as they connect to the conceptual model as well as the related Nexus elements and Nexus policy goals. Further the table includes the thematic models which cover the Nexus interactions: IM = IMAGE, E3 = E3ME, MN = MAGNET, MP = MAgPIE, GL = Globio, CAPRI = CP.

1.4.2 What are the main Nexus challenges foreseen in the case study?

From the analysis of the Nexus policy goals at the European level done in the Sim4Nexus deliverable 2.1 it appears that there are many synergies. Resource efficiency in particular plays a key part in the policy goals of nearly every element of Nexus. For example the goal to ensure provision of environmental public goods in the agriculture sector (F3, from appendix B) is complementary with the goal to address and mitigate water scarcity and drought (W6) as well as the goal to incentivise climate friendly land use (C5). However, there are a few areas particularly related to the transition to a low carbon economy that appear to present some nexus challenges, i.e. where achieving a policy goal in one area of the Nexus might be detrimental to a policy goal in another nexus area. The following areas will most likely be the focus of our analysis in this case study.

The first is the goal of increasing production of bio-energy including bio-fuels. This goal has potential conflicts with the goals of food security, preventing indirect land-use change (ILUC) and enhancing forest cover (afforestation). Likewise, related to the goal of preventing ILUC, converting previously uncultivated land into a source for bio-energy land could have a negative impact on the goal of ensuring provision of environmental public goods to the agricultural sector. It also has trade-offs with goals of reducing water abstraction and improving water quality and ecological status of water bodies. Bioenergy (BECCS, bioenergy with carbon capture and storage) and afforestation (carbon sequestration) are two key options to achieve negative emissions that are needed to reach the climate targets. Both need land and therefore compete with food production\food security and nature\biodiversity. Similarly, a potential conflict appears between the goal of increasing hydro-power production and ensuring good quality status of rivers and floodplain waters, as well as the provision of environmental public goods to the agricultural sector.

A third area of potential conflict is the conflict between the goal of reducing GHG emission consistent with 2 degrees of warming and the goals of maintaining economic competitiveness in trade. Reducing GHG emission through regulation or taxation imposes an extra cost to production particularly in agriculture and energy intensive production. Analysing the impact of the cost increase of mitigation policies at the European level and determining whether economic competitiveness can still be maintained without putting undue pressure on food, land and water will be a core focus of this case study.

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

The Continental European case was discussed during the internal project meeting in the Hague (October 2 & 3, 2017), as part of the joint internal workshop with the global case study and the thematic modelling teams. An external workshop is foreseen to be held in Brussels in 2018. The European case will contribute to this event through:

- Understanding the Nexus in the context of Europe, and present the key interactions between the Nexus sectors water, energy, food, land and climate.
- Present cases where the Nexus concept could strengthen coherence of policy in the EU.
- Showcase the transition towards a low-carbon economy and the contributions of the energy sector and land-based activities in mitigating climate change.

SIM4NEXUS will plan for such a science-policy event in Brussels and launch it in 2018. This workshop might be organised with other Nexus-related projects.

2 Conclusions and follow-up

This deliverable is the first step in process of model harmonization and nexus analysis that was agreed upon in the internal workshop in The Hague on the 2nd and 3rd of October 2017. We have compared the results from the thematic models on selected Nexus indicators for a qualitatively harmonized baseline scenario as well as results from a 2 degree mitigation scenario submitted by each modelling team. From the comparison we see that while there is wide agreement on the overall trends, many areas still require further harmonisation and a deeper understanding of which aspects are included in the various thematic models. This is to be expected as the thematic models are all very different, they have different structures and they have been designed for different purposes to answer different policy questions. Further we are modelling the future trends until 2050 and there are many different equally plausible pathways even within the qualitatively defined SSP2 narrative. Two examples of these differences between models are: Are crop residues, in addition to energy crops, considered as a source of bio-mass for bio-energy, and if so at what scale? Will there be improvements in emission coefficients even without a carbon price? If so how much? The analyses described in this report on the first run baseline results provide valuable progress towards scenario harmonization and understanding between the thematic models on a European scale. Further in this deliverable, beyond agreement on the general future nexus trends at the European scale until 2050, we described European nexus policies to be adopted in the baseline scenario across all models (see section 1.2).

The process of baseline harmonization of the policies and trends at the European scale is difficult but unavoidable work for creating a coherent narrative in analysing the nexus and this task will have continue in the coming months. Once this is completed it will not only serve the European case study but will be a useful for the national and regional cases studies and support communication between all case studies in the project.

The analysis and policy narratives developed in section 1.1 and 1.2 have helped to inform the preliminary conceptual model shown in section 1.3 as well as the selection of nexus policy options that could be included in the dynamic systems model in section 1.4. Taken together these two sections form a preliminary overview of the serious game at the European scale by providing the structures of the nexus interactions, the policy options available to the player and the feedback information that the player could receive on the outcome of the chosen policy.

In addition to the further harmonization of the baseline scenario and the continued development of the conceptual model, the focus of this case study in the coming half year will be to implement a harmonized mitigation scenario to restrict global warming to 2 degrees. This will be developed together with the global case as the impacts of such a mitigation scenario will depend on the behaviour of the rest of the world. Also, as European policy is implemented at the national level the mitigation scenario would preferably also be developed with inputs from the national case studies. It is expected that with implementation and analyses of the harmonized baseline and mitigation scenarios, the European case study would then be fully equipped to discuss the results with the stakeholders in Brussels.

3 References

Bijl, D. L., Bogaart, P. W., Kram, T., de Vries, B. J., & van Vuuren, D. P. (2016). Long-term water demand for electricity, industry and households. *Environmental Science & Policy, 55*, 75-86.

European Commission (EC) (2013)
Overview of CAP reform 2014-2020; Brussels, Agricultural Policy Perspectives Brief No. 5, December 2013

EC (2017)
Rural Development Programmes 2014-2020; PPT-presentation downloaded at November 17, 2013 via website: https://ec.europa.eu/agriculture/sites/agriculture/files/rural-development-2014-2020/country-files/common/rdp-list_en.pdf

European Environment Agency (EEA) (2012). European waters — current status and future challenges; Synthesis. 52 pp. ISBN 978-92-9213-341-2; doi:10.2800/63931.

Marchal, V., Dellink, R., Van Vuuren, D., Clapp, C., Chateau, J., Magné, B., & van Vliet, J. (2011). OECD environmental outlook to 2050. *Organization for Economic Co-operation and Development*.

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

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., . . . van Vuuren, D. P. (2013). A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Climatic Change, 122*(3), 387-400. doi:10.1007/s10584-013-0905-2

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*(1-2), 5-31. doi:10.1007/s10584-011-0148-z

4 Appendix A: Climate-food nexus analysis with the CAPRI model

CAPRI has been applied to assess the impact of climate change on food at the European Union level in 2030 while considering international market response. The combination of CAPRI with biophysical models allows for analysing the effects of climate-induced crop productivity changes in agri-food markets. Yield changes provided by biophysical models (WOFOST for EU and LPJmL for non-EU regions) are, therefore, introduced in CAPRI as exogenous productivity shifters.

Several scenarios are assessed to consider uncertainties surrounding climate change impacts on crop productivity. The baseline scenario assumes current climate conditions in 2030 and no climate-induced changes in crop yields between 2010 and 2030. The simulation scenarios include different crop yield shocks according to 1) climate projections from three general circulation models (GCMs) (HadGEM2-ES, MIROC-ESM-CHEM and IPSL-CM5A-LR), and 2) carbon fertilization effects (simulation with and without carbon fertilization). All scenarios assume the RCP 8.5 and a middle-of-the-road socioeconomic pathway (SSP2).

Climate-induced changes in crop yields

Results from biophysical models show climate-induced changes in crop yields. As observed in Figure 1, overall, crop yields decrease under the scenarios without carbon fertilization effects. However, a moderate increase in yields for most crops and GCMs (except for maize and potatoes) is expected with carbon fertilization effects.

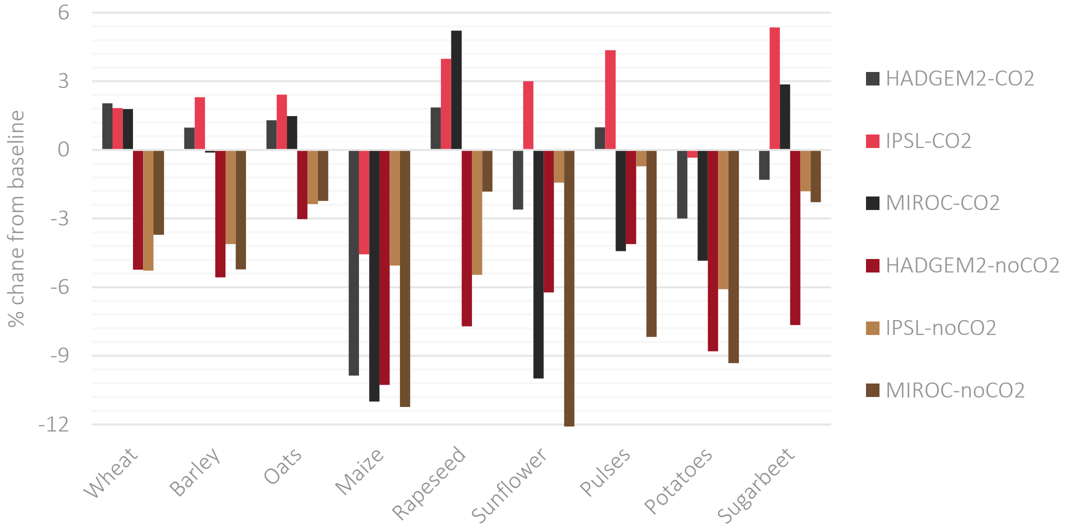


Figure 7: Climate-induced yield changes in 2030 for wheat, barley, oats, maize, rapeseed, sunflower, pulses, potatoes and sugarbeet under different simulation scenarios. Source: WOFOST model simulations.

Climate-induced crop yield changes on EU agricultural production and prices

Results provided by CAPRI highlight a significant drop in crop production despite the positive yield effect (Figure 2). Nevertheless, these aggregated results conceal divergences at the subnational level within the EU. As presented in Figure 3, cereal production decreases in most regions in scenario with carbon fertilization, while increases in scenario without carbon fertilization. Both yield changes and price effects lead to interregional adjustment in production.

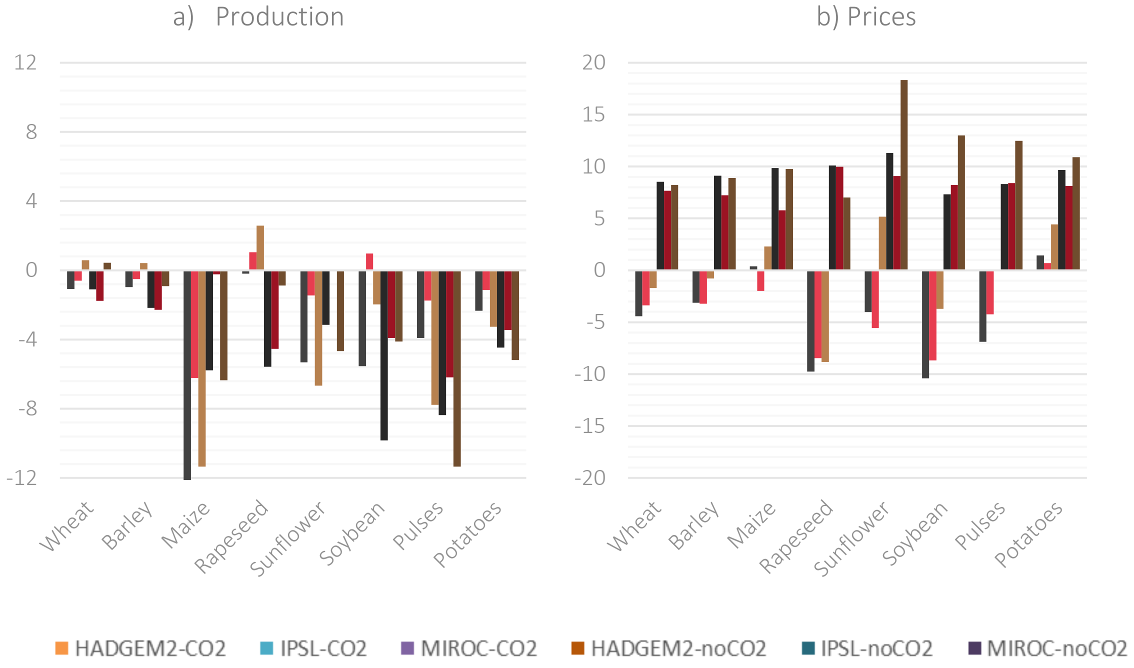


Figure 8: Changes in a) production and b) prices in the EU in 2030 for wheat, barley, maize, rapeseed, sunflower, soybean, pulses, potatoes under different simulation scenarios (% change relative to baseline values by 2030). Source: CAPRI simulations.

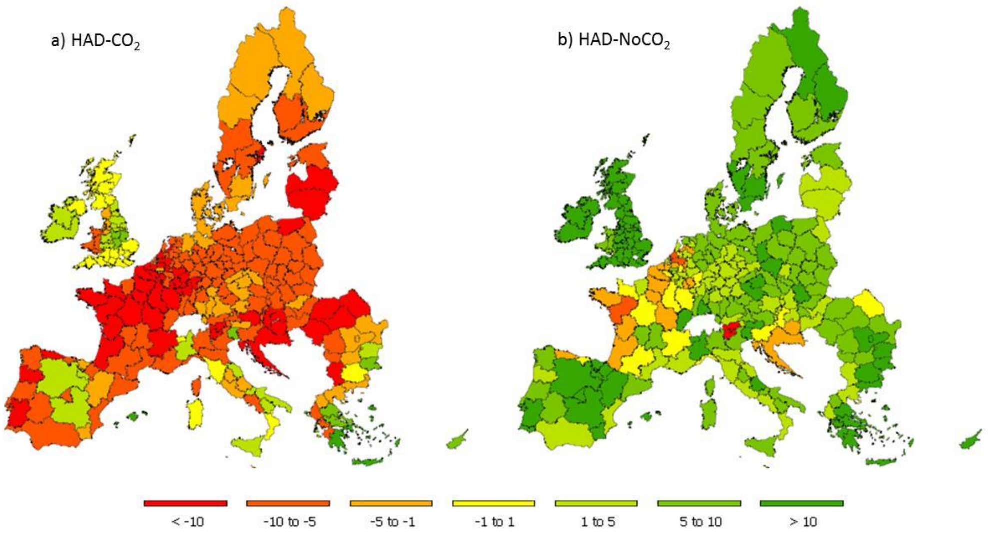


Figure 9: EU cereal production in 2030 in the scenarios a) 85_HAD-CO2 and b) 85_HAD-noCO2 (% change from baseline). Source: CAPRI model simulations.

Trade as adaptation strategy to climate change

Trade plays an important role as an adaptation strategy to attenuate climate change impacts on agriculture. For example, the EU will significantly increase (decrease) imports (exports) of wheat in the HADGEM-CO2 scenario due to a decline in EU wheat production as a consequence of climate change (Figure 4). In contrast, countries that benefit from climate change (Canada and USA) will increase wheat exports as seen in Figure 5.

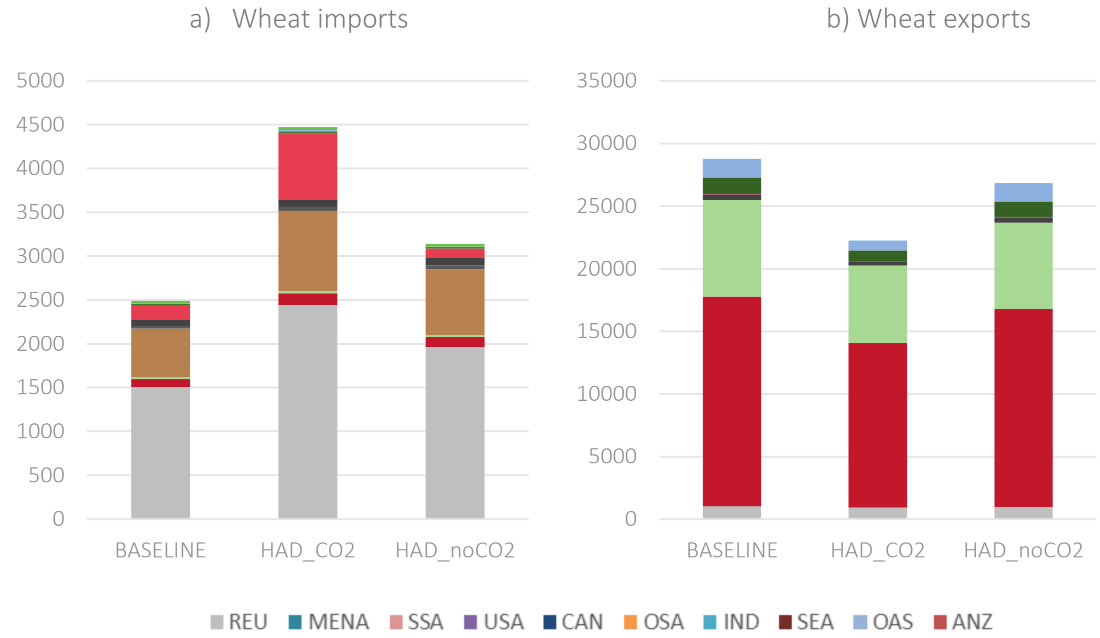


Figure 10: Wheat trade in the European Union in 2030 by trading partner. Country/Regions: Australia and New Zealand (ANZ), Other Asia (OAS), South East Asia (SEA), India (IND), Other South and Central America (OSA), Canada (CAN), United States (USA), Sub-Saharan Africa (SSA), Middle East and North Africa (MENA), Rest of European Union (REU). Values in thousand tons. Source: CAPRI model.

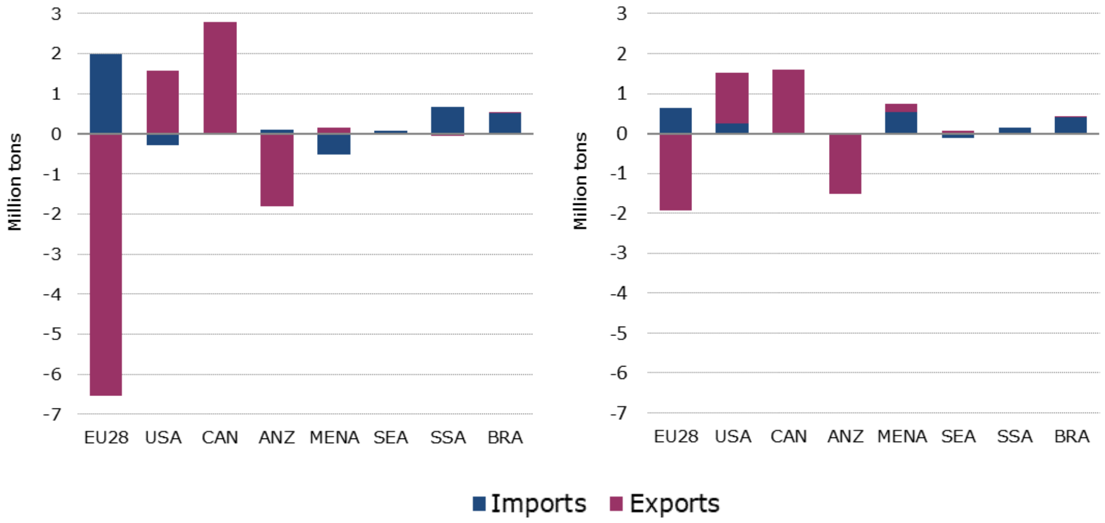


Figure 11: Wheat trade for the main traders in 2030 under scenarios a) 85_HAD_CO2 and b) 85_HAD_noCO2 (absolute change from baseline). Source: CAPRI model simulations.

Water-food nexus analysis with CAPRI

CAPRI-Water enables the analysis of the water-food nexus based on the interplay between irrigation water and food production. It has been used to analyse different scenarios in 2030 considering water pricing and irrigation efficiency. The baseline scenario assumes current situation in 2030 while the two simulations are defined as follows:

- Scenario W1: an increase in water price of 5 €/m^3 of irrigation water.
- Scenario W2: water price as in the scenario W1 and 0.1% annual increase in irrigation efficiency for both water application efficiency and water transport efficiency.

Results from these scenarios show changes in production due to the additional price for irrigation water. As shown in Figure 5, these effects vary depending upon the crops considered. For water-intensive crops (e.g., grain maize or sugar beet), the relative profitability declines given higher production costs, even though the producer price for these crops has risen. For less water demanding crops (e.g., wheat or barley), the relative profitability increases because higher production costs translate into higher market prices, which spur production.

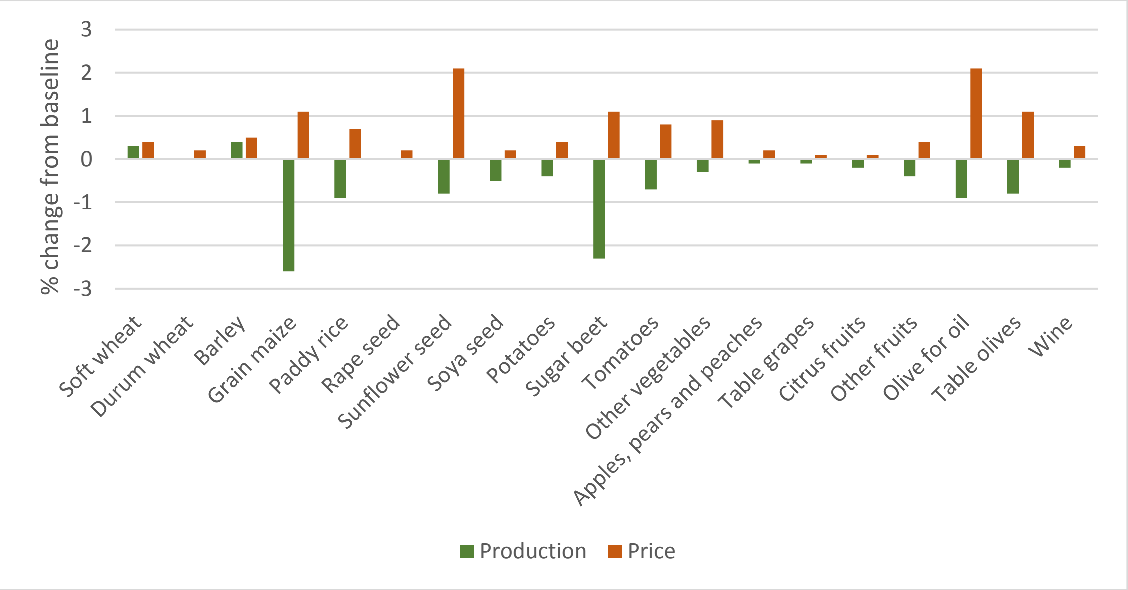


Figure 12: Effects of EU water pricing on crop producer price and crop production under scenario W2 (% change from baseline). Source: CAPRI-Water simulations.

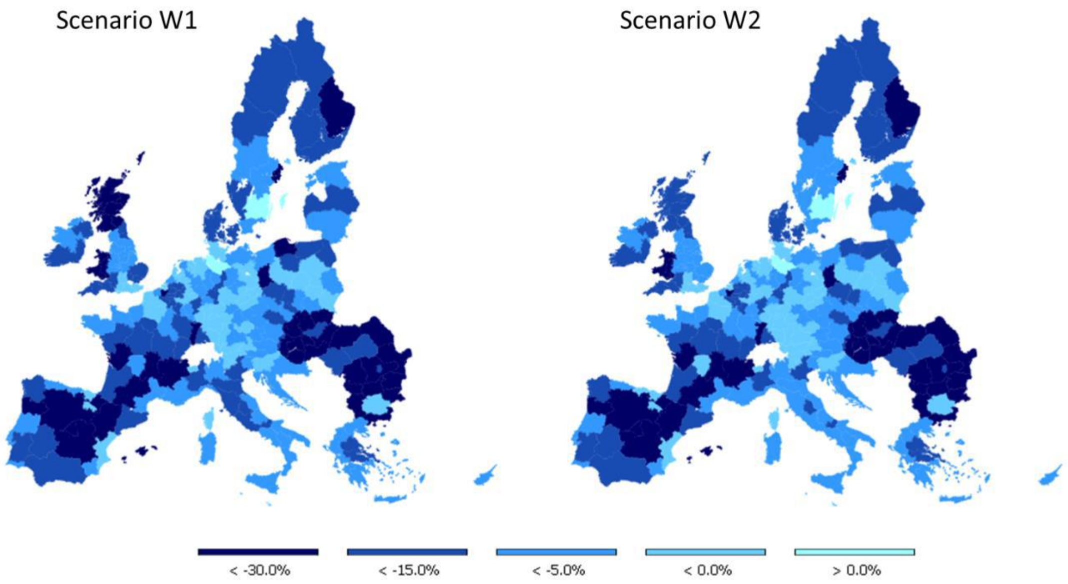
Looking at the total and irrigated area, water-intensive crops will experience limited increases (e.g., grain maize) or even decreases (e.g., rice) in total area (Table 1). A significant drop in the irrigation share is foreseen for less water-intensive crops (e.g., wheat). In scenario W1, a 24% decrease in both total EU irrigated area and irrigation water use is expected. In scenario W2, the irrigation efficiency improvement will result in a smaller decrease in irrigated area (23%) and a further reduction in water use (approximately 27%). These aggregated results hide regional differences within the EU as presented in Figures 6 and 7.

Table 1: Effects of water pricing on irrigated area and water use (EU-28, percentage change from baseline)

	BAS	**Scenario W1**			**Scenario W2**		
	Irrigation share (%)	Total land	Irrigated land	Irrigation water use	Total land	Irrigated land	Irrigation water use
Utilised agricultural area		0.1	–23.8	–24.1	0.1	–23.2	–26.9
Soft wheat	3.1	0.4	–46.1	–71.0	0.4	–45.4	–71.9
Durum wheat	7.2	0.9	–73.1	–82.5	0.9	–72.1	–82.7
Barley	5.2	0.7	–68.7	–81.7	0.7	–67.4	–81.9
Grain maize	20.8	0.4	–34.1	–33.7	0.4	–32.8	–35.5
Paddy rice	100.0	–0.9	–0.9	–1.3	–0.8	–0.8	–5.4
Rape	1.1	0.0	–50.5	–74.6	0.0	–49.9	–75.2

Sunflower	5.4	1.4	–79.4	–84.1	1.4	–78.9	–84.6
Soya	0.1	–0.4	–58.2	–70.9	–0.4	–56.4	–70.1
Potatoes	24.8	0.3	–10.1	–15.2	0.3	–9.7	–18.2
Sugar beet	22.8	–0.2	–28.8	–31.3	–0.2	–27.6	–33.1
Tomatoes	51.6	–0.1	–4.1	–4.9	–0.1	–3.9	–8.8
Other vegetables	41.6	0.0	–3.3	–4.5	0.0	–3.1	–8.4
Apples, pears, peaches	27.2	0.0	–1.8	–2.5	0.0	–1.7	–6.6
Other fruits	33.4	0.1	–6.7	–12.0	0.1	–6.4	–15.4
Citrus fruits	68.6	–0.1	–1.8	–3.0	–0.1	–1.7	–7.0
Table grapes	42.4	0.0	–0.4	–0.5	0.0	–0.4	–4.8
Olives for oil	23.1	0.2	–8.5	–9.8	0.2	–8.2	–13.3
Table olives	28.1	0.0	–7.7	–8.1	0.0	–7.4	–11.8
Wine	15.7	0.0	–2.8	–5.2	0.0	–2.7	–9.1

Source: CAPRI-Water simulations.


Scenario W1

Scenario W2

Figure 13: Total irrigation land at the subnational level within the EU in scenarios W1 and W2 (% change from baseline). Source: CAPRI-Water simulations.

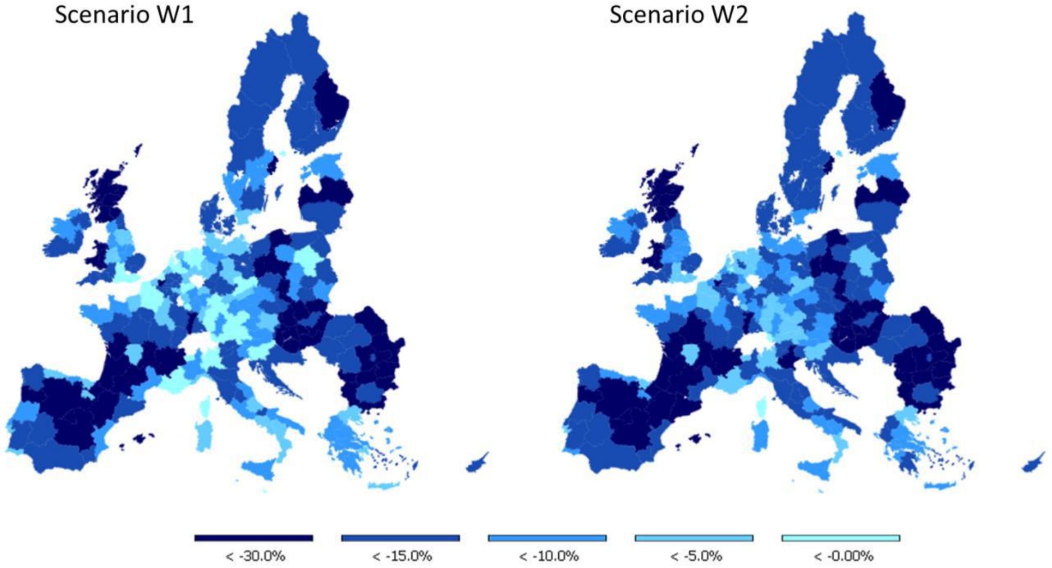


Figure 14: Irrigation water use at the subnational level within the EU in scenarios W1 and W2 (% change from baseline). Source: CAPRI-Water simulations.

Climate-water-food nexus analysis with CAPRI

CAPRI-Water provides detailed insights into the specific climate change impacts in European agriculture when considering irrigation. CAPRI-Water incorporate different yield shocks for irrigated and rainfed crops in EU regions. For non-EU regions, as irrigation is not defined explicitly, the yield shock is introduced as an average.

In line with the AGMIP standardized scenario assumptions within the EU (AGMIP S6 scenario), three different climate change (CC) scenarios have been used to analyse the potential impacts of climate change on food in 2030:

- CC: considers RCP 8.5, the GCM HadGEM2-ES and crop yield changes from DSSAT. No change in water availability from the baseline and no change in irrigation efficiency is assumed.
- CCLessW: 30% decrease in irrigation water availability from the baseline, no change in irrigation efficiency.
- CCIrrEff: 30% decrease in irrigation water availability from the baseline and annual irrigation efficiency improvement of 0.1% in both water application efficiency and water transport efficiency.

The results from scenario CC indicate that, despite the diverging crop yield changes across crops and regions, the overall effect on production is negative, leading to market price increases both worldwide and for the EU (Figure 8).

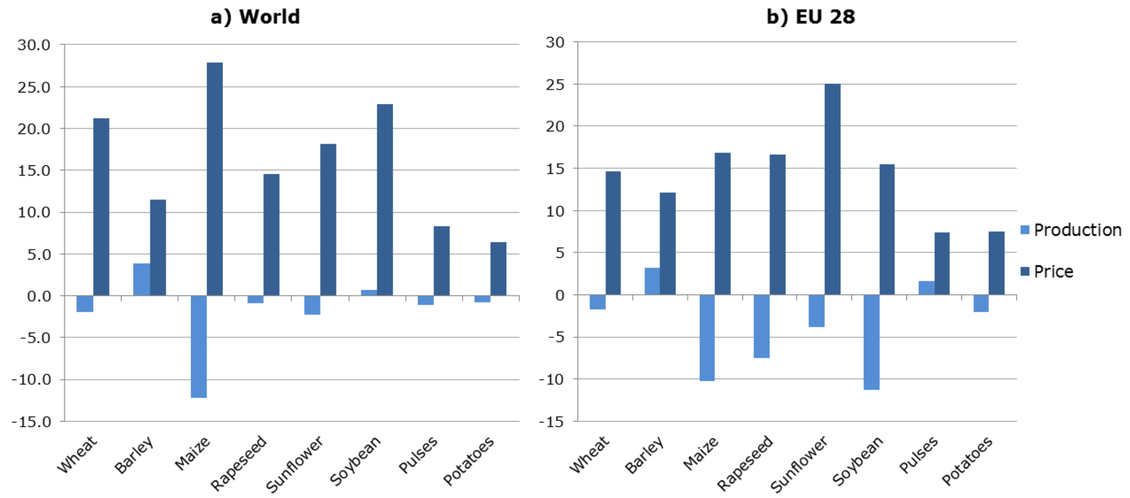


Figure 15: Production and price effects at the world and the EU-28 level under scenario CC (% change from baseline)

As shown in Figure 9, yield effects are more negative for rainfed than for irrigated activities, leading to substitution of rainfed for irrigated areas. Irrigation seems, thus, to play an important role in adapting to climate change.

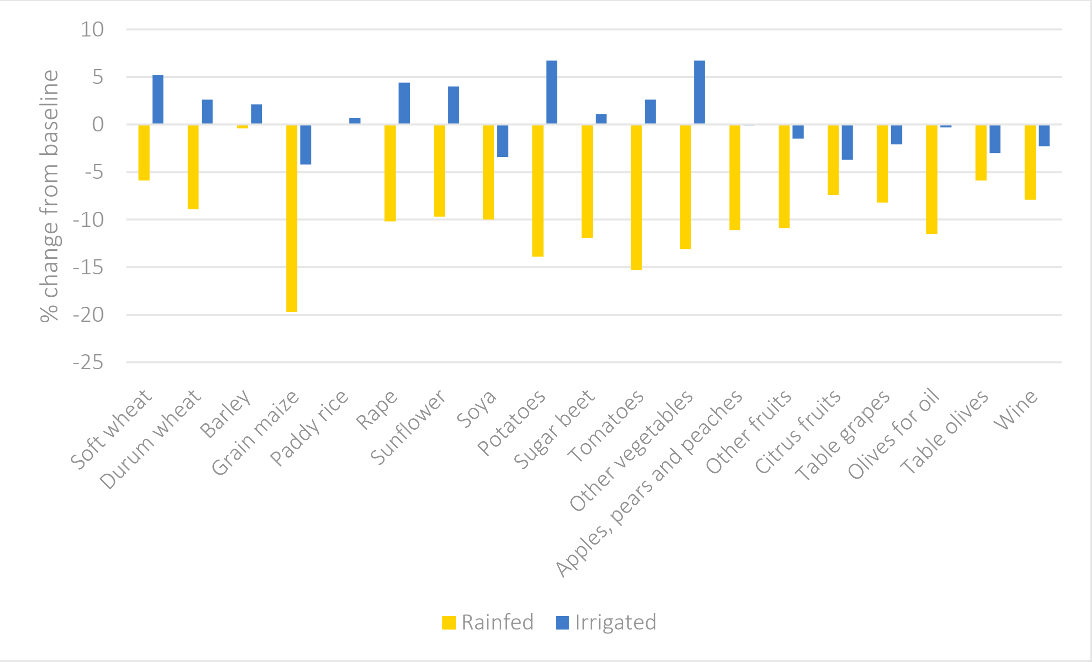


Figure 16: Effects of climate change on EU crops yields under scenario CC (% change from baseline). Source: CAPRI-Water simulations.

Climate-induced changes in yields and prices will lead to an increase in irrigated land and water devoted for crops with high water productivity (e.g., maize, vegetables) while it will decrease for crops with lower water productivity (e.g., wheat), as observed in Table 2.

Compared to scenario CC, in the scenario with reduced irrigation water availability (CCLessW), irrigated area and water use will drastically decrease (23% and 25% respectively). When considering an increase in irrigation efficiency (scenario CCIrrEff), the decrease in irrigation water use is similar to scenario CCLessW (25%). However, this decline in irrigation water use is achieved with a much lower reduction in irrigated area (19%) (Table 2). Therefore, improving irrigation efficiency partially counterbalance negative production effects from reduced water availability.

Table 2: Effects on EU irrigated area and water use (% change from baseline)

	Scenario CC			Scenario CCLessW			Scenario CCIrrEff		
	Total land	Irrigated land	Water use	Total land	Irrigated land	Water use	Total land	Irrigated land	Water use
Utilised agricultural area	1.1	6.0	5.2	1.2	−22.8	−25.1	1.2	−19.7	−25.1
Soft wheat	4.6	−2.7	−5.3	5.1	−47.1	−67.9	5.0	−43.4	−65.2
Durum wheat	−1.4	−27.0	−39.2	−1.2	−85.3	−88.7	−1.1	−84.6	−89.0
Barley	3.4	−13.9	−15.7	3.9	−59.2	−67.4	3.9	−54.5	−64.2
Grain maize	4.4	10.3	7.4	3.5	−33.6	−33.4	3.7	−28.8	−31.8
Paddy rice	0.7	0.7	0.8	−3.4	−3.4	−4.6	−2.7	−2.7	−7.8
Rape	2.7	−18.0	−16.2	2.8	−58.8	−73.7	2.8	−56.2	−71.3
Sunflower	5.3	5.1	3.7	6.3	−54.4	−61.0	6.2	−48.7	−57.3
Soya	−1.6	37.6	49.9	−1.5	−35.5	−25.8	−1.5	−28.8	−23.0
Potatoes	−1.1	35.3	28.5	0.6	8.1	−4.4	0.3	11.7	−4.3
Sugar beet	5.6	−29.0	−30.2	6.0	−57.8	−58.3	5.9	−56.7	−59.3
Tomatoes	−0.4	6.8	6.8	−1.1	−10.4	−12.9	−0.9	−7.9	−14.0
Other vegetables	0.1	19.0	16.8	0.1	7.5	2.1	0.1	9.1	−0.5
Apples pears and peaches	0.1	5.6	4.6	0.0	0.2	−1.9	0.1	1.1	−5.1
Other fruits	0.1	5.3	2.7	0.2	−7.9	−21.1	0.2	−5.8	−21.1
Citrus fruits	0.1	1.0	1.3	−0.2	−0.7	−1.6	−0.1	−0.5	−5.4
Table grapes	0.0	3.4	3.3	0.0	2.0	1.6	0.0	2.2	−2.6
Olives for oil	0.0	11.8	12.4	0.8	−17.7	−19.3	0.7	−13.8	−18.8
Table olives	0.0	2.1	2.0	0.3	−33.7	−33.0	0.2	−28.7	−31.4
Wine	−0.1	4.7	3.0	−0.1	0.6	−5.4	−0.1	1.2	−8.3

Source: CAPRI-Water simulations.

References:

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

Blanco M, Ramos F, Van Doorslaer B, Martínez P, Fumagalli D, Ceglar A, Fernández FJ (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

Martínez P, Blanco M, Van Doorslaer B, Ramos F, Ceglar A (2017). What role will climate change play in EU agricultural markets? An integrated assessment taking into account carbon fertilization effects. Spanish Journal of Agricultural Research, 15(3), e0115. doi: https://doi.org/10.5424/sjar/2017153-9899

5 Appendix B: Policy objectives for the assessment of interactions in the WLEFC-nexus

Table B1: Selected EU policy objectives for the assessment of interactions in the WLEFC-nexus identified in Sim4Nexus deliverable 2.1 (table 7 from D2.1).

EU WATER POLICY	
W1	Achieve good water quality status
W2	Ensure sufficient supply of good quality surface water and groundwater for people's needs, the economy and the environment
W3	Increase water efficiency
W4	Reduce water consumption
W5	Assess and manage flood risk and mitigate flood effects
W6	Address and mitigate water scarcity and drought
EU ENERGY POLICY	
E1	Increase production of biofuel
E2	Increase consumption of biofuel
E3	Increase production of energy from biomass (excluding biofuel)
E4	Increase consumption of energy from biomass (excluding biofuel)
E5	Increase hydro-energy production
E6	Increase hydro-energy consumption
E7	Increase energy efficiency
E8	Reduce energy consumption
E9	Push forward important energy infrastructure projects (grid, network, interconnectors, etc.)
E10	Achieve energy supply security
EU LAND USE POLICY	
L1	Restoring degraded soils to a level of functionality consistent with at least current and intended use
L2	Prevent soil degradation
L3	Maintain and enhance forest cover
L4	Prevent indirect land use change from nature to productive use
EU FOOD AND AGRICULTURE POLICY	
F1	Contribute to farm incomes (if farmers respect rules on environment, land management, soil protection, water management, food safety, animal health and welfare - 'cross-compliance')
F2	Improve competitiveness of agricultural sector (including sector-specific support and international trade issues)
F3	Ensure provision of environmental public goods in the agriculture sector
F4	Support rural areas economy (employment, social fabric, local markets, diverse farming systems)
F5	Promote resource efficiency in the agriculture, food and forestry sectors
F6	Reduce and prevent food waste
F7	Reduce intake of animal protein in human diet (non-binding objective; expressed intention on a research phase)
EU CLIMATE POLICY	
C1	Reduce GHGs emissions to keep global temperature increase within 2 degrees
C2	Increase efficiency of the transport system
C3	Support the development and uptake of low-carbon technology
C4	Support the development and uptake of safe CCS technology
C5	Incentivize more climate-friendly land use
C6	Promote adaptation in key vulnerable EU sectors and in MSs

Horizon 2020 Societal challenge 5

Climate action, environment, resource

Efficiency and raw materials

D5.2: THE MAIN NEXUS CHALLENGES FOR THE GLOBAL CASE’

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Table of Contents

Glossary / Acronyms

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

SDG	SUSTAINABLE DEVELOPMENT GOALS
GHG	GREENHOUSE GAS
GDP	GROSS DOMESTIC PRODUCT
SSP	SHARED SOCIO-ECONOMIC PATHWAY
RCP	REPRESENTATIVE CONCENTRATION PATHWAY
REDD	REDUCTION OF EMISSIONS FROM DEFORESTATION AND FOREST DEGRADATION
TPES	TOTAL PRIMARY ENERGY SUPPLY
IEA	INTERNATIONAL ENERGY AGENCY
GAEZ	GLOBAL AGRO-ECOLOGICAL ZONES
IIASA	INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
FAO	FOOD AND AGRICULTURE ORGANIZATION
UN	UNITED NATIONS

1 Introduction

The objective of the global case study is to identify and assess nexus issues at the global scale. The main tool for these analyses are the six participating thematic models: E3ME-FTT, MAGNET, CAPRI, IMAGE-GLOBIO, OSeMOSYS and MAgPIE. Therefore, the focus of the global case lies on nexus issues that are represented by these models. Specifically, these are the interactions between the water, land, food, energy and climate systems.

The aim of this deliverable is to present an overview of the nexus challenges using scenario data of each model. The scenario analyses have been discussed during a workshop in The Hague in October 2017, where also a first draft of a conceptual model was developed. This draft was used to develop a first version of the conceptual model of the global case which is presented in this deliverable. In addition, model-specific global case studies are presented to highlight a selection of nexus issues and to provide more background information on implementations of the models.

The deliverable is structured as follows. Section 1.1 presents an overview of the Nexus challenges based on the scenario data that were shared between the modelling groups. Section 1.2 elaborates on the scenarios that have been used for these analyses providing more background information on the model procedure and underlying scenario assumptions. Section 1.3 presents the first version of the conceptual model of the global case. In section 1.4 the model-specific global case studies are presented to provide more detail on nexus studies as performed by the participating thematic models.

1.1 Description of the Nexus challenges

1.1.1 Food

In order to meet the demand of a growing and increasingly wealthy world population, food demand can be expected to strongly increase in the coming decade. This will be a challenge to provide in particular the least developed countries with sufficient food security (SDG2: No Hunger), but also to change diets in high-income countries from unbalanced to healthy diets (SDG3: Good Health and Wellbeing), and to avoid wasting behaviour in households and the supply chain (SDG12: Responsible Consumption and Production). At the same time, food production is the primary interface between the human economy and the environment: It is responsible for about one third of global land use (Nexus Element Land, SDG 15: Life on Land), two thirds of annual freshwater withdrawals (Nexus element water, SDG 14: Life below water), and one quarter of global greenhouse gas emissions (Nexus element climate, SDG13: Climate action). Food production may in the future strongly compete with the cultivation of bioenergy, which is one of the climate mitigation options to remove CO_2 emissions from the atmosphere (Nexus element water, SDG7: Affordable and clean energy). Finally, food production will also be strongly affected by the developments in the other Nexus elements, in particular by climate impacts.

Within SIM4NEXUS, currently five models of the global case study cover food consumption explicitly: IMAGE, MAgPIE, MAGNET, OSeMOSYS and CAPRI. In a first experiment, we compare the business-as-usual projections for per-capita calory availability (including food intake and household waste) between the models, as well as the impact of a 2° mitigation scenario on food demand (Fig1). The starting points differ due to different coverage of product categories. Per-capita demand in IMAGE, MAGNET, OsEMOSYS and CAPRI is further increasing due to population and income growth (Figure 1). MAgPIE projects stagnating global per-capita demand. While demand is still strongly increasing in developing countries, per-capita demand declines in high-income countries due to demographic change with lower intake of an elderly population. Also, countries with lower per-capita demand also tend to have an over-proportional population growth, and receive a larger weight in the global total. In contrast, IMAGE and MAGNET assume a stabilization of global per-capita calories after 2030. The high level of per-capita demand indicates that food waste in households will further increase as it exceeds plausible intake rates.

Climate change mitigation can be expected to increase food prices for various reasons: the scarcity of land and water increase due to competition with afforestation and bioenergy, the production costs will increase due to implementation of mitigation practices, and finally, the tax on residual emissions will be rolled over to consumers. But on the other hand, climate change mitigation will also reduce climate impacts on crop yields, which could lower crop prices. The consequences of rising prices on per-capita consumption has been estimated with MAGNET, and for the first time also with a new version of MAgPIE. MAgPIE also includes different climate impacts between mitigation and no-mitigation scenarios into the analysis. The impacts are considerably higher in IMAGE than in MAgPIE, which can be traced back to differences in elasticity parameters and the climate impacts.

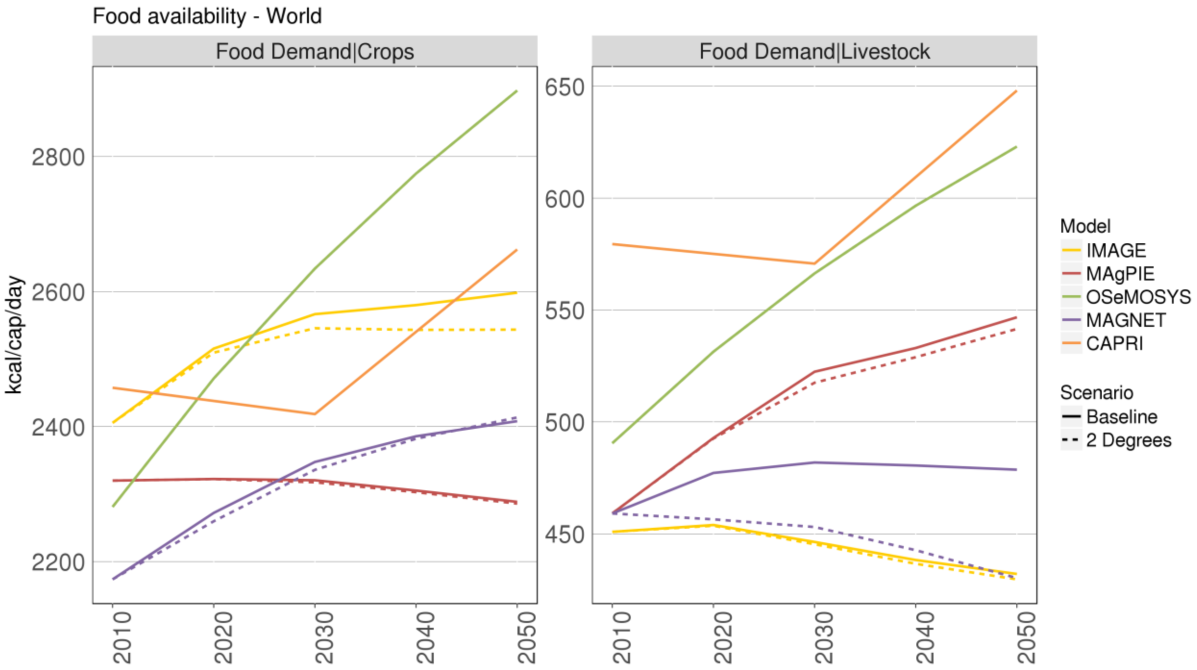


Figure 1: food availability for the period 2010-2050 in the reference and 2 degree scenarios

Within food consumption, animal products play a particular role due to their higher resource requirements. Again driven by the strongly rising incomes in the low-income countries, the per-capita calorie demand increases most strongly in OSeMOSYS, followed by MAgPIE and MAGNET. In IMAGE, the demand for livestock products saturates and then slightly declines, as high population growth in low-income regions lowers global average livestock product consumption. IMAGE, MAgPIE and MAGNET also simulate the effects of climate change mitigation on per-capita demand and find a price-related decline in the consumption of animal products, mainly in low-income regions.

The increasing per-capita demand for crop and in particular livestock products, along with a growing population leads to a strong increase in food and feed production (Figure 2). An additional pressure is the demand for bioenergy, in particular if a mitigation target is set. In total, our simulations indicate that agricultural production has to double until 2050 relative to 2010 and may even triple if large-scale bioenergy is cultivated for climate change mitigation.

Figure 2: agricultural production in 2010, 2030 and 2050 in the reference and 2 degree scenarios

1.1.2 Water

Global water problems can be summarized as: 'too little, too much, or too dirty'. SDG 6 aims at 'ensuring availability and sustainable management of water and sanitation for all'. Various environmental assessment have indicated that a key environmental problem in the next decades could be increasing water scarcity (Bijl, Bogaart, Kram, de Vries, & van Vuuren, 2016; Marchal et al., 2011). Water scarcity can be a threat to ecosystems, food production, rural livelihoods and electricity production. Agriculture is the dominant sector in water demand, most importantly through large-scale irrigation. In addition, the electricity, industry and municipal sectors create substantial water demand. Especially in more arid regions and during dry periods of the year, overall demand and competition between different sectors can cause scarcity. Water scarcity in turn will have effects in other parts of the water-land-food-energy-climate nexus. Water withdrawals from groundwater affect biodiversity on land (SDG 15: Life on land), while extraction from lakes and rivers including reservoir constructions disturb the natural flow regime for fish and other biota (SDG 16: Life under water). Apart from water quantity, water quality is a still increasing problem, making water unsuitable for human use (SDG 6.1: safe drinking water, and 6.3: Improve water quality) or for the biota dependent on it (SDG 6.6: Protect and restore water-related ecosystems). Climate change combined with disruption of natural water systems will increase the risk of flooding for millions of people (SDG 11: Safe and resilient cities).

From the thematic models considered in the global case, IMAGE, MAgPIE and OSeMOSYS calculate water demand from irrigated agriculture (Figure 3). Global irrigated water demand is uncertain, as is evident from the difference in starting point in 2010. IMAGE shows a modest increase from 2010 to 2050, which is partly due to limited increases in irrigated area and the SSP assumption that climate change impacts are not taken into account. MAgPIE shows a stronger increase, especially from 2020 to 2050 due to larger increases in irrigated area. OSeMOSYS shows a much stronger increase up to four times current levels due to strong expansion of irrigation. Also, a clear difference is observed between the Baseline scenario and the 2 Degrees scenario where climate change mitigation policies lead to increased water use. This is due to agricultural intensification as demand for land-based mitigation such as bioenergy production and afforestation leads to substantial competition between land use sectors resulting in higher investments in agricultural intensification and irrigation expansion.

IMAGE and OSeMOSYS also project water withdrawal in the electricity and industrial sectors. Both sectors show substantial increases due to increased demand for energy and industrial production. Water withdrawal for electricity generation shows a strong decrease in the 2 degrees scenario in IMAGE, as stringent climate policy causes coal-fired power plants to go out of service reducing demand for cooling water. IMAGE is the only model that projects water withdrawal for the municipal sector. This is most importantly household use, which increases substantially due to continued population growth and increasing GDP per capita.

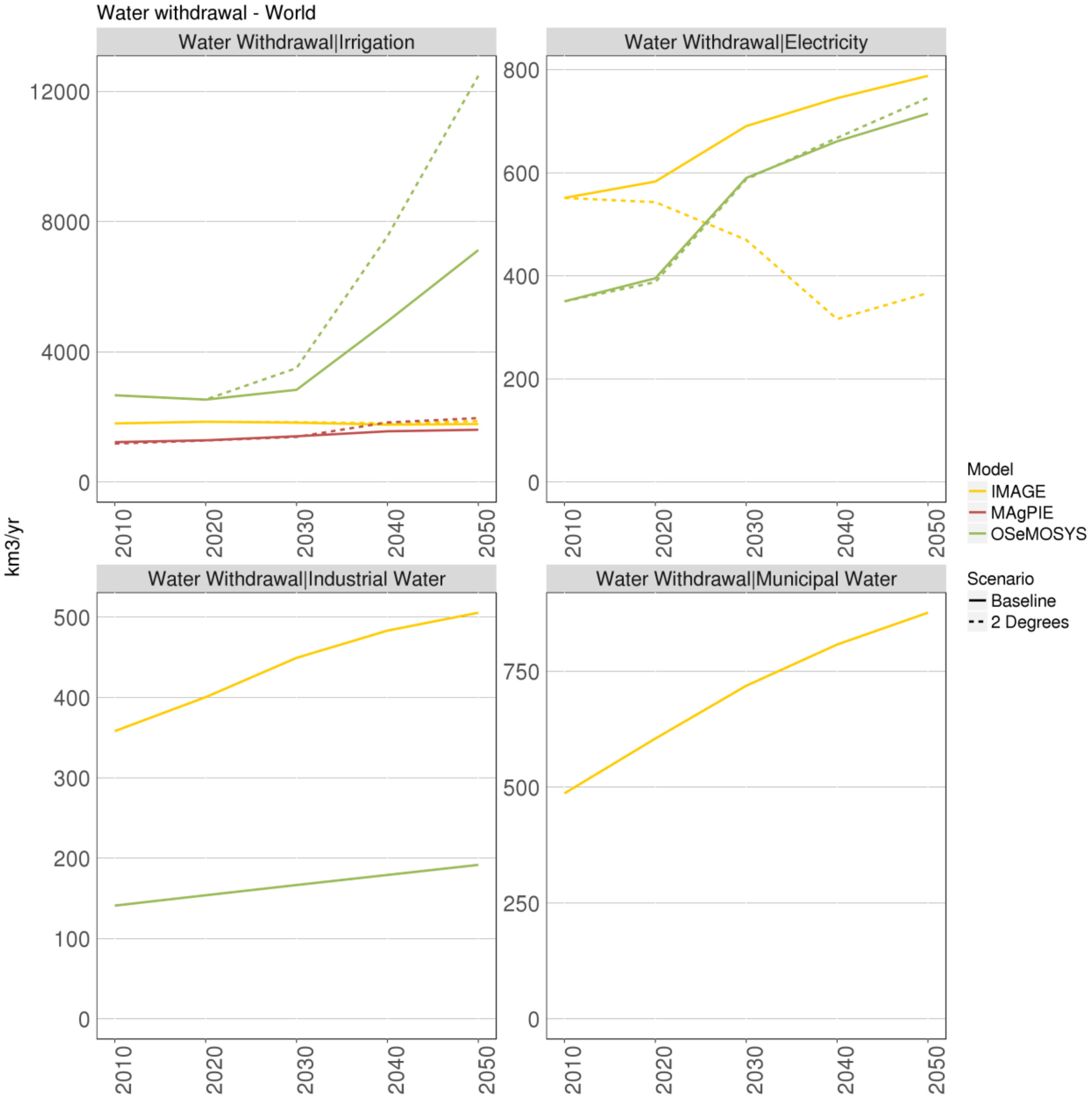


Figure 3: water withdrawal for four sectors: irrigation for agriculture, electricity, industry and municipal water use

Water quality and biodiversity are covered by the IMAGE-GLOBIO model. The model projects a further decrease of aquatic biodiversity intactness in 2050 to, on average, about 70% of the natural value in the temperate climate regions and 50% in the tropical realms. This decline is for about ¾ due to direct and indirect effects of land-use changes (including eutrophication) and for ¼ to hydrological disturbances like dam construction and water extraction. Eutrophication will increase the number of lakes with harmful algal blooms above the WHO standard to …%, and increasing algal bloom problems in coastal waters e.g. leading to fish kills. Increase in water temperature due to climate change will aggravate these problems.

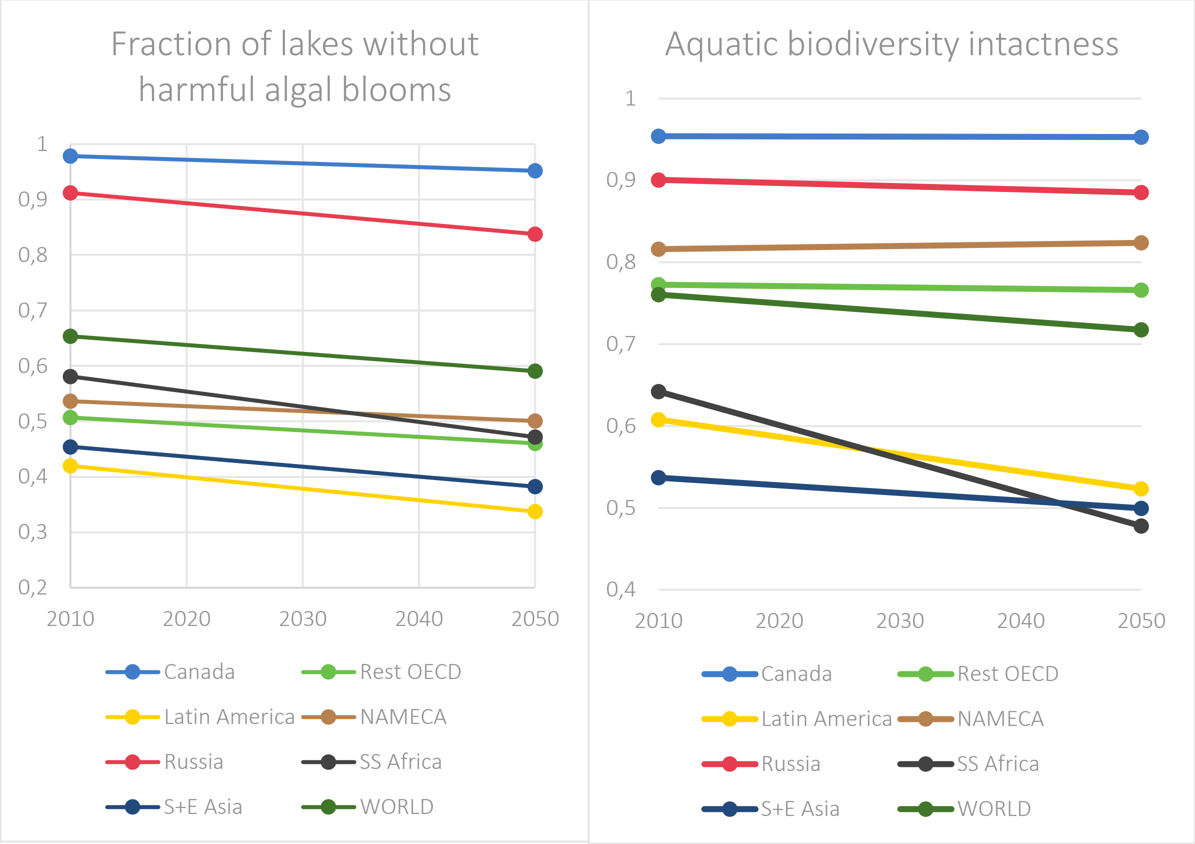


Figure 4: aquatic biodiversity indicators for the baseline scenario according to IMAGE-GLOBIO

1.1.3 Land

Figure 5 summarizes the change in land use between 2010 and 2030 as well as between 2010 and 2050 for the SSP2 baseline scenario and also for the 2 degree mitigation scenario. Five thematic models have been able to provide results on land use change for the baseline scenario: IMAGE, MAgPIE, OSeMOSYS, MAGNET and CAPRI. The first four models have also provided results for the 2 degree mitigation scenario. IMAGE, MAgPIE and OSeMOSYS report changes to multiple types of land use, while MAGNET and CAPRI report changes in land use strictly as it relates to agriculture.

The baseline scenario for all models show an increase in cropland in 2030 and a further increase in 2050. The models show varying results for the changes in other type of land use however. Of the three models that report changes to pasture land, IMAGE and MAGNET show an increase in pasture land as production rises to meet the increase in demand. MAgPIE reports a significant decrease in global pasture land. In Figure 2 showing global agricultural production MAgPIE reports little or no increase in the production of livestock. Therefore an increase in the livestock efficiency with respect to land would account for the reduction in the use of pasture land.

Similarly IMAGE and OSeMOSYS report a decrease in the forest cover and other land while MAgPIE reports an increase.

In the 2 degree scenario, the three models which report on pasture land (IMAGE, MAgPIE, MAGNET) show a decrease in pasture land compared with the baseline SSP2 scenario. All models the show an increase in cropland compared to the baseline scenario with the exception of MAgPIE which shows a modest decrease. In MAGNET the increase in demand for cropland is driven by the reduction in yields from less fertilizer use which is a large emitter of N2O. Also in MAGNET the dairy and meat cattle sectors are reduced as they are a large producer of CH4 emissions reducing the demand for pasture land.

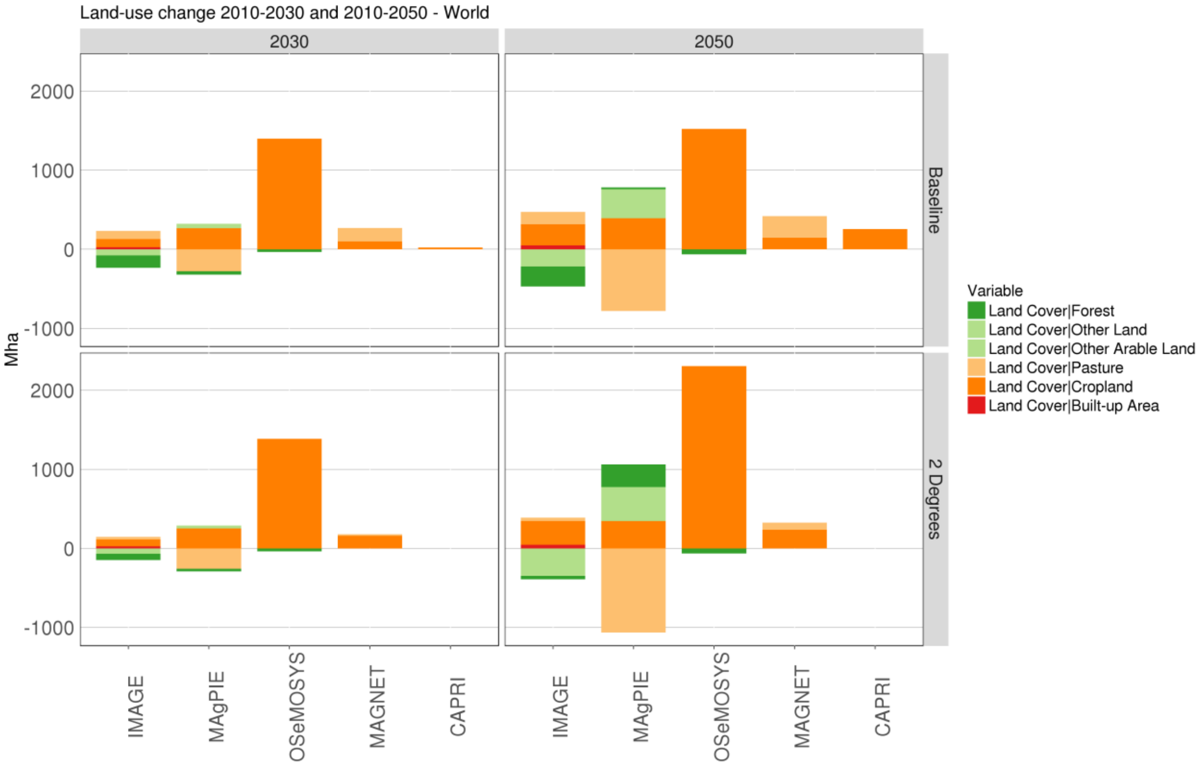


Figure 5: land-use change for periods 2010-2030 and 2010-2050

1.1.4 Energy

To eradicate poverty and ensure social and economic development of human society, one important step is to grant universal access to electricity and energy services (Nerini et al, 2017; UN DESA, 2014). The (UN) Sustainable Development Goal number 7: “Ensure access to affordable reliable, sustainable and modern energy for all” and the related action plan outlined in the Agenda 2030 stand for reminding and stimulating us in engaging for the substantial changes that are required for achieving this goal.

The development of the energy system in this direction will increase the overall demand for energy, which will foster the use of natural resources (e.g. water and land for biomass production) for enabling the system to meet this demand. The energy sector is already significantly affecting food and water security as well as the provision of ecosystem services (Nerini et al, 2017). Water for instance is used for cooling thermal processes in the power generation sector as well as primary energy source for hydropower plants, thus affecting its availability for other purposes, forcing people’s displacement, compromising ecological values like fish migration and reducing sediment transport. Land resources have been increasingly allocated to biofuel production, with large impact on maize and wheat demand worldwide, as well as on food prices (Howells et al, 2013; Renzaho et al, 2017). In fact, it is shown that food prices have constantly increased since 2000 in close relation with the increase of biofuel and food production costs (Renzaho et al, 2017).

To ensure the restoration and preservation of the environment, as well as its sustainable use in the future, a Nexus approach is fundamental for finding a new balance in optimally managing the resources available and addressing the different human needs.

Within the SIM4NEXUS global case study, the following four different models were used to analyse the long-term evolution of the energy sector worldwide through an integrated assessment: E3ME, IMAGE, OSeMOSYS and MAgPIE. Figure 6 presents an overview of the Total Primary Energy Supply (TPES) mix estimated by the different models, for the baseline and a 2C scenarios, up to 2050.

Looking at the baseline scenario results from the different models, all of them show an increase over the long term future. This seems to drive the system towards investing on power generation coming from renewable energy sources, namely biomass, hydropower, solar and wind energy. However, a large share of production is still expected to rely on coal and gas. Particularly, in IMAGE and OSeMOSYS, coal and gas are expected to represent still 60% of the TPES in 2050. This can be due to the lower costs associated to these technologies.

Looking at the 2°C Scenario instead, where climate change mitigation policies are considered by setting constraints on the level of greenhouse gas (GHG) emissions allowed from the system, it is worth noticing that all the models present a significant increase in nuclear and biomass power generation, together with a significant decrease in coal, oil and gas generation. This can be explained considering that nuclear power plants have a lower level of emissions compared to traditional fossil fuel-based power plants.

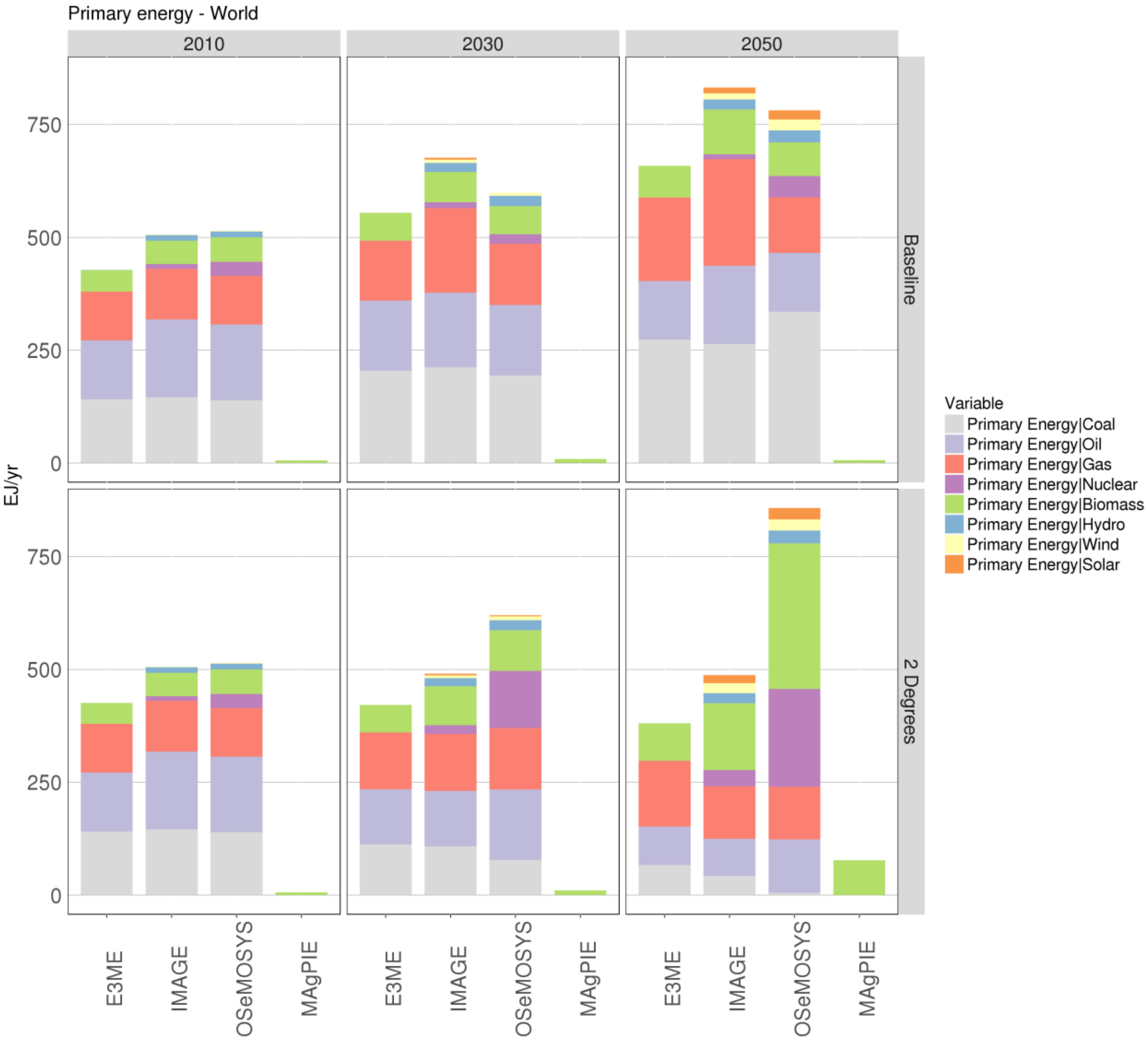


Figure 6: primary energy production per energy carrier in 2010, 2030 and 2050

1.1.5 Climate

Figure 7 summarises the Global CO_2 emission results in the baseline and 2-degree scenario. E3ME, IMAGE, OSeMosys, MAGNET and MAgPIE were able to provide results for the baseline. E3ME, IMAGE, OSeMOSYS and MAgPIE also provided CO_2 emission results for the 2-degree scenario. MAgPIE was able to provide emission only for land-use only, while the other model provided energy emissions and, in some cases, process emissions.

Historical CO_2 emission results are very similar across the different models used, with the exception of OSeMosys, where energy-related CO_2 emission are reported a bit higher compared to other models. The baseline CO_2 emission trends are also very similar across models, when looking and energy-related emissions. OSeMosys energy-related CO_2 emission projections in 2050 are somewhat higher compared to results from other models. Looking at baseline land-use CO_2 emissions, E3ME and IMAGE projections are very similar over the forecast period, however MAgPIE projections are significantly lower.

Looking at the 2-degree scenario results, we see that the energy-related CO2 emission reduction is of similar scale both in E3ME and IMAGE. OSeMosys CO_2 emission levels are somewhat higher when compared to IMAGE and E3ME results. IMAGE also estimate a reduction on CO_2 emissions from land-use. This is not the case in E3ME, where changes in land-use emissions cannot be captured in the modelling yet.

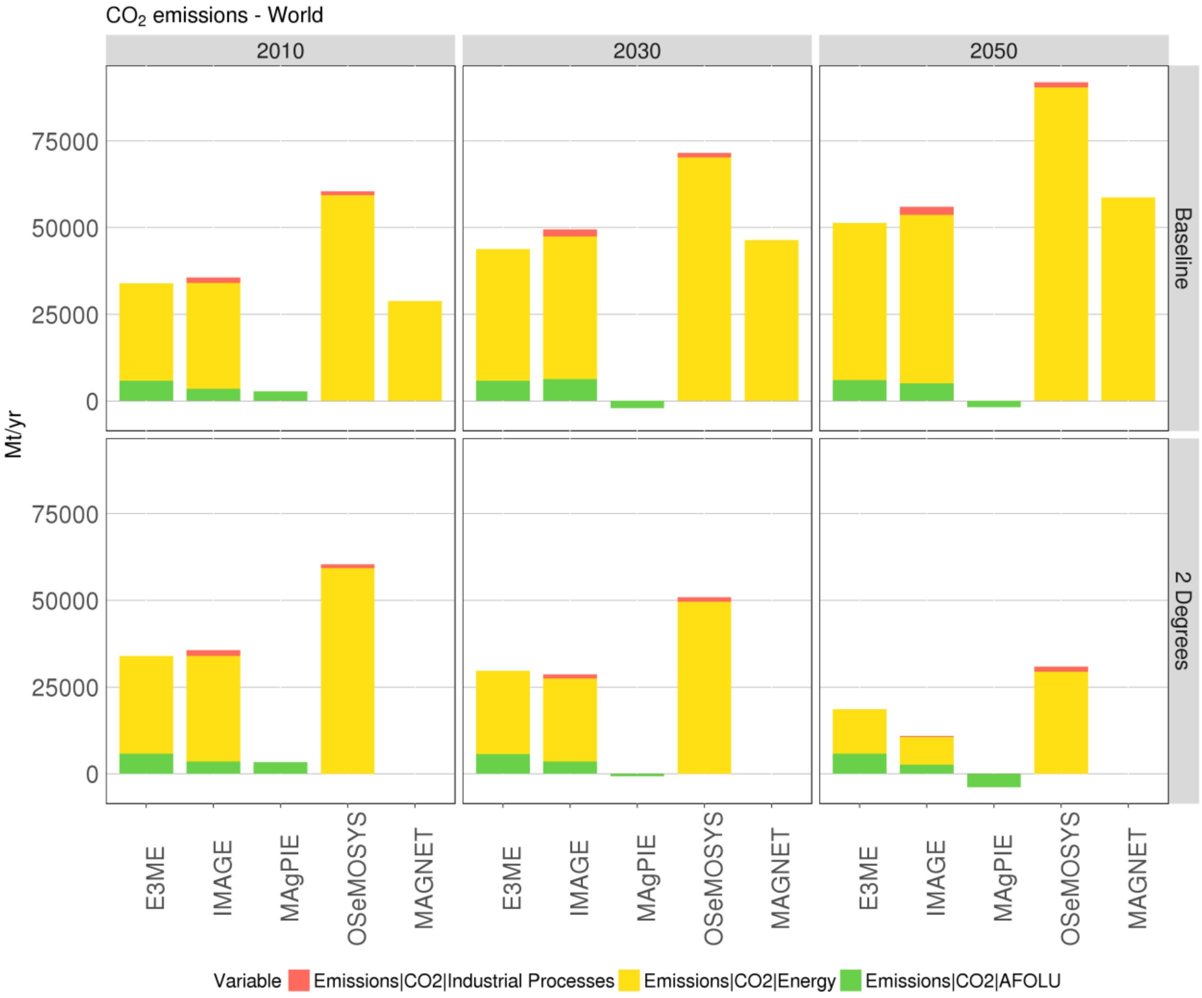


Figure 7: CO_2 emissions per source in 2010, 2030 and 2050

Figure 8 summarises the methane (CH_4) and nitrous dioxide (N_2O) emission results for the baseline and 2-degree scenario. Both E3ME and IMAGE have quite similar projection of N_2O levels both in the baseline and 2-degree scenario. E3ME CH_4 emission results are slightly higher in the baseline compared to IMAGE results. The CH_4 emission reduction in E3ME is also significantly smaller compared to the IMAGE results. MAGNET CH_4 and N_2O emission projections are roughly twice the size of the E3ME and IMAGE results. In contrast to the other models, MAGNET does not include exogenous emission savings technology in the baseline. Therefore the change in emissions is due solely to the change in the production or use of the commodity responsible for the emissions. Further the preliminary mitigation scenario implemented in MAGNET only examine mitigation policies that target agriculture even through the model includes emissions from the entire economy. Agriculture is only responsible for 33 percent and 75 percent respectively of total CH4 and N20 emissions, so the emission reduction from agriculture small compared to the total global CH4 and N20 emissions.

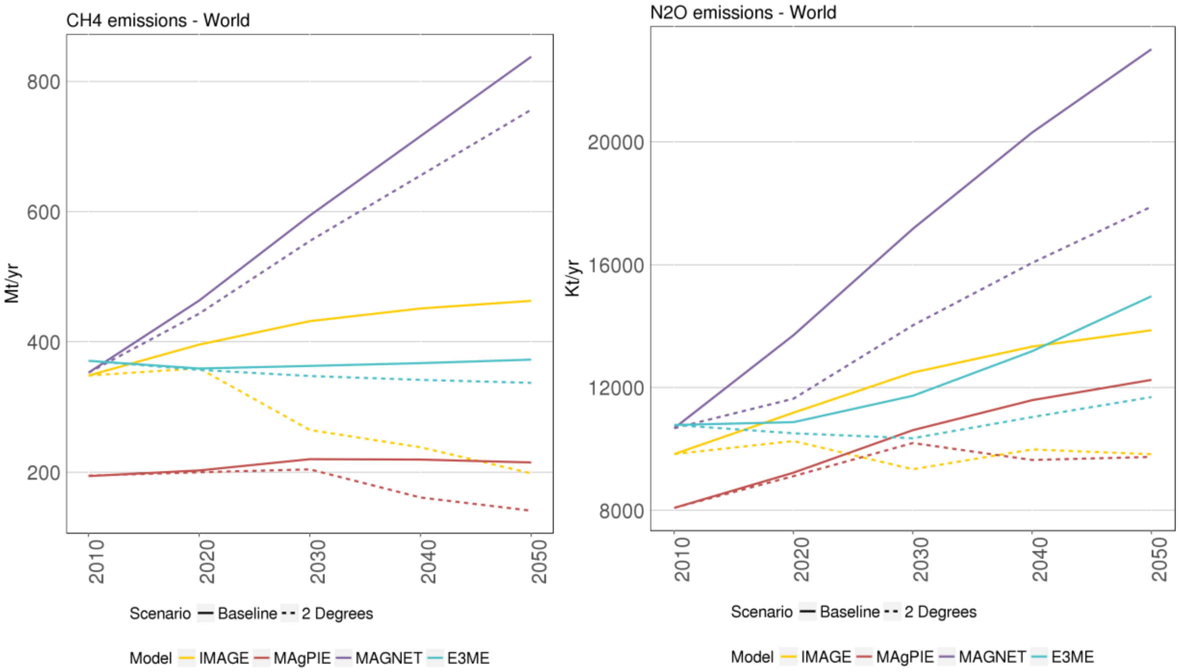


Figure 8: CH_4 and N_2O emissions from 2010 to 2050 for four models: E3ME, IMAGE, MAgPIE and MAGNET

1.2 Description of the pathways

The data presented in section 1.1 is derived from one baseline scenario and one mitigation scenario (when available) developed by each modelling team. The reference scenarios are business-as-usual cases. In MAgPIE, MAGNET, IMAGE-GLOBIO and CAPRI these are represented by the SSP2 scenario from the Shared Socio-economic pathway framework (O'Neill et al., 2013). In OSeMOSYS, the baseline scenario is built from different sources, mainly the (IEA) and the (FAO) of the United Nations publications, together with the (GAEZ) database for different land categories considered. All models except for CAPRI also report a mitigation scenario where the baseline scenario is combined with a carbon price or other climate change mitigation policies in order to limit global temperature rise to a maximum of 2 degrees (RCP2.6). Table 1 provides detailed descriptions of a range of important scenario assumptions.

Scenario setup and assumptions per model	**MAgPIE**	**IMAGE-GLOBIO**	**MAGNET**	**OSeMOSYS**	**E3ME**	**CAPRI**
Agricultural system						
Yield increase	Climate impacts from LPJml and endogenous yield increase.	Exogenous tech. increase according to FAO agricultural outlook (2012), endogenous increase following MAGNET	Endogenous model result, exogenous tech. increase according to FAO agricultural outlook (2012)	Based on: FAO (2011) *Looking Ahead in World Food and Agriculture: Perspectives to 2050.*	-	Medium - 75% of the exogenous yield growth from GLOBIOM implementation, 25% CAPRI endogenous
Irrigation	endogenous irrigation area increase	Irrigation area increases following the FAO agricultural outlook of irrigated harvested area, irrigation efficiency increases by 0.2%/yr for the share newly irrigated area	-	Irrigation requirements based on the Global Agro-Ecological Zones (GAEZ) database version 3.0	-	-
Livestock intensification	Medium intensification	Exogenous tech. increase according to FAO agricultural outlook (2012), endogenous increase following MAGNET	Endogenous model result, exogenous tech. increase according to FAO agricultural outlook (2012)	-	-	Medium - Model endogenous adjustments emulated through a 2.5 EUR/t carbon price
Land-use change regulation	Linear increase of protected forest areas by factor 1.5 between 2010 and 2100	Medium – Protected areas are extended to achieve the Aichi target of 17% of the terrestrial area, gradually implemented from 2010-2050.	same as IMAGE	-	-	Medium - Model endogenous adjustments emulated through a 2.5 EUR/t carbon price

Nitrogen fertilzer use	Soil nitrogen uptake efficiency converges to 60% globally by 2050; constant thereafter.	Following largely the projections by FAOs agricultural outlook	endogenous model outcome	-	-	Medium - Model endogenous adjustments emulated through a 2.5 EUR/t carbon price
Land degradation	-	-	-	Residual capacity of land is assumed linearly declining by 4% each year till 2050, based on World Bank Open Data (2013) *Agricultural land.*	-	-
Food system						
Food demand	Endogenous, but depends on demographic and income drivers as well as storyline-dependent parametrization of the food demand system leading to medium food demand and low demand for livestock products. Additionally, livestock share in rich countries are not falling below 15%.	from MAGNET	endogenous model outcome	Exogenous data and projections based on FAO (2011) *Looking Ahead in World Food and Agriculture: Perspectives to 2050.*	-	Business as usual
Waste	Included in food demand (driven by demography and income)	from MAGNET	current levels of food losses	-	-	Business as usual
International trade						
Agricultural trade barriers	Agricultural trade barriers decline by 0.5% per year	from MAGNET	Current tariffs and subsidies.	-	Current tariffs and subsidies.	Business as usual
Energy system						

Energy technology specifications	-	medium assumptions from IMAGE energy model (TIMER, van Vuuren et al., 2017)	-	IEA *Energy Technology Perspectives* (2012); OECD and Nuclear Energy Agency *Projected Costs of Generating Electricity* (2010); IEA ETSAP *Energy Supply Technology Briefs.*	-	-
Energy demand	exogenous bioenergy demand based on previous coupling runs with REMIND with and without mitigation target (Klein et al 2014)	medium assumptions from IMAGE energy model (TIMER, van Vuuren et al., 2017)	-	Energy consumptions and efficiency improvements data considered are based on IEA *Energy Technology Perspectives* (2012)	-	-
Energy system policy	-	no climate change mitigation policy	-	-	All existing regulation and policies implemented by government by early 2016 (NB this includes ETS schemes and other carbon/energy pricing). EU ETS values in line with PRIMES 2015. Non EU carbon prices in line with WEO 2016 CPS.	-
Climate change mitigation						
2 Degree scenario	cost-optimal mitigation pathway based on endogenous trade and fertilization patterns, MAC-curves from Lucas et al. (2007) for non-co2 GHG emissions, and endogenous mitigation for CO2 emissions from land use change and afforestation	cost-optimal mitigation pathway based on cost-curves from IMAGE and MAC-curves from Lucas et al. (2007), all forest >15tC/ha are strictly protected	exponential carbon price pathway up to $1000 in 2070 implemented in agricultural sector (AGCLIM50-II project), MAC-curves from Lucas et al. (2007)	Scenario characterised by a CO2eq emission cap as from the IEA *Energy Technology Perspectives* (2012);	Mitigation policies include carbon taxes, RES support, energy-efficiency policies, EVs support and some biofuel mandates.	-

Table 1: scenario setup and assumptions per model for the baseline and mitigation scenario

1.3 Develop a conceptual model

The workshop in The Hague resulted in a first draft of a conceptual model of the water-land-food-energy-climate nexus for the global case. First, a schematic overview was made of the nexus linkages that are represented by at least one of the thematic models participating in the global case (Figure 9). This shows that a very large number of interlinkages between the nexus systems are represented. Some of these are present in most of the models, for example GHG emissions from the energy system to the climate system and the interactions between food and land are represented by four models. Others such as energy use from food production, the limitations of water shortages on food production and the biodiversity effects of climate change are represented by one model.

The overview of the model linkages is used for the second step working towards a conceptual model that can serve as a basis for the systems dynamic model and serious game at a later stage of the project. (Figure 10). A number of the linking processes are biophysical, such as climate impacts on land and water and emissions from energy to climate. Other parts of the conceptual model interact though market dynamics such as the food and energy systems.

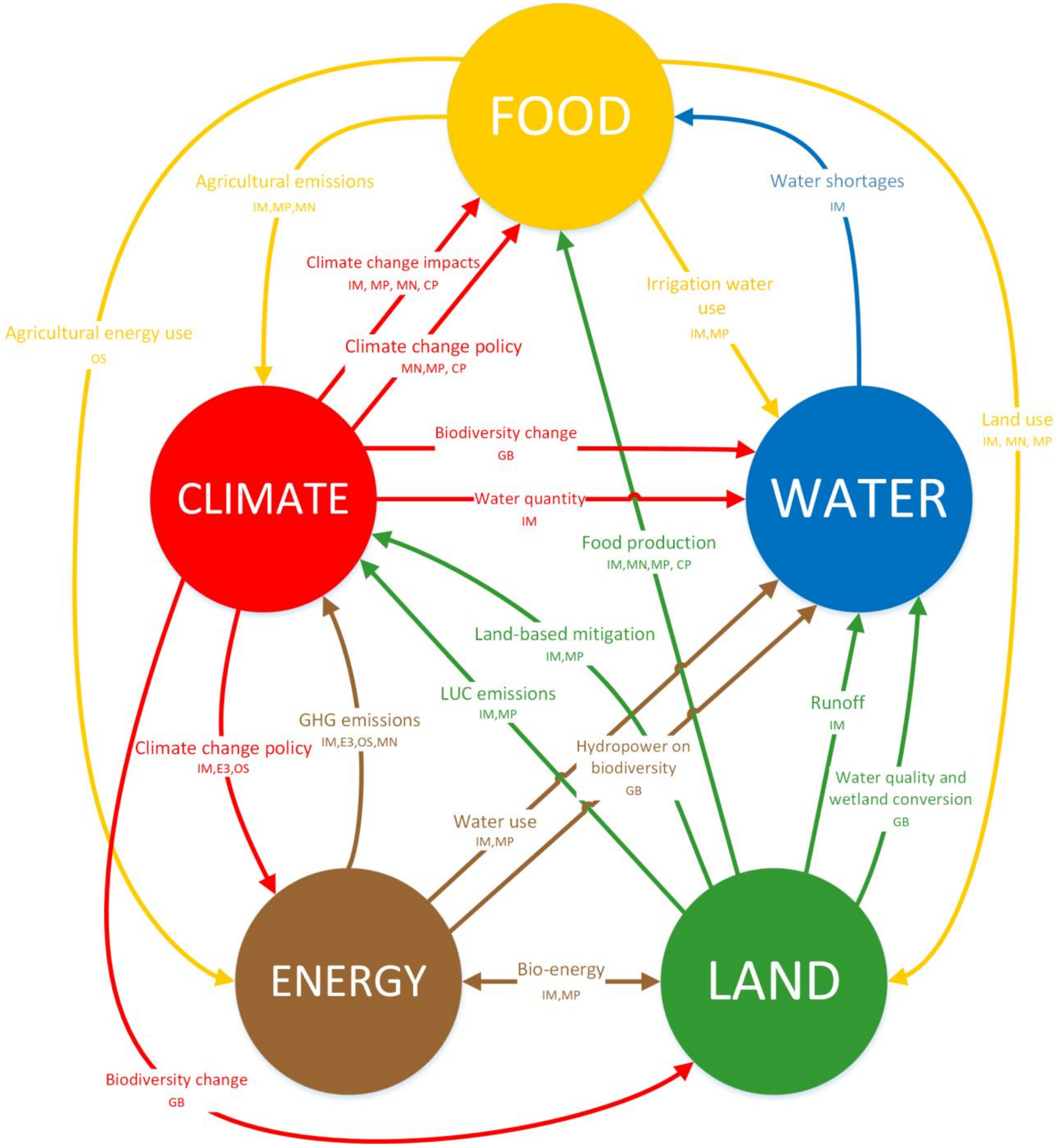


Figure 9: schematic overview of the interactions in the water-land-food-energy-climate nexus that are represented by at least one of the models in the global case: IM = IMAGE, E3 = E3ME, OS = OSeMOSYS, MN = MAGNET, MP = MAgPIE, CAPRI = CP, GB = GLOBIO

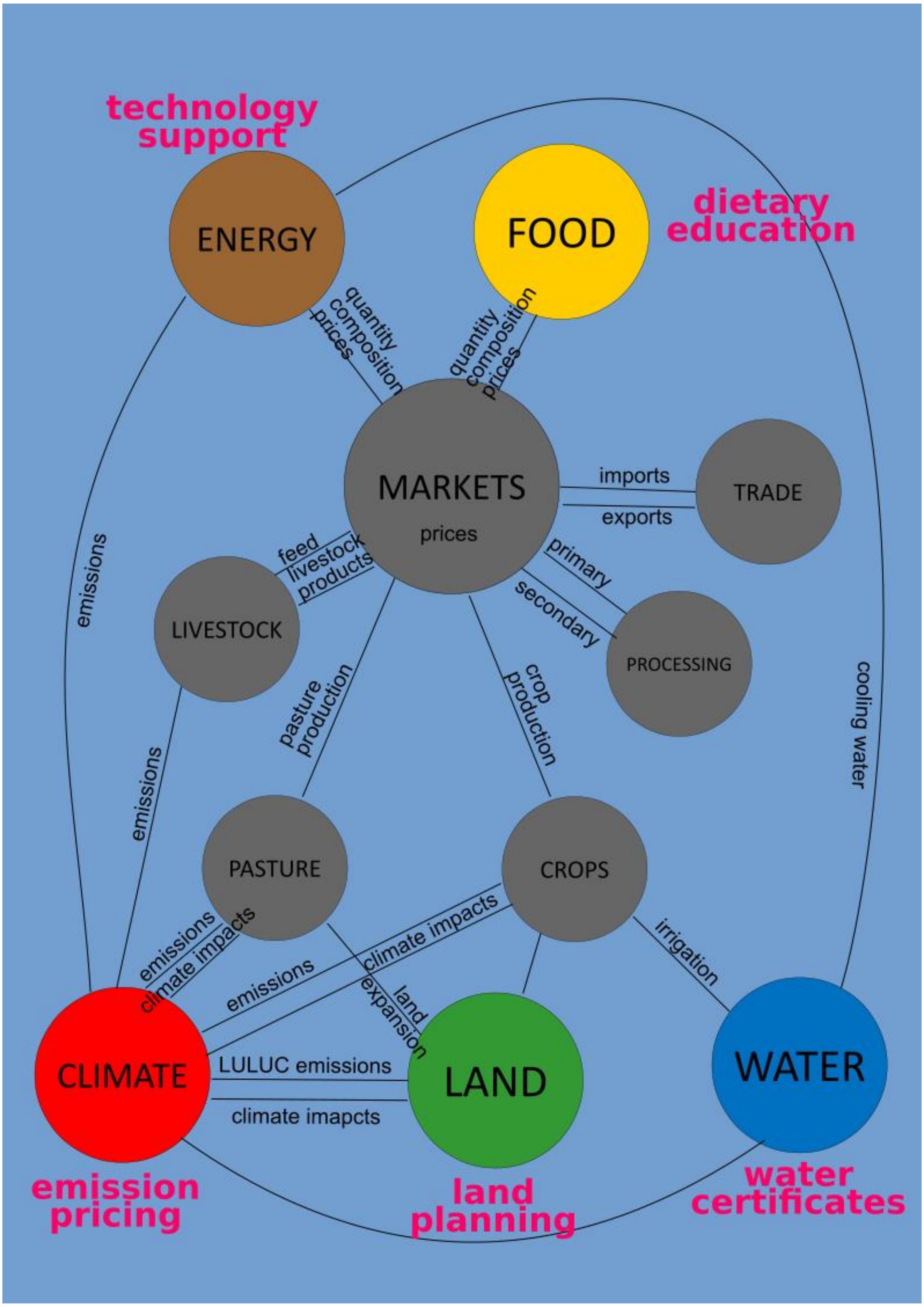


Figure 10: conceptual model of the global case

1.4 Use of thematic models in understanding the Nexus

1.4.1 The nexus of land use, climate change mitigation and the food system in IMAGE-GLOBIO using the SSP scenarios

During the preparatory phase of SIM4NEXUS the teams of the IMAGE and MAgPIE models were co-developers of the *Shared Socio-economic Pathway Scenarios* (O'Neill et al., 2013; Detlef P. van Vuuren et al., 2012). These scenarios provide a framework that aims to strengthen cooperation between various modelling communities. The five SSP scenarios describe a range of possible socio-economic futures, thus covering a large range of uncertainty on e.g. demographic and economic developments. The diverging socio-economic futures are combined with different climate targets aiming to limit global warming by the end of the century to 3, 2 or 1.5 degrees. These targets are also represented by the representative concentration pathways: RCP 4.5, RCP 2.6 and RCP 1.9, respectively. As the socio-economic futures include projections about the land, food and agricultural systems, these scenarios are well suited to analyse interactions in the land-climate-food nexus.

Agricultural land-use change is driven by population, agricultural efficiency, consumption depending on GDP per capita and food prices, land availability, food losses, and dietary preferences. Detailed descriptions of these drivers and the resulting land-use dynamics are published in Popp et al. (2017), Detlef P van Vuuren et al. (2017) and Doelman et al. (in press). Global land-use trends show moderate increases in the Middle-of-the-Road scenario SSP2, while the Sustainability scenario SSP1 shows substantial reduction due to limited population growth and environmental awareness (Figure 11). Climate-change mitigation policy has substantial effects on land-use dynamics: bioenergy production increases as this is an attractive option in combination with carbon capture and storage, REDD limits the expansion of agriculture and reforestation of degraded forest increases the share of forest reducing the category other land.

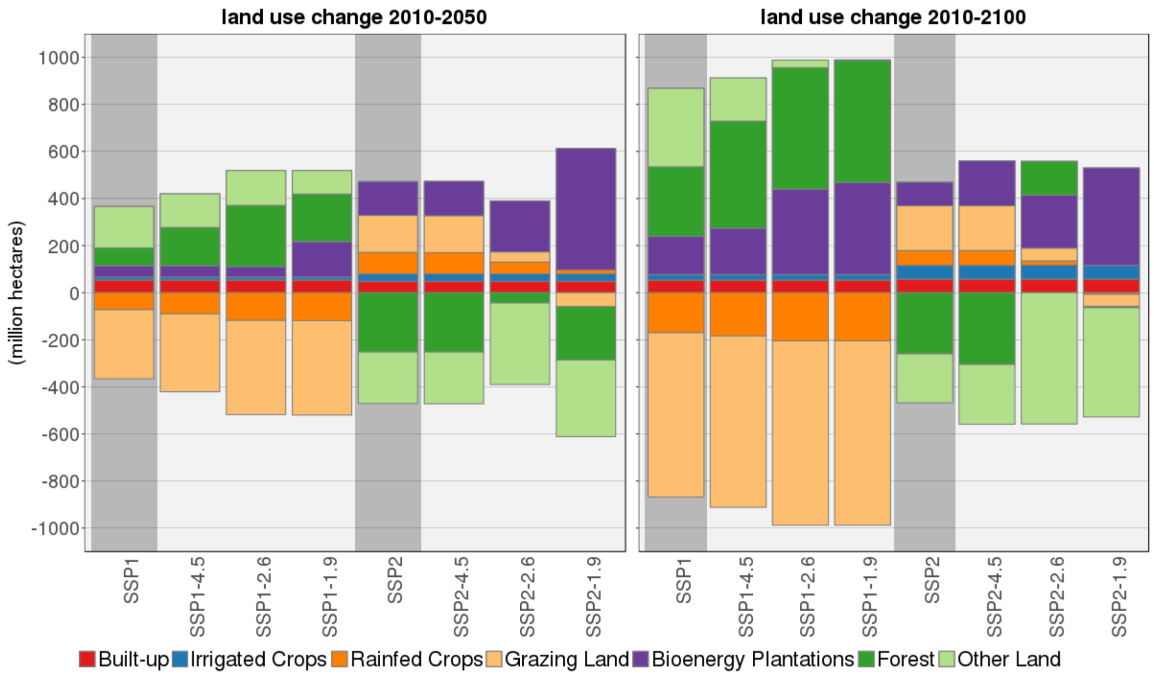


Figure 11: global LUC in 2010-2050 and 2010-2100 for the SSSP1 and SSP2 baseline and three increasingly 580 ambitious mitigation targets: 4.5, 2.6 and 1.9.

The land sector is crucial to achieve ambitious mitigation targets. Especially for the 2 and 1.5 degree targets net negative emissions (carbon dioxide removal) are indispensable as they can compensate other emissions that are difficult to mitigate such as methane and nitrous oxide from agriculture. Bioenergy with carbon capture and storage, and reforestation are technologies that are suitable for this purpose and are relatively cheap. However, they do require substantial land areas thus creating trade-offs with food production and other land-based services such as water provision, water quality and biodiversity on land and in water.

Analyses with the coupled IMAGE-MAGNET model framework show that the different socio-economic assumptions of the SSPs produces a wide range in food security effects. Especially SSP3 results in limited improvements in food availability and nearly a tripling in food prices on a global scale, due to large increases in population and low economic growth. SSP1 on the other hand shows substantial increases in food availability while food prices decrease. On a regional scale, especially Sub-Saharan Africa and India are negatively affected with high food prices and increasing import dependency. Land-based mitigation affects food security through the implementation of REDD which limits the expansion of agricultural land. Especially in Sub-Saharan Africa, agriculture is projected to expand substantially and REDD has large potential due to extensive tropical forests. Protecting these forests limits agricultural expansion and results in lower growth in food availability, higher food prices and increases import dependency.

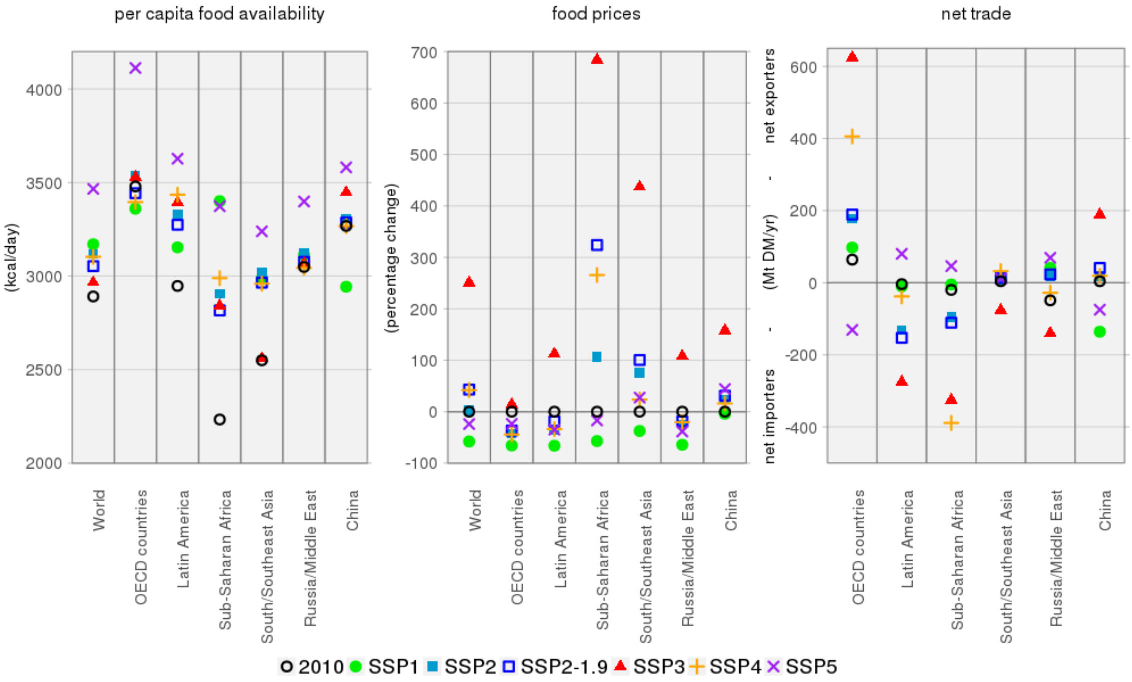


Figure 12: regional food security indicators for 2010 and 2100 for five baseline scenarios and the SSP2 1.5°C mitigation scenario (1.9 W/m^2) scenario: per capita food availability of food crops and animal products in kcal/cap/day, changes in average food prices, and net trade between the regions.

1.4.2 The nexus between energy supply, food production and related use of land resources in OSeMOSYS

The OSeMOSYS-based model for the global region is based on the Global Least-cost User-friendly Climate, Land ,Energy, Water (CLEW) Open Source Explanatory (GLUCOSE) model, originally developed in preparation of the Prototype Global Sustainable Development report (2014) published by the United Nations Department of Economic and Social Affairs (UN DESA).

The GLUCOSE model was initially developed with the aim of providing a wide-scale long-term integrated systems model that takes into consideration both socioeconomic elements and the relevant technology details characteristics in a transparent, user friendly and easily accessible way. It consists of three main modules: the energy sector, the material sector, the land and food sector.

The module of the energy sector is the most detailed one, considering a wide range of power generation technologies and related characteristics. It aims at identifying the cost-optimal mix of resources to satisfy the demand that is exogenously defined in detail in the model, split in between different sectors: residential, industry and transport. Therefore, the optimization model allows for considering various investment opportunities, investigating different generation technologies and infrastructure shifts. Concerning the transport sector, the model also investigate options based on biodiesel or electricity. Input data and technology characteristics for this sector, as well as demand projections, were based mainly on IEA sources (IEA, 2012; UNDESA, 2014).

For the land module different land categories, related productivities and irrigation requirements were defined based on the GAEZ database version 3.0 (IIASA and FAO, 2012). The biomass produced by each type of land is used in the model to meet the demand for meat and vegetarian food, as well as energy production through the link with the energy sector in the model. FAO data were used to project yield improvements and food productivity, whereas food demand was coupled with population projections as from UN data.

The materials module focuses on the potential for efficiency improvement in the use of key materials (aluminium, cement, fertilizer, iron and steel, pulp and paper, petrochemicals) and related energy flows, for enhancing the sustainability of their production processes. The materials considered are the ones identified as most critical in relation to present consumption patterns and for which better input data were available. The links between this module and the other two in the model are several. Materials are extracted from land resources and transformed through industries that consume energy and generate emissions. The dispatch of final products can also require long distance transportation, causing additional fuel demand and emissions generation. The demands linked to this module were estimated based on existing projections from IEA (2012), and assuming improvements in the efficiency of the processes considered (Weirich, 2013 and UNDESA, 2014).

Considering the energy module as part of an integrated assessment model.

In this section, the integrated GLUCOSE model results generated in OSeMOSYS are compared with results generated when running just the related energy module in isolation. This analysis aims at highlighting the benefits of the integrated approach in identifying key issues that might affect the availability of different resources in the long term future.

Looking at the baseline scenarios, from a Nexus perspective it is interesting to focus on the results for biomass use in the Total primary energy supply (TPES) as shown in Figure 13.

In the GLUCOSE model, the energy module is linked to the land sector, providing the fuels and electricity needed for producing biomass and transforming it into food products. At the same time, some of the biomass produced is also used as fuel input to the energy module to produce energy. When running the energy module in isolation, the results projected 125 EJ of biomass use against 74.5 EJ as estimated by the entire GLUCOSE model in 2050. This consistent difference in results can be explained by the fact that food demand input in the integrated model, as well as the expected production costs related to that, they represent a constraint on energy production. In fact, they act by limiting the amount of biomass that is left available to the energy sector at a cost competitive price.

The land resources available and their expected yield are defined in the model as input data, based on the GAEZ database. In order to meet the demand for food, the GLUCOSE model allocates the most productive land categories to food production first. This reduces significantly the amount of biomass in the GLUCOSE model that is available for power generation in comparison to the isolated energy module, where no limitation on land resource availability and related biomass production for energy purposes is set. Moreover, the integrated model requires the system to invest more on irrigating and harvesting the land, in order for the biomass resource left available from the food production to be fully exploited (UNDESA, 2014). Therefore, this outcome proves how the integrated management of different resource sectors can ensure a more sustainable development pathway for the entire system.

This closer analysis of the energy sector, and its nexus with other resources, shows how aiming at ensuring the cost-optimal design and development of the energy system only might lead to underestimate some of the burdens that affect biomass production and related food security in the long-term future. This might provide in the end misleading information to the decision-makers, leading.to the development of policies that might impact the availability of natural resources in a negative way.

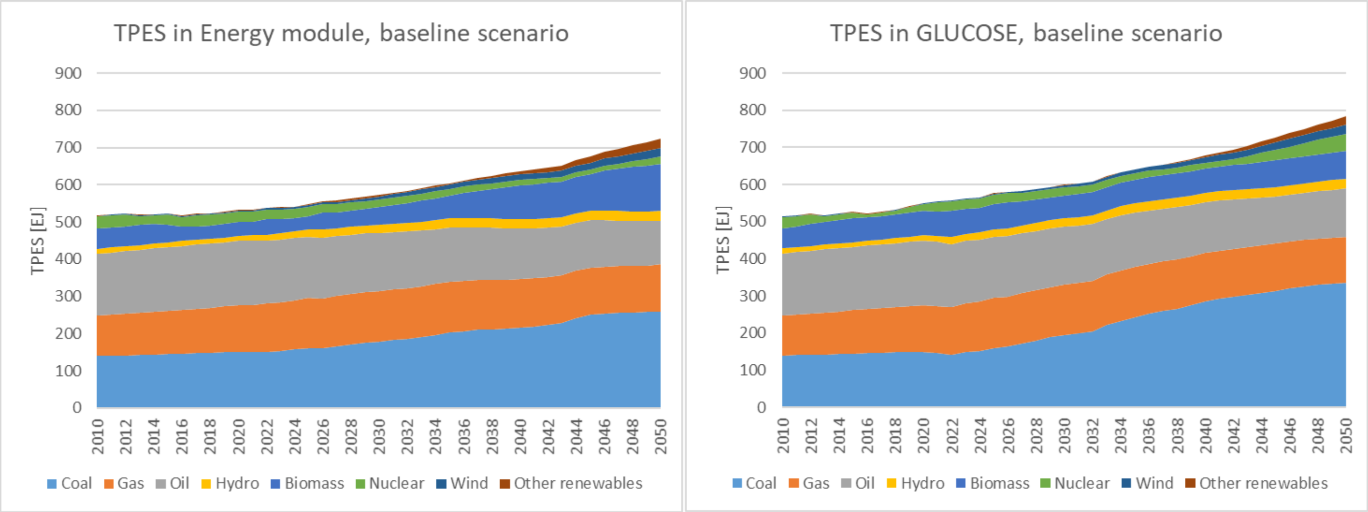


Figure 13 - Total Primary Energy Supply (TPES) mix in the baseline scenario, computed in OSeMOSYS for the separate global Energy model (left) and the related integrated GLUCOSE model (right).

1.4.3 Climate-Food nexus analysis with CAPRI

CAPRI has been used to analyse the impact of climate change on food at the global level in 2030. The modelling approach followed to analyse this nexus linkage consists of the combination of CAPRI with biophysical models. In detail, climate-induced changes in crop yields provided by biophysical models (WOFOST for EU and LPJmL for non-EU regions) are introduced in CAPRI as exogenous productivity shifters to analyse the climate change impacts on agrifood markets.

As climate change impacts on crop productivity are surrounded by uncertainties, several scenarios are assessed. While the baseline scenario assumes current climate conditions in 2030 and no climate-induced changes in crop yields between 2010 and 2030, the simulation scenarios include different crop yield shocks according to different climate projections and CO_2 effects. The simulation scenarios are then based on a combination of: 1) emission scenarios (RCP 4.5 and RCP 8.5); 2) climate projections from three general circulation models (HadGEM2-ES, MIROC-ESM-CHEM and IPSL-CM5A-LR); and 3) carbon fertilization effects (simulation with and without carbon fertilization). All scenarios adopt the middle-of-the-road socioeconomic pathway (SSP2) which implies a moderate capacity to address climate change mitigation and adaptation in the medium term.

Climate-induced changes in crop yields

Results from biophysical models indicate that climate-induced changes in crop yields tend increase when carbon fertilization is considered. Regarding crops, the highest range of uncertainty corresponds to soybean and rapeseed likely because the regional production concentration makes these crops more sensitive to climate projections. The lowest range of uncertainty is observed for maize because, as C4 crop, it not significantly affected by carbon fertilization effects (Figure 1).

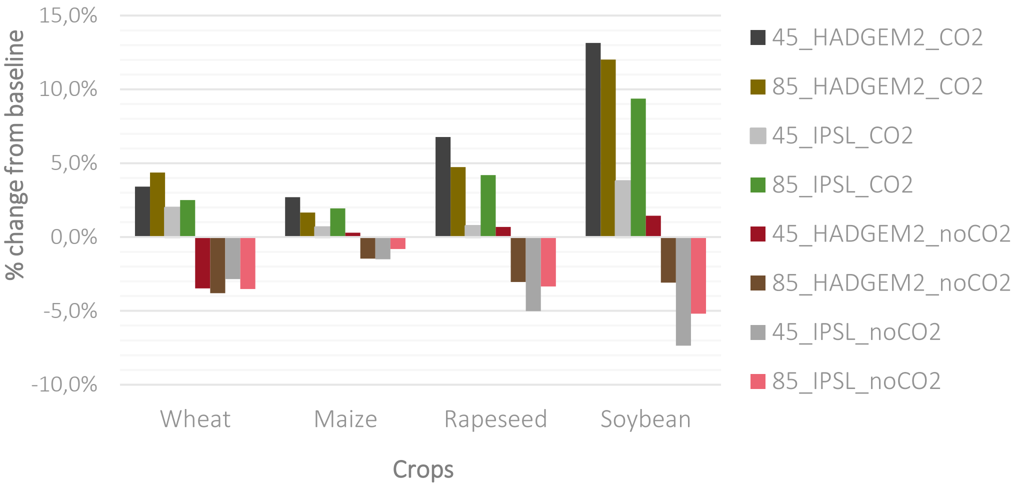
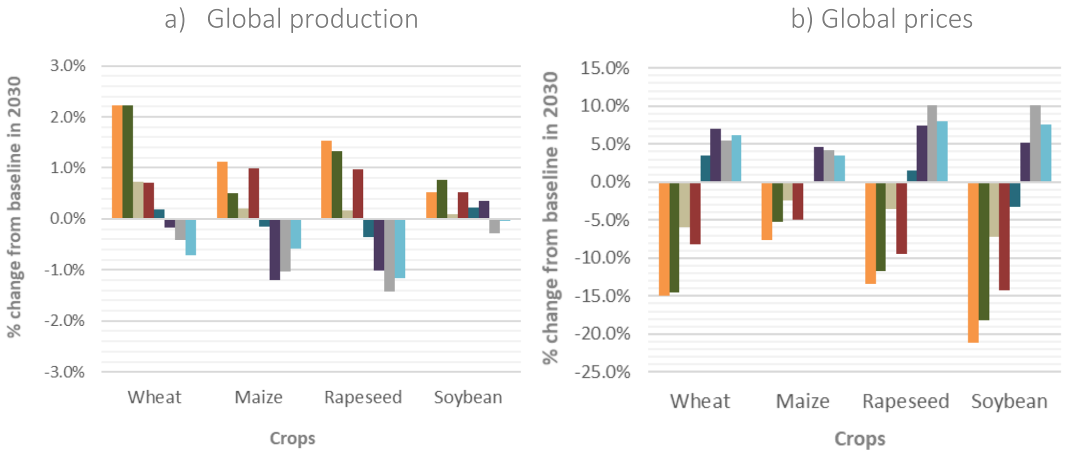


Figure 14: Global yield changes in 2030 for wheat, maize, rapeseed and soybean under different simulation scenarios. Source: LPJmL model simulations.

Climate-induced yield changes on agricultural production and prices

Results provided by CAPRI show that the comparatively large changes in crop yields (Figure 1) lead to moderate changes in agricultural production (Figure 2a), along with significant price variations (Figure 2b). Therefore, the shift in crop prices in response to yield changes counterbalances the impacts of climate change on agricultural production at global level.



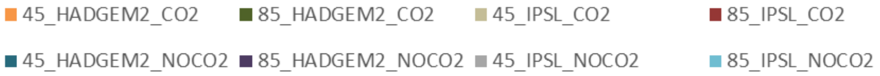


Figure 15: Changes in a) global production and b) global prices in 2030 for wheat, maize, rapeseed and soybean under different simulation scenarios (% change relative to baseline values by 2030). Source: CAPRI simulations.

While production effects at global level are moderate, disaggregated effects on crop production highlight significant regional divergences across the world. As presented in Figure 3 for wheat, overall production increases in high latitudes and decreases in medium and low latitudes (Figure 3).

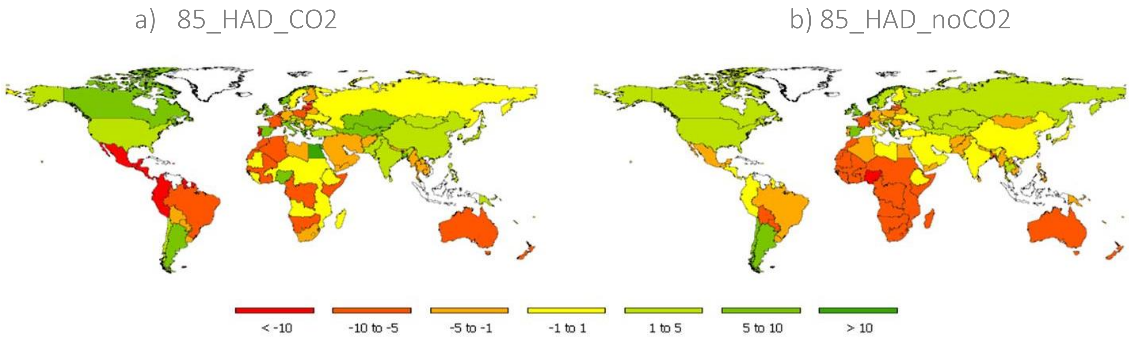


Figure 16: Wheat production across the world in 2030 under scenarios a) 85_HAD-CO2 and b) 85_HAD-noCO2 (% change from baseline). Source: CAPRI model simulations.

International trade as adaptation strategy to climate change

Trade offsets the diverging effects on production across regions, playing an important role as an adaptation mechanism to tackle climate change impacts on food. Focus on wheat as an example, the main exporters for this commodity are the EU, the USA, Canada and Australia and New Zealand, while major importers are Middle East and North Africa, Sub-Saharan Africa, South East Asia and Brazil. As a consequence of climate change, major exporters regions will undergo important changes in wheat production: while the USA and Canada will benefit from climate change, the EU and, specially, Australia and New Zealand will experience a decline in wheat production (Figure 4). Notwithstanding, uneven effects across these regions are balanced by trade. As depicted in Figure 5, the USA and Canada will increase their exports and the EU and Australia and New Zealand will drastically reduce wheat exports.

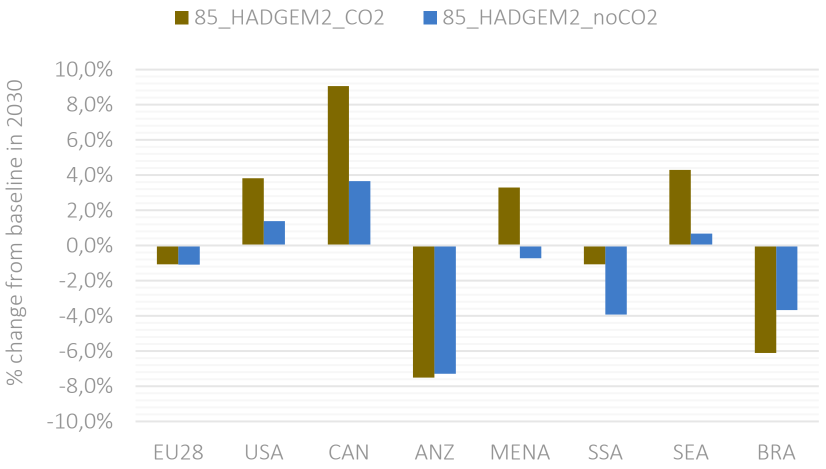


Figure 17: Wheat production changes in the major country/region traders in 2030 under scenarios 85_HAD_CO2 and 85_HAD_noCO2 (% change from baseline). Country/Regions: Australia and New Zealand (ANZ), Other Asia (OAS), South East Asia (SEA), India (IND), Other South and Central America (OSA), Canada (CAN), United States

(USA), Sub-Saharan Africa (SSA), Middle East and North Africa (MENA), Rest of European Union (REU). Values in thousand tons. Source: CAPRI model simulations.

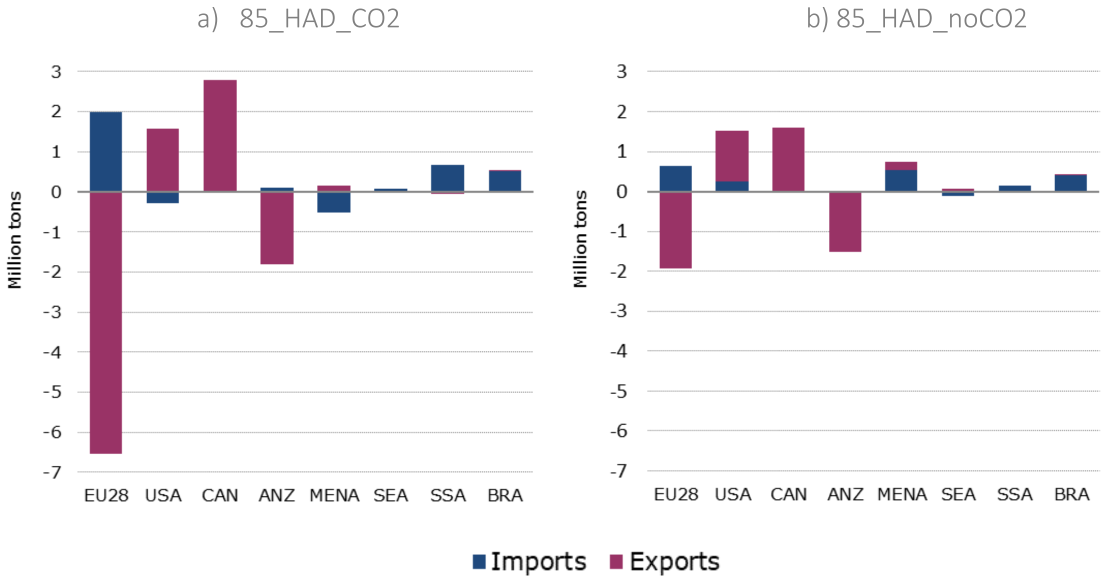


Figure 18: Wheat trade for the main traders in 2030 under scenarios a) 85_HAD_CO2 and b) 85_HAD_noCO2 (absolute change from baseline). Source: CAPRI model simulations.

1.4.4 Investigating the food-land-water-climate nexus with the MAgPIE model

In the SIM4NEXUS preparation phase, REMIND-MAgPIE and IMAGE contributed along with three other Integrated Assessment Models to the development of *the Shared Socioeconomic Pathways*. The work on the agricultural sector has been published in a multi-model inter-comparison which covers the NEXUS elements Food, Land, Climate and Energy (Popp et al 2017). This exercise provided an excellent preparation for the SIM4NEXUS work, as it helped to harmonize and document assumptions between models, establish commonly defined indicators and harmonized data formats between models.

Within the SIM4NEXUS project, the MAgPIE model has been applied to investigate a number of highly nexus relevant aspects of the global agro-food system. They have been recently published in three articles in the ISI journals ***Global Environmental Change***, ***Environmental Research Letters*** and ***Global and Planetary Change.***

Weindl et al (2017a) and Weindl et al (2017b) analyse the central role of the livestock sector within the NEXUS, looking at the interplay between the Nexus Topics food, land, water and climate. Two different dietary scenarios (high and low meat consumption) in combination with four different livestock productivity scenarios were simulated to identify the consequences on CO_2 emissions from land use change, blue water consumption, green water consumption, irrigated area, cropland area and intensification (see Figure 1). The reduction of animal-based calories can strongly reduce the cropland expansion and thereby reduce deforestation and their related emissions. Interestingly however, the potential of more vegan diets to reduce blue water usage is very limited, as irrigated areas remain competitive also when demand is reduced. Similarly, the results for an intensification of the livestock industry are ambiguous: While intensification reduces deforestation by reducing pasture areas, it leads to increasing cropland areas and higher agricultural water withdrawals. With regard to carbon emissions, consequences of livestock intensification depend on the productivity level. While in extensive systems, productivity gains have a high potential to mitigate emissions from land use change, the loss of soil carbon impedes further emission savings at higher productivity levels. The worst outcome in terms of carbon emissions is a continuation of current trends, where high consumption of animal-based calories comes together with high intensification of the livestock production in high-income countries and stagnating productivity in low-income countries. In contrast, reducing intensity of high-productive systems has no substantial effect on emission, land expansion or water withdrawals.

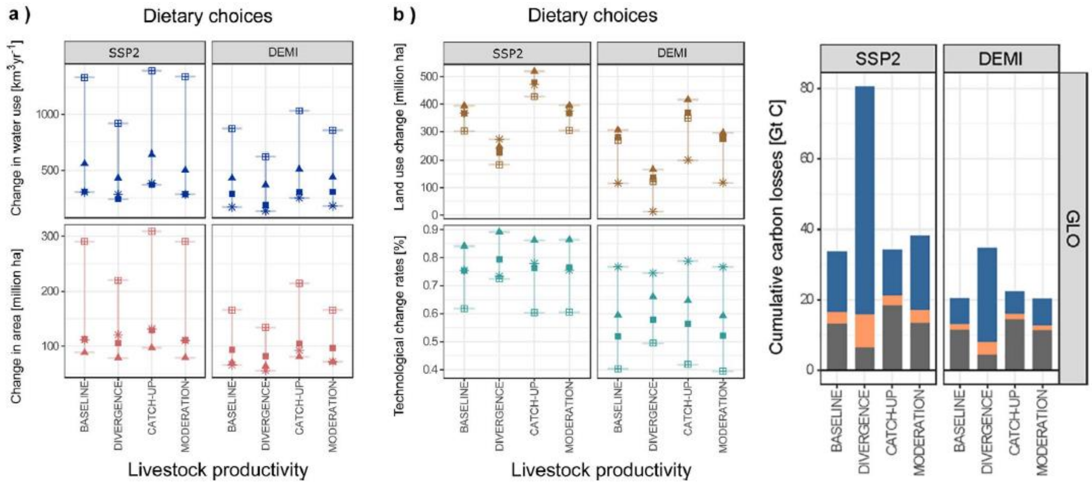


Figure 19: Consequences of dietary changes (SSP2 vs DEMI) and livestock productivity pathways (Baseline, Convergence, Catch-Up, Moderation) on blue water consumption (left panel, top), irrigated area (left panel, bottom), cropland expansion (middle panel, top), cropland intensification (middle panel, bottom) and carbon losses from land use change (right panel). Adapted from Weindl et al (2017a, 2017b).

In Humpenöder et al (2017), the full nexus is covered, including food, land, water, energy and climate. The study analyses how key indicators in each nexus element may develop throughout the 21st century, and in particular how the large-scale cultivation of 2nd generation bioenergy crops that are required to achieve climate targets well below 2° may affect the various dimensions of sustainable development. Moreover, the study investigates how various policies could help to ease certain negative side-effects of bioenergy cultivation and ease trade-offs with multiple sustainable development indicators. The results show, that without environmental protection and land-sparing measures at least until the mid of the 21st century, the pressure for all SIM4NEXUS elements will increase, and that large-scale bioenergy cultivation will even increase problematic developments in respect to greenhouse gas emissions, land use, water withdrawals, food prices and nitrogen losses. However, the results also show that a smart combination of measures, including the shift towards sustainable diets, R&D investments, water protection schemes and CO_2 taxation are an important step towards sustainable development within the Nexus.

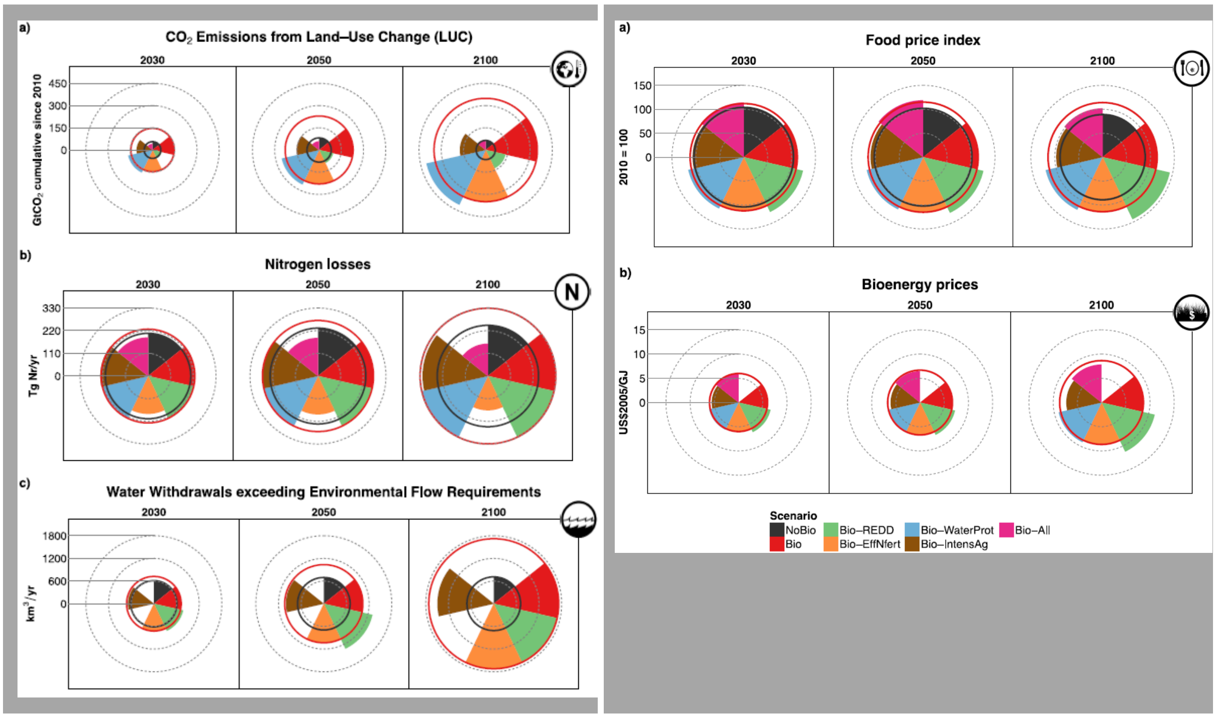


Figure 20: left: Environmental and socio-economic indicators for 2030, 2050 and 2100 at the global scale. Left: a) CO₂ emissions from LUC, b) nitrogen losses and c) water withdrawals exceeding environmental flow requirements. Right: a) Food price index and b) bioenergy price index. Solid black circles mark indicator levels without bioenergy production (NoBio scenario). For scenarios with bioenergy production, values outside black circles indicate adverse side-effects of bioenergy production (e.g. LUC CO₂ emissions in Bio). The environmental protection and land-sparing measures included our scenarios apply not only on bioenergy production but on agricultural production in general. Hence, co-benefits can occur, which are indicated by scenario results located inside black circles (e.g. nitrogen losses in Bio-EffNfert). Solid red circles mark indicator levels of bioenergy production without complementary measures (Bio scenario). If scenario results are located outside solid red circles for a particular indicator, the underlying measure increases adverse-side effects of agricultural production in this dimension, i.e. the measure, which may successfully lower other impacts, involves a new sustainability trade-off (e.g. LUC CO₂ emissions in Bio-WaterProt).

1.4.5 Nexus topic E3ME- Energy transitions in the 2-degree scenario

Overview of CO$_2$ emissions trends

Figure 21: shows the pathway of CO$_2$ emissions at global level in the 2-degree scenario. The results from the E3ME climate modelling suggest that these emissions levels are broadly consistent with a 66% chance of meeting a 2°C target.

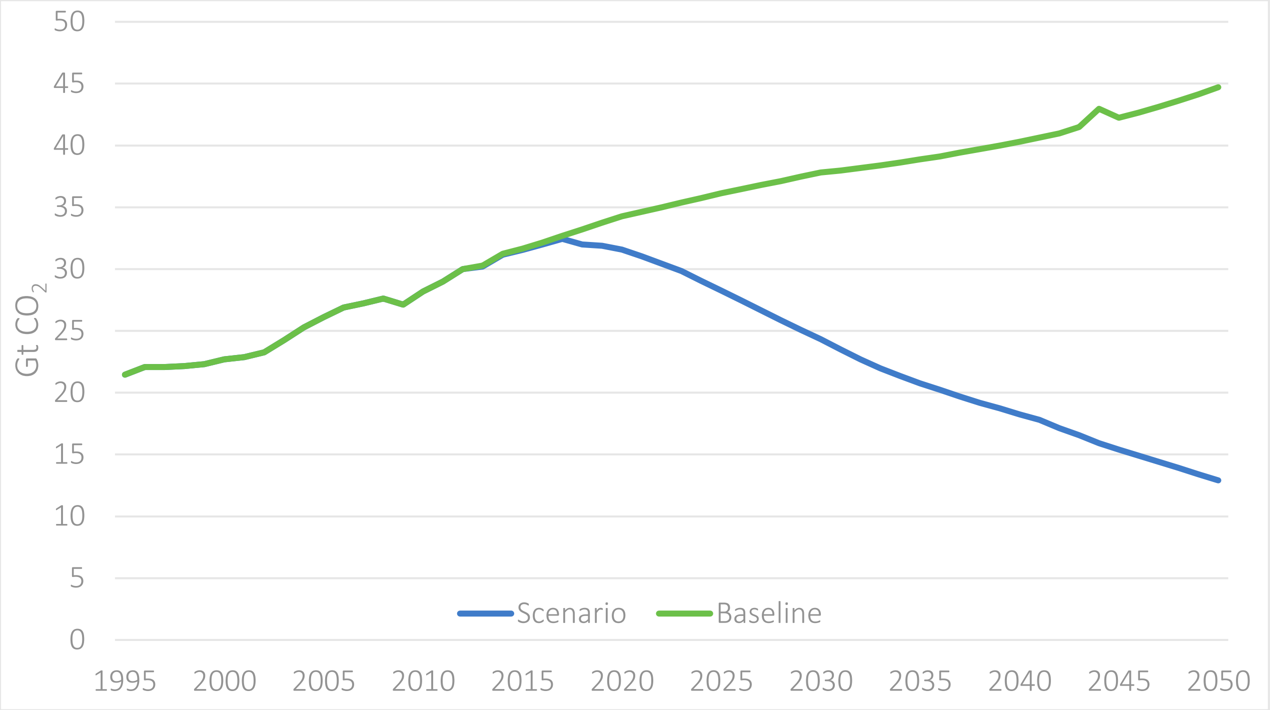


Figure 21: Global CO_2 emissions (Gt CO_2)

CO_2 emissions are projected to continue increasing in the baseline scenario, but are expected to decrease from 2017 onwards in the 2-degree scenario. It is a feature of the scenario that policies are implemented immediately from 2017, rather than no action until 2020, which would make meeting the scenario target more difficult. All countries must make substantial reductions in emissions over the period to reach the 2-degree target; it only requires one large country to fail in taking action to considerably affect the chances of reaching the 2-degree emission reduction target. The emission reductions (in percentage terms compared to the baseline) are largest in the US, China and India; for the EU28 the estimated emission reduction is lower in part because partial decarbonisation of the power sector is already taking place in the baseline.

Transformation of the power generation sector

Figure 22 and Figure 23 show the mix for global power generation in the baseline and 2-degree scenario, and how these are expected to change over time.

In the baseline, the total amount of power generated is higher than in the 2-degree scenario, as there are substantially fewer energy efficiency measures implemented. The baseline case also shows a continuing reliance on coal; the share of generation from coal increases over time, accounting for just under half (47%) of all energy generated in 2050. Although the amount of energy from renewable sources is projected to increase, the relative share of renewables of the overall energy generation remains largely unchanged in the baseline (increasing from 26% in 2030 to 29% in 2050). The relative share of nuclear in the power mix declines from 6% to 4%.

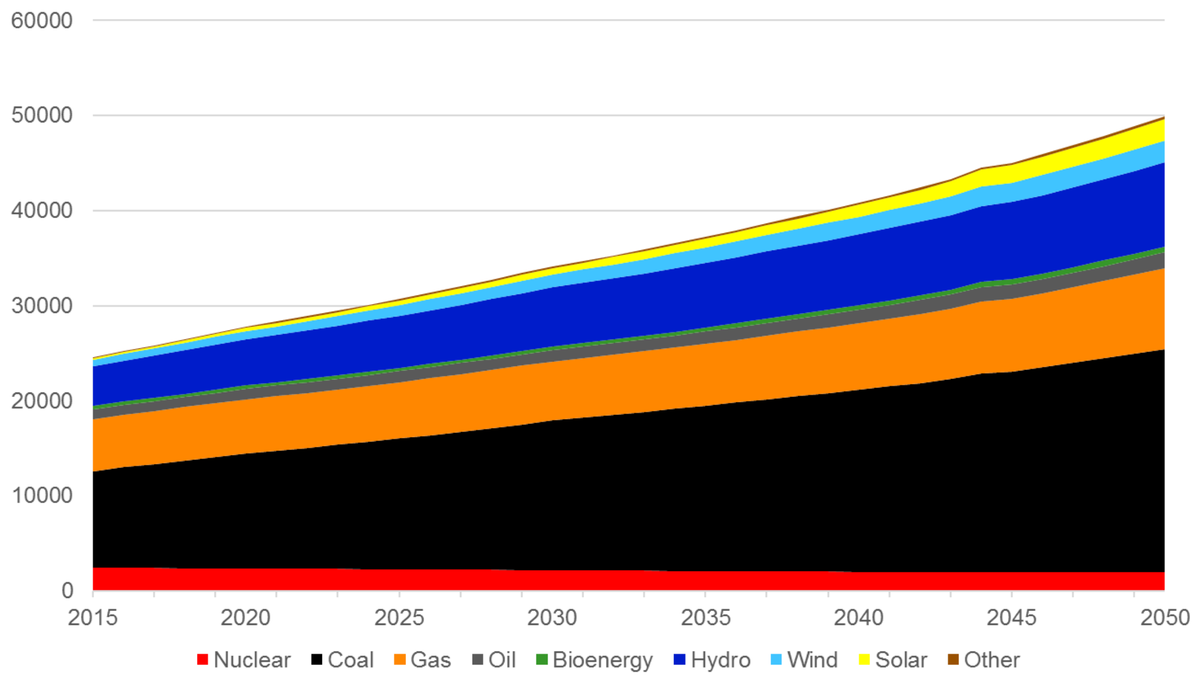


Figure 22: Global power generation mix, baseline, (TWh/y)

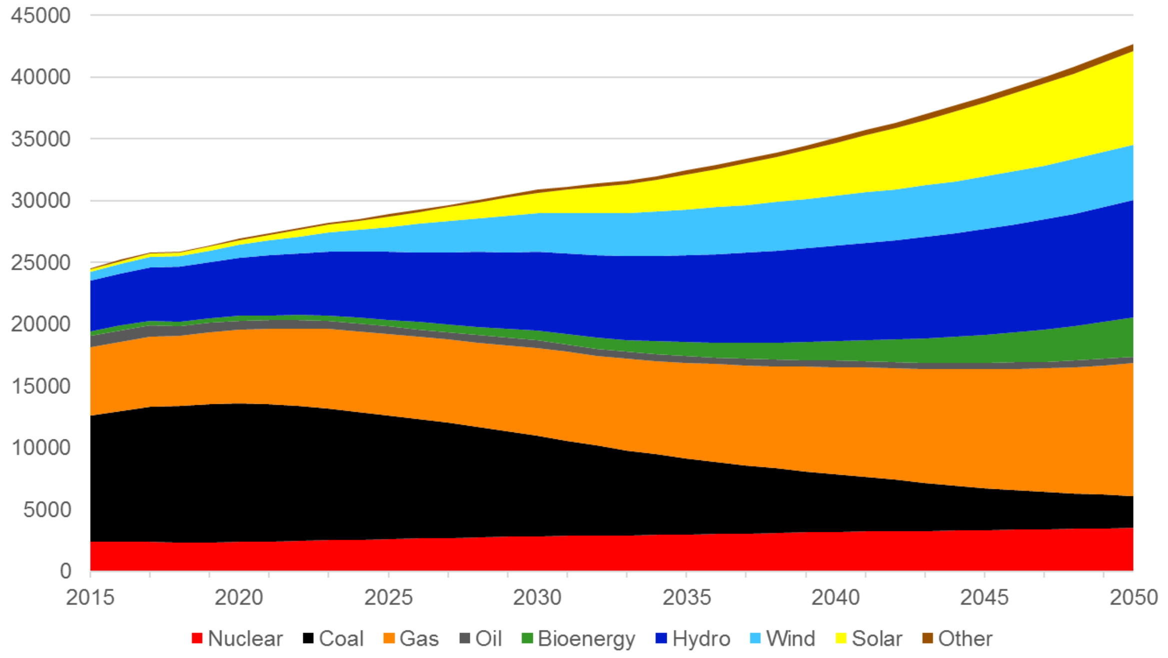


Figure 23: Global power generation mix, baseline, TWh/y

In the 2-degree scenario, the structure of the power generation sectors is substantially different from the baseline. Figure 23 shows a large shift to renewables, with renewables accounting for the majority of electricity generated in 2050 (60%). Hydro generation plays an important role in delivering the high renewables share, although both wind and solar generation are expected to increase rapidly by 2050. A small increase in bioenergy generation is also expected. Coal generation is expected to fall almost to zero, however gas generation is expected to remain in the system, primarily as a back-up generation for intermittent technologies.

Transformation of the road transport sector

The global level E3ME results from the baseline scenario are presented in Figure 24 and the 2-degree scenario in Figure 25. The data are measured in billions of passenger kilometres (Bpkm) per year for each fuel type. Notably, the total number of passenger kilometres is higher in the baseline compared to the 2-degree scenario.

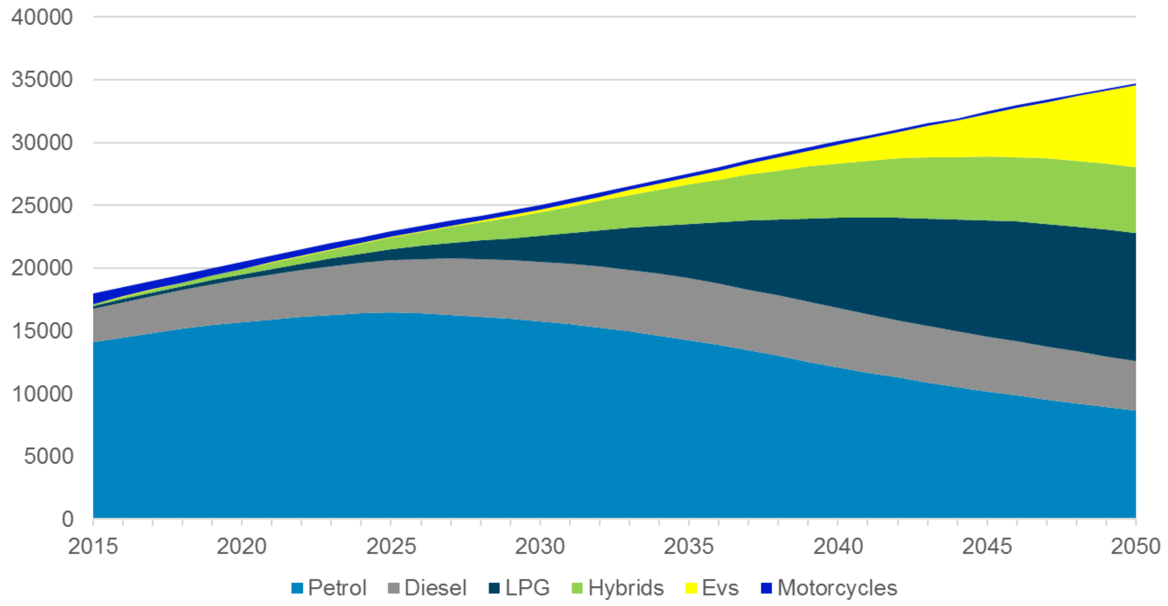


Figure 24: Vehicle shares by technology, Baseline, Bpkm/y

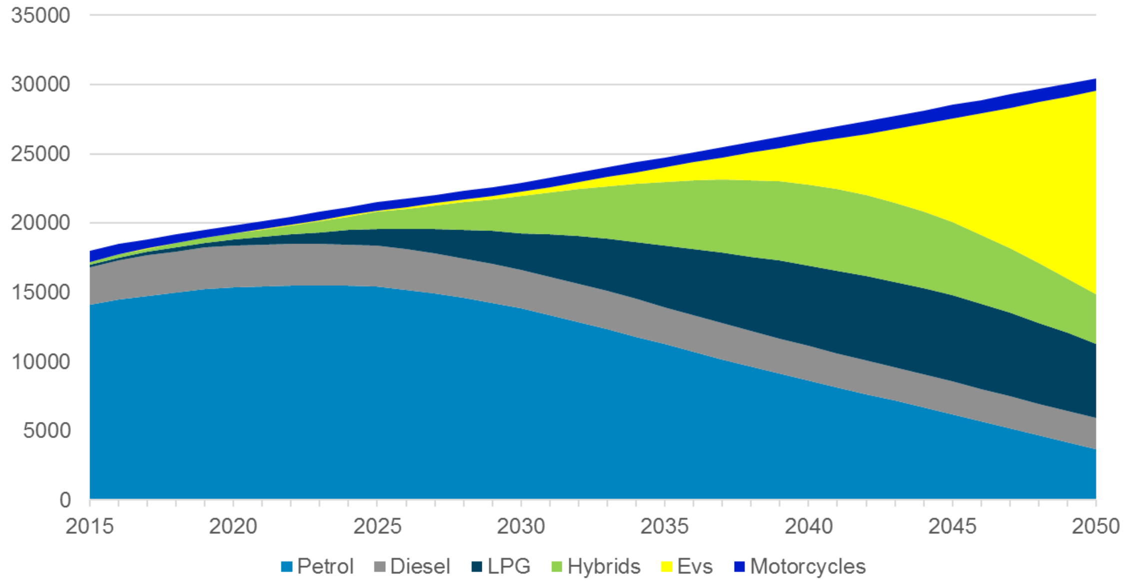


Figure 25: Vehicle shares by technology, Scenario, Bpkm/y

In the baseline, diesel and petrol technologies remain the dominant technologies over the projection period, although the share of hybrid and electric technologies grows over time. By 2050 EVs and hybrids account for around a third of the total vehicle stock.

In the 2-degree scenario there is higher take-up of lower carbon technologies. A rapid increase in the take-up of hybrids and EVS is expected. The rapid increase in the use of hybrids reaches its peak 2040, before starting to decline, to be replaced by pure electric vehicles.

As we move towards 2050, biofuel mandates are gradually stepped up, meaning that the use of the remaining petrol, diesel and hybrid vehicles also becomes less carbon-intensive. This contributes a substantial part of the total bioenergy consumed in the 2-degree scenario; however, the vehicle fleet is likely to be fully electrified soon after 2050 in this scenario, so the demand for biofuels in the transport sector would decline rapidly after this point.

Conclusion

A range of policies are required to achieve the 2-degree target. These include both regulations and carbon pricing. Some of these policies seem much more politically feasible than others but it seems clear that strong political leadership would be required to drive forwards full implementation of such policies.

In the 2-degree scenario, coal consumption is expected to fall by up to 90% by 2050, with most of the reduction taking place by 2030. Oil and gas consumption also fall substantially, with reductions in oil demand resulting primarily from a shift to hybrid and eventually electric vehicles.

Hydro is expected to play an important role in the decarbonisation of the power generation sector and this may raise some concerns with respect to water availability and use. Demand for bioenergy is also expected to increase as a result of increasing biofuel mandates towards 2050, however the use of biofuels is expected to decrease after 2050 as more of the vehicle fleet becomes electrified (with conventional internal combustion engine vehicles dropping out of the stock). We do not expect the increase in bioenergy use to put much pressure on food crop production and land-use.

1.4.6 Investigating the Bioenergy Nexus with the MAGNET and IMAGE models.

An evaluation of trade-off and synergy effects of global bioenergy use within the Nexus.

An introduction to the Bioenergy Nexus

The production and use of bioenergy is closely linked with every element of the Nexus (Climate, Energy, Land, Water and Food). Several assessments show that biomass will become an important source of energy in the 21st century if ambitious climate change policies are implemented (e.g., Chum et al., 2017; Creutzig et al., 2015; Winchester & Reilly, 2015)). However, the use of biomass for energy production can potentially lead to higher prices of agricultural land and agricultural commodities, which can lead to undesirable effects on food consumption and food security. Moreover, the use of biomass can also lead to deforestation and other types of land use change, which can lead to a loss of biodiversity and to greenhouse gas emissions from land use change.

In this study several strategies to safeguard the sustainability of biomass supply are examined 1) a shift in the use of first generation biofuels made from food crops to the use of second generation biofuels made from lignocellulose biomass (which includes residues from agriculture and forestry, and woody and grassy energy crops), 2) diverting the production of woody and grassy energy crops to areas not suitable for agriculture (and not forested) and 3) protecting biodiverse areas[1]. Therefore, the objective

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[1] The text and analyses presented here are based on analyses carried out within the Knowledge Infra Structure (KIS) project (KIS, 2016), which is funded by the European Climate Foundation and the Ministry of Economic Affairs of the Netherlands.

of this section to provide insights in the various trade-off and synergy effects within the Nexus and more specifically the impacts on the price of agricultural commodities, land use change and land use change induced greenhouse gas emissions, and the price of crops and lignocellulose biomass used for the production energy.

Bioenergy Nexus assessment framework

To evaluate the synergy and trade-off effects of strategies to ensure the sustainability of biomass supply within the Nexus we evaluate the impacts of a worldwide large-scale use of bioenergy in 2030 with and without these strategies. The analyses are evaluated using the MAGNET-IMAGE modelling framework. The Modular Applied GeNeral Equilibrium Tool (MAGNET) is a recursive dynamic global computable general equilibrium (CGE) model developed by Wageningen Economic Research (Woltjer, Kuiper, & team, 2014). IMAGE 3.0 is an integrated assessment model of interacting human and natural systems, which is operated by the Netherlands Environmental Assessment Agency (PBL; (Stehfest *et al*. 2014)). It is suited to assess the large-scale and long-term (up to the year 2100) interactions between human development and the natural environment, and integrates a range of sectors, ecosystems and indicators. MAGNET is applied to evaluate the impacts of bioenergy use on land use and agricultural markets, while IMAGE is used to assess the GHG emissions from expansion of agricultural land into natural vegetation.

First, a baseline scenario is introduced in which no ambitious climate changes policies are introduced and the use of bioenergy remains relatively limited. Second, four scenarios are introduced that include the large-scale use of bioenergy (biofuels for transport and bioelectricity) in 2030 with and without strategies to ensure the sustainability of biomass supply (Table 2).

Table 2: Overview of scenarios and the contribution of bioenergy to energy supply in 2030.

	Scenario name	Description	Share of bio-electricity in electricity	Share of 1st gen biofuels in oil based fuels	Share of 2nd gen biofuels in oil based fuels
n/a	Baseline	Baseline scenario **without ambitious climate change policies**, i.e. without large scale use of bioenergy.	4	8	0
S1	First generation biofuels	High bioenergy use, mainly based on first generation biofuels	6	19	2
S2	Second generation biofuels	High bioenergy use, mainly based on second generation biofuels	6	7	14
S3	Second generation biofuels – use of low productive/marginal areas for woody and grassy energy crops	Same as S2, but woody and grassy energy crops use are produced on low productive/marginal land unsuitable for conventional agriculture.	6	7	14

S4	Second generation biofuels - Reduced land availability	Same as S2, but with biodiversity protection; i.e. the availability of land is reduced.	6	7	15

Bioenergy Nexus effects

Figure 26 shows the impact of large scale use of bioenergy in 2030 and the trade-off and synergy effects of the three strategies (S2,S3 and S4) to improve the sustainability of biomass supply compared to the S1 baseline scenario[2].

S1 First generation biofuels

The use of conventional crops (wheat, maize, sugar beet, sugar cane, rapeseed, palm fruit) for the production of first generation biofuels leads to undesirable effects, such as an expansion of agricultural land (47 Mha) and land use change emissions equivalent to 16 gCO_2/MJ bioenergy (biofuels for transport and bioelectricity). The price of agricultural commodities increases by 5%.

S2 Second generation biofuels

A shift from the use of first generation biofuels (S1) to second generation biofuels (S2) has various favourable effects. The price of agricultural commodities actually decreases by -1% in S2. This decrease is the result of the use of residues from agriculture, extra income from residues incentivises farmers expand the production of the main crop, which increases supply and leads to lower crop prices. The expansion of agricultural land and resulting greenhouse gas emissions are 9 gCO_2/MJ bioenergy, which is 60% of the 16 gCO_2/MJ bioenergy in the S1 First generation biofuels scenario. The favourable impact on prices of conventional agricultural commodities and LUC come primarily from the use of residues (98 %), with biomass from dedicated energy crop woody and grassy energy crops contributing the remaining 2 %.

However, an important trade-off is that the price of biomass nearly doubles compared to S1, which makes the use of bioenergy to mitigate climate change potentially costly. This effect is caused by residues becoming increasingly scarce and the production of woody and grassy energy crops is not attractive remains low in this scenario as it competes with other agricultural activities for land use.

S3 Second generation biofuels – use of low productive/marginal areas for woody / grassy energy crops

The doubling of the price of biomass in S2 can be avoided if it is possible that woody and grassy energy crops are produced on low productive/marginal areas that are not usable for agriculture. It is thereby assumed that the price of low productive/marginal areas used for woody and grassy energy crops remains constant, since the use of these areas does not compete with agriculture or other uses. In that case the price of biomass increases by 5%. However, this strategy has various trade-off effects. One effect is the lower price for biomass and crop residues in particular reduces the incentive of farmers to increase crop production and therefore the crop prices do not fall decrease as they do in S2. Compared

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[2] The impacts of the S3 are compared to a baseline scenario in which the woody and grassy energy crops are established on low productive/marginal areas. The impacts of S4 are compared to a baseline scenario in which the availability of land is reduced. The energy use in these scenarios is nearly the same as in the baseline scenario presented in (**Error! Reference source not found.**).

to the baseline scenario the price of agricultural products is constant in S3, compared to a 5% increase in the S1 First generation biofuels scenario and -1% in the S2 Second generation biofuels scenario. The lower value of residues reduces the expansion of agricultural land compared to S2, but the expansion of woody and grassy energy crops is much higher (73 Mha) and consequently also the total conversion of natural vegetation is higher (82 Mha of which 73 Mha from expansion of woody and grassy energy crops and 8 Mha from expansion of conventional crops compared to 25 Mha higher agricultural land use in S2).

S 4 Second generation biofuels - Protecting natural vegetation

In the S4 Second generation biofuels - Protecting natural vegetation scenario the area available for the expansion of agricultural land and energy and woody energy crops is restricted to protect the biodiversity. Protecting natural vegetation restricts the expansion effects of agriculture to 17 Mha, which is less compared to the 25 Mha in the S2 Second generation biofuels scenario and 47 Mha in the First generation biofuels scenario, while the area used for energy crops remains negligible in all three scenarios. The emissions from the expansion of agriculture and energy crops are 4 gCO_2/MJ, compared to 9 gCO_2/MJ and 16 gCO_2/MJ in, respectively the S 2 Second generation biofuels and S1 First generation biofuels scenario. However, the price of lignocellulose biomass nearly doubles compared to the S1 First generation biofuels scenario, as is also the case in the S 2 Second generation biofuels scenario.

The 1% price decrease of agricultural commodities in the S2 Second generation biofuels scenario does not occur in the S4 Second generation biofuels - Protecting natural vegetation scenario, because the crop expansion and price decreasing effect of the use of residues in agriculture is restricted by the lower availability of land. However, compared to the S1 First generation biofuels scenario (5% higher prices of food) the food price effects of second generation biofuels use are favourable, even in case of higher protection of natural vegetation.

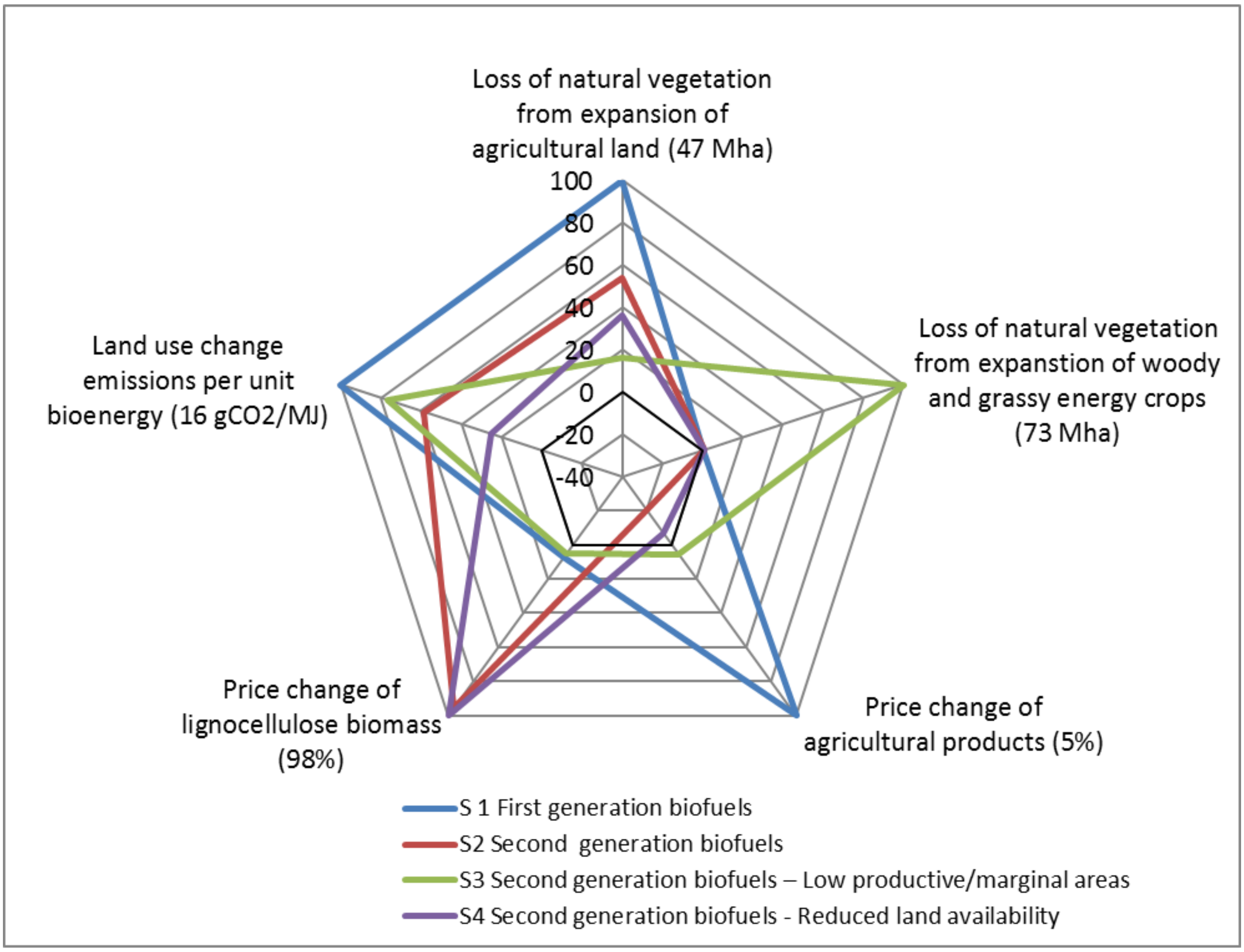

Figure 26. Trade-offs and synergy effects within the Bioenergy Nexus between key indicators of the macro-economic and GHG emission analyses, by strategy. Results are shown relative to the scenario with the highest impact per indicator, which is set at 100%, and absolute figures are presented in the parentheses.

1.5 Addressing the Nexus issues with stakeholders / Engaging stakeholders in the case study

On the 2nd and 3rd of October 2017 a workshop was organized in The Hague by the MAGNET team to bring together the partners of the various thematic modelling groups. The partners are considered to be important stakeholders in the global case study.

During the meeting, the different Nexus processes as represented and investigated by the thematic modelling teams were discussed. On the basis of these discussions, an overview was created of these interlinkages between the nexus systems in the various models (Figure 9). This then served as a basis for the development of the conceptual model (Figure 10).

In addition, it was discussed how model results would be shared, compared and harmonized. It was decided that a selection of output data from two scenarios (a baseline and a 2 degree scenario) would be combined in a single datacube using a standardized reporting format. This served as a basis for the model comparison in section 1.1. Next to that, important assumptions on model and scenario setup were shared in a standardized table to provide insight in differences between models and scenarios (Table 1). At a later stage in the project this will be used to improve harmonization between the models.

2 Conclusions and follow-up

This deliverable is a next step in the cooperation between the thematic models that participate in the global case. The production of a harmonized reporting system and datacube enabled us to compare Nexus indicator results between models. In addition, the information on model and scenario assumptions improves our understanding of differences between the models. The stakeholder workshop held in The Hague formed the basis of a first version of a conceptual model for the global case. Lastly, nexus applications are presented to illustrate the implementation and assessment of the nexus in the various thematic models.

As a follow-up to this deliverable, continued discussions are required on the development of the conceptual model. The model a presented in section 1.3 is not final and is open for discussion with other partners of the consortium. Next to that, additional effort is required to improve harmonization between the models. The current scenarios are all business-as-usual scenarios, however important input/calibration parameters such as GDP and population are not harmonized. Also, important assumptions on efficiency developments in the energy and agricultural systems and climate change mitigation policy have not been harmonized. It has to be discussed how much harmonization is required and feasible over the course of the project.

3 References

Bijl, D. L., Bogaart, P. W., Kram, T., de Vries, B. J., & van Vuuren, D. P. (2016). Long-term water demand for electricity, industry and households. *Environmental Science & Policy, 55*, 75-86.

Chum, H. L., Foust, T. D., Mendes Souza, G., Ballester, M. V. R., de Brito Cruz, C. H., Dale, B., . . . Van der Wielen, L. (2017). The Role of Bioenergy in a Climate-Changing World. *Environmental Development*, Medium: ED; Size: 253 KB.

Creutzig, F., Ravindranath, N. H., Berndes, G., Bolwig, S., Bright, R., Cherubini, F., . . . Masera, O. (2015). Bioenergy and climate change mitigation: an assessment. *GCB Bioenergy, 7*(5), 916-944. doi:10.1111/gcbb.12205

Doelman, J. C., Stehfest, E., Tabeau, A., van Meijl, H., Lassaletta, L., Gernaat, D. E. H. J., . . . van Vuuren, D. P. (in press). Exploring SSP land-use dynamics using the IMAGE model: regional and gridded scenarios of land-use change and land-based climate change mitigation. *Global Environmental Change*.

KIS. (2016). *Managing LUC-induced GHG emissions and price impacts from bioenergy under different scenarios. Deliverable 13.* Retrieved from The Hague and Utrecht, The Netherlands:

Marchal, V., Dellink, R., Van Vuuren, D., Clapp, C., Chateau, J., Magné, B., & van Vliet, J. (2011). OECD environmental outlook to 2050. *Organization for Economic Co-operation and Development*.

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., . . . van Vuuren, D. P. (2013). A new scenario framework for climate change research: the concept of shared socioeconomic pathways. *Climatic Change, 122*(3), 387-400. doi:10.1007/s10584-013-0905-2

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

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 Environmental Change, 22*(1), 21-35. doi:10.1016/j.gloenvcha.2011.08.002

van Vuuren, D. P., Stehfest, E., Gernaat, D. E., Doelman, J. C., Van den Berg, M., Harmsen, M., . . . Edelenbosch, O. Y. (2017). Energy, land-use and greenhouse gas emissions trajectories under a green growth paradigm. *Global Environmental Change, 42*, 237-250.

Winchester, N., & Reilly, J. M. (2015). The feasibility, costs, and environmental implications of large-scale biomass energy. *Energy Economics, 51*, 188-203. doi:http://dx.doi.org/10.1016/j.eneco.2015.06.016

Woltjer, G., Kuiper, M., & team, L.-M. (2014). *The MAGNET model - Module description. LEI Report 14-057*. Retrieved from The Hague:

Martínez P, Blanco M, Van Doorslaer B, Ramos F, Ceglar A (2017). What role will climate change play in EU agricultural markets? An integrated assessment taking into account carbon fertilization effects. Spanish Journal of Agricultural Research, 15(3), e0115. doi: https://doi.org/10.5424/sjar/2017153-9899

Blanco M, Ramos F, Van Doorslaer B, Martínez P, Fumagalli D, Ceglar A, Fernández FJ (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

Humpenöder, Florian, Alexander Popp, Benjamin Leon Bodirsky, Isabelle Weindl, Anne Biewald, Hermann Lotze-Campen, Jan Philipp Dietrich, et al. 2017. "Large-Scale Bioenergy Production: How to Resolve Sustainability Trade-Offs?" Environmental Research Letters. https://doi.org/10.1088/1748-9326/aa9e3b.

Weindl, Isabelle, Benjamin Leon Bodirsky, Susanne Rolinski, Anne Biewald, Hermann Lotze-Campen, Christoph Müller, Jan Philipp Dietrich, et al. 2017. “Livestock Production and the Water Challenge of Future Food Supply: Implications of Agricultural Management and Dietary Choices.” Global Environmental Change 47 (Supplement C):121–32. https://doi.org/10.1016/j.gloenvcha.2017.09.010.

Weindl, Isabelle, Alexander Popp, Benjamin Leon Bodirsky, Susanne Rolinski, Hermann Lotze-Campen, Anne Biewald, Florian Humpenöder, Jan Philipp Dietrich, and Miodrag Stevanović. 2017. “Livestock and Human Use of Land: Productivity Trends and Dietary Choices as Drivers of Future Land and Carbon Dynamics.” Global and Planetary Change 159 (Supplement C):1–10. https://doi.org/10.1016/j.gloplacha.2017.10.002.

Fuso Nerini, F., Tomei, J., To, L.S., Bisaga, I., Parikh, P., Black, M., Borrion, A., Spataru, C., Castán Broto, V., Anandarajah, G., Milligan B., Mulugetta, Y., 2017. Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nature Energy*, [e-journal]. https://doi.org/10.1038/s41560-017-0036-5.

Howells, M., Hermann, S., Welsch, M., Bazilian, M., Segertröm, R., Alfstad, T., Gielen, D., Rogner, H., Fischer, G., van Velthuizen, H., Wiberg, D., Young, C., Roehrl, R.A., Mueller, A., Steduto, P., Ramma, I., 2013. Integrated analysis of climate change, land-use, energy and water strategies. *Nature Climate Change*, 3, 621-626. http://dx.doi.org/10.1038/nclimate1789.

Renzaho, A.M.N., Kamara, J.K., Toole, M., 2017. Biofuel production and its imnpact on food security in low and middle income countries: Implications for the post-2015 sustainable development goals. *Renewable and Sustainable Energy Reviews*, 78, 503-516. https://doi.org/10.1016/j.rser.2017.04.072

United Nations Department of Economic and Social Affairs (UNDESA), 2014. *Prototype Global Sustainable Development Report.* New York: United Nations Department of Economic and Social Affairs, Division for Sustainable Development.

(IIASA) and Food and Agriculture Organization (FAO) of the United Nations, 2012. *GAEZ - Global Agro-Ecological Zones*. Available online at: http://www.fao.org/nr/gaez/en/ [Accessed 10 October 2017]

International Energy Agency (IEA), 2012. *Energy Technology Perspectives 2012.* Paris: Organisation for Economic Co-operation and Development.

Weirich, M, 2013. *Global resource modelling of the climate, land, energy and water (CLEWs) Nexus using the open-source energy modelling system (OSEMOSYS).* (KTH and United Nations Department of Economic and Social Affairs, 2013). Available online at: http://www.diva-portal.org/smash/get/diva2:656757/FULLTEXT01.pdf

Janse, J.H., J.J. Kuiper, M.J. Weijters, E.P. Westerbeek, M.H.J.L. Jeuken, M. Bakkenes, R. Alkemade & J.T.A. Verhoeven (2015), *GLOBIO-aquatic, a global model of human impact on the biodiversity of inland aquatic ecosystems.* Env. Sci. Pol. 48: 99-114.

Kok, M. & R. Alkemade (eds) (2014), *How sectors can contribute to sustainable use and conservation of biodiversity.* CBD Technical Series 79. PBL Netherlands Environmental Assessment Agency, The Hague/Bilthoven.

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