D2.3: REPORT ON SELECTED MODEL IMPROVEMENTS

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0.1	Version 0.1	14/05/2019	Draft
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Executive summary

Changes with respect to the DoA

No individual improvements for the model MITERRA are foreseen as the resources are very limited and will be required to conduct scenario analysis. To compensate for the reduced activities under MITERRA planned improvements under MAGNET and AGMEMOD are extended compared to the DoA.

Dissemination and uptake

This Deliverable is based on contributions from each of the modelling team of the SUPREMA toolbox. Each of the teams will disseminate its individual model improvements to the scientific community at those workshops and conferences where the topic is applicable. Outcomes of the model improvements will be presented at the third Stakeholder Workshop which will be held in early 2020. This Deliverable will be made available to public on the SUPREMA website.

Short Summary of results (<250 words)

For each model a number of improvements for the individual models are planned. They will cover a wide range of improvements which are necessary to conduct the planned Narrative scenarios and take-up some of the priorities identified by stakeholders. Hence, not all priorities can be taken up, as data is not available, implementation will require more efforts and time, or additional research is required. The plan is quite ambitious and it realisation in some cases will depend on the speed on the progress and data access. For AGMEMOD is foreseen the expansion and improvement of the existing market expert network, improved representation of the price transmission mechanism, a better representation of agricultural policies, improved representation of environmental regulation/constraints and an alignment with shared socio-economic pathways until 2050. With respect to CAPRI it is planned to improve the integration across spatial scales, to undertake further steps to broaden activity and land-use representation in non-EU countries, to improve mitigation modelling and to represent better adoption of new technologies by farmers. The plans for GLOBIOM comprise an expanded representation of SDGs with a focus on SDGs related to the environment and production and to cover extreme weather events. In MAGNET, it is foreseen to improve the representation of SDGs with a focus on SDGs related to socio-economic issues, cover extreme weather events, to improved land use change representation and the adoption of technologies so as to account for innovation.

Evidence of accomplishment

Deliverable D2.3

Glossary / Acronyms

AEC	Agriculture-environment-climate
AECM	Agriculture-environment-climate measures
AFOLU	Agriculture, forestry and other land use
AFOLU+BE	Agriculture, forestry, other land use and bio-energy
AGMEMOD	Agriculture in the Member States and the EU modelling
CAP	EU Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact Modelling System
CGE	Computable General Equilibrium
DG AGRI	Directorate-General for Agriculture and Rural Development
EC	European Commission
E.G.	For example
ECAMPA2	An economic assessment of GHG mitigation policy options for EU agriculture 2
Ecampa-III	An economic assessment of GHG mitigation policy options for EU agriculture 3
Engage II FWC	Support to the economic modelling of agriculture and rural development policies in Europe framework contract
ESR	
Et al.	And others
Etc.	Et cetera
EU	European Union
EU-15	15 countries that were Member States prior to the accession of 10 candidate countries in 2004
EU-28	28 Member States of the EU
EU-N13	13 Member States that acceded to the EU between 2004 and 2013
EuroCARE	European Centre for Agricultural, Regional and Environmental Policy Research
ES	Eco-schemes
FAO	Food and Agriculture Organisation of the United Nations

FAST	Farm Sustainability Tool for Nutrients for the EU CAP
G7NS	
GAINS	Greenhouse gas - Air pollution Interactions and Synergies
GDP	Gross Domestic Product
GENUS	Global Expanded Nutrient Supply
GHG	Greenhous gas emissions
GLOBIOM	Global Biosphere Management Model
Ha	Hectare
HadGEM2-ES	Hadley Global Environment Model 2 - Earth System
IFM-CAP	individual farm level model
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre
kcal	kilocalorie
LUC	Land use change
LULUCF	Land Use, Land-Use Change and Forestry
N	Nitrate
MAGNET	Modular Applied General Equilibrium Tool
MITERRA-EUROPE	Deterministic and static model which calculates N and phosphorus (P) balances, emissions of NH3, N2O, NOx and methane (CH4) to the atmosphere, and leaching of N to ground water and surface waters
MS	EU Member State
NRD	Nutrient Rich Diet
pp.	Page
RDP	rural development
SDG	Sustainable Development Goals

SDG2	Food security
SDG6	Irrigation water consumption
SDG12	Healthy diets and food waste
SDG13	Climate Change
SDG15	Biodiversity protection
SUPREMA	Support for Policy Relevant Modelling of Agriculture
SUSFANS	Food systems for health - environment - equity and enterprise
UNEP-WCMC	United Nations Environment Programme World Conservation Monitoring Centre
UNFCCC	United Nations Climate Change
US$	US-Dollar
USDA	United States Department of Agriculture
VCS	Voluntary coupled support
WDPA	World Database on Protected Areas
WP	Work Package
WR	Wageningen Research
WWF	World Wide Fund for Nature

1 Introduction

The Deliverable 2.3 aims to identify and to support technical improvements which are related to the efforts in WP3. Under this task, the development of entirely new components is not foreseen; however, the intension is to reduce possible gaps regarding expectations, limitations and deficiencies in the models. In doing so, recommendations and conclusions from WP1 are picked-up. Given the current strategies for further development of each modelling system in the following improvements will be considered which are related to model distinct model. Any requirement of improvements evoked by the linkage of individual models on the model platform will be discussed in Deliverable 2.2 (Task 2.2). In Table 1, first insights can be gained what is regarded as an improvement from an individual model perspective and what from a linkage perspective. Due to evolvement of the SUPREMA project some limited changes in the anticipated improvements are envisaged.

At the current stage the following individual model improvement appear as relevant

- In AGMEMOD the following improvements are envisaged:
- the expanding and improving the existing market expert network and related tools for validation;
- price transmission with respect to world market, across regions and selected products;
- improved representation of existing and future agricultural policies;
- In CAPRI it is planned
- To improve the integration across spatial scales;
- To undertake further steps to broaden activity and land-use representation in non-EU countries;
- To improve mitigation modelling;
- To represent better adoption of new technologies by farmers;
- In GLOBIOM it is foreseen
- To expanded representation of SDGs; focus on SDGs related to the environment and production
- To cover extreme weather events;
- In MAGNET, it is foreseen:
- To expanded representation of SDGs; focus on SDGs related to socio-economic issues;
- To cover extreme weather events;
- To improved land use change representation and to widen the representation of existing agriculture and other land use activities;
- To better implement the adoption of technologies so as to account for innovation.

These listed improvements in Deliverable 2.3 deal only with the individual model improvements. In Chapter 2 those individual model improvement are shortly featured and discussed, separately for each model. In Chapter 3 planned individual model improvements are faced with the planned "Narratives" and the consequences derived hereof on one hand and on the other with priorities set at the Workshop "Needs" to see what improvements are essential to achieve the project objectives. In the final Chapter 4 first conclusion are drawn whether the planned individual model improvements are sufficient to fulfil the prioritized "Needs" (see Table 1) and which improvements will be postponed to be addressed later on. Those will become part of the "SUPREMA roadmap of future directions for modelling".

Table 1. Areas to improve the capacity of current models and linkages achieved

Area	Model improvement	Linkages
Better integration across spatial scales	CAPRI (Task 2.3)	MAGNET, AGMEMOD, CAPRI, IFM-CAP, GLOBIOM(Task 2.2, 3.1, 3.2, 3.3)
Wider variety of agricultural and other land use activities	GLOBIOM, MITERRA-EUROPE (Task 2.3)	AGMEMOD, MITERRA-EUROPE, GLOBIOM, CAPRI (Task 2.2)
Improved representation of existing and potential future agricultural policies	AGMEMOD (Task 2.3)	CAPRI, IFM-CAP (Task 2.2)
Representation of new technologies adoption enhanced	GLOBIOM, CAPRI (Task 2.3)	GLOBIOM, CAPRI (Task 2.2)
Land use	GLOBIOM, CAPRI (Task 2.3)	GLOBIOM, CAPRI (Task 2.2); CAPRI, GLOBIOM, MAGNET (Task 3.3)
Low carbon economy	MITERRA-EUROPE (Task 2.3)	CAPRI, GLOBIOM, MAGNET, MITERRA-EUROPE, AGMEMOD (Task 2.2); All (Task 3.3)
Climate change	CAPRI, MITERRA-EUROPE, GLOBIOM (Task 2.3)	GLOBIOM, CAPRI, AGMEMOD, MITERRA-EUROPE, IFM-CAP (Task 2.2); All (Task 3.3)
Sustainable development goals	GLOBIOM (Task 2.3)	-
Linking agricultural production to upstream and downstream sectors (working of supply chains)	-	MAGNET, AGMEMOD (Task 2.2)

Source: Own compilation based on the Workshop "Needs"

2 Individual model improvements required in the light of the Stakeholder Workshops "Needs" and "Narratives"

2.1 Improvements and priorities based on the Stakeholder Workshop "Needs"

The Workshop "Needs" (March 2018) aimed to capture views of stakeholders on the future societal challenges of the Common Agricultural Policy (CAP) and other related policy areas as well as to identify stakeholder needs and priorities for model-based analyses (both medium-term until 2030 and long-term until 2050) which may affect future agri-food systems and may require adaptation in model-based policy analyses for an evidence-based decision making. Also perceived short-comings in current impact assessments were mentioned and analysed so that, a consequence, desired improvements in models to cover future needs and better options to present the outcomes could be defined and pursued in the further evolvement of the SPREMA project.

The workshop was set up interactively to discuss challenges, needs and shortcomings of the current model outcomes. To structure the discussion topics were grouped into: 1. Global perspectives and climate change, 2. value chain and market aspects and 3. farm risks. The following needs and challenges were perceived under 'global perspectives and climate change'

- **Food demand** analysis
- **Feedback loops**
    - Environmental -> degradation -> impacts on agriculture and vice versa (as with environmental restrictions)
    - Climate change
- **Baseline or scenario**
    - Paris Agreement
    - Legislation to be implemented - binding or non-binding
- Increased **European standards** pose trade barriers, CAP compensate within EU
- **SDGs and demography**
- Trade agreements to **consider sustainability** (societal demand)
- **Subsidies** (too) simplistic – more **tailored and targeted**

Under shortcomings and required improvements under 'global perspectives and climate change' were mentioned

- **Demand dimensions** (diets, health, societal expectation, lifestyle)
- Coverage of
    - **Population, migration**, demography
    - **SDGs' role** (operational indicators)
    - **Land** use, land abandonment, land for biomass, non-ag land
    - Circular economy, technology transfers, new manufacturing, new trade flows **(long-term horizon)**
    - **Interaction between growth and climate** – analyse mitigation
- Adaptations with respect to **water** - spatial issue
- **Parameters** for new technologies, products, policies, activities should reflect
- **Interaction** between economists - other experts, model linkages
- Unrealistic/unreliable **trade outcomes**

Under 'value chain and market' the following challenges and needs were compiled:

- **Sustainability** in the entire **value chain**
- **New developments in food processing**
  - New attributes: nutritional aspects, health, use of antibiotics
  - Change in priorities of society, short and local value chains
- **Competition in material use**: food, feed, bioenergy, bio material
- **Data** availability and data quality
- Strong **structural changes** in agriculture and processing
- **Trade wars**
- **Private standards** versus role of public entities
- **Resource base** and degradation, soil situation, extreme weather, GHG emissions
- **Long-term feedback loops** between agriculture, resources and climate

As shortcomings and required improvements under 'value chain and market' the following items were compiled:

- Coverage of **productivity along entire value chain**
- **Impact** of trade agreements on **specific sectors and countries**
- Conduct impact assessment on **regulations, NTMs, environment, health, Pillar 2 measures**
- Models provide **economic outcomes**, but should also cover other dimensions (**social and environmental** dimensions), risk
- **Improve communication**
  - between modelers, policy makers, decision makers, and the media
  - of results by provision of a coherent story - provide one-pager plus extended appendix
- **Competition between models** important - deeper involvement of the public

Under 'farm' the following challenges and needs were addressed:

- Farm practices, **farmers' behavior**, adoption of new technologies depend on education
- **Endogenize technological change**
- Minimize of resource inputs
- Model **public goods** - animal welfare, food safety, societal needs
- Need to move from **markets to farms to farming systems to practices**
- **Differentiated yields** by practices (key parameters may change)
- **Sustainability**
  - Cover **all dimensions**
  - Sustainability reflected in products - Who will pay for public goods
- Past trends may not explain the future

Participants put together the following shortcomings and required improvements under 'farm':

- Model **management of water, whole carbon cycle, soil**
- Impact of **farmers' behavior on environmental**
- How farmers **adapt to policies**
- Better representation of
  - **Mitigation techniques**
  - **Supply chain** and interlinkages
  - Industrialized farms, structural change, organization of farms
  - Incorporating **off-farm income** -> persistence
  - land markets, access to credit, new actors from outside ag (Investments)
- Mixed methods (models and choice experiments)
- Value chain
  - **Market size and competitiveness** in the VC
  - **Distribution of value added** in VC

Stakeholders also attributed priorities to the different topics by distributing scores to the mentioned keywords. A list with the highest scores is shown below in in Fehler! Verweisquelle konnte nicht gefunden werden.. With respect to the area of global perspective covering climate change and low carbon economy, sustainable development goals (SDGs), land and water constraints, high priorities are put on income generation and distribution affecting the well-being of all humans on the planet as growth and distribution provides the means to deal and overcome existing problems. Additionally also inequality is mentioned as further challenge. Income and its distribution are also strongly linked to the topic future food demand development and its implication for trade which is found on rank 4. Highly scored was environmental degradation of soil, water and bio-diversity and the feedback to the economy in general by increasing cost but also by inducing adaptation and mitigation. Water is also mentioned as separate topic on rank 5 addressing quantity and quality of water, its scarcity but also its sudden surplus by flooding. An important issue is seen in defining SDG indicators as description of SDGs is often relative vague and contradictions between different SDGs may arise due to their interpretation. An additional issues but not scoring as high was that SDG goals are defined for the year 2030 and therefore they should be reflect in 2050 in the models to allow for the necessary time to adjust; however, some participants found it also important to go up to 2070 with model simulations.

Climate change and low carbon economy challenges are perceived by participants with high priorities. In this context, an emphasis is put on consumer preferences and consumer behaviour which are seen as key elements whereas both depict different perspectives. To what extent changes will materialize may depend on the circumstances like e.g. their availabilities, labelling, and income situation. Although demand shifts are evolving quite smoothly disruptive changes may occur quite sudden, often in combination with quality, hygienic, disease or animal welfare problems. In important challenge is to internalize positive and negative externalities. To model public goods like animal welfare, food safety, needs arising with societal and cultural changes requires a representation of whole supply chain. Any adjustment implemented in models needs to reflect consumers' needs (organic products, animal welfare). Further elements of disruptive character are sudden technologies shifts (e.g. digitalising agriculture, chain technologies) and are related to technology diffusion and adoption. As these particular events have not been observed in the past the models need to be adapted by calibration of new activities (farms, processing) or new trade flows but perceived with high priority.

Under the 'market and value chain' international integration of agri-food sectors, integration of agriculture with up- and downstream sectors as well as societal concerns and ethical issues are addressed. Here, participants stated more challenges than in the other two areas (global, farming), resulting in lower scores. Highly ranked with respect to the value are the representation of bio economy and the integration of this newly developing sector in models. Global low carbon economy and topics on adaptations have been also discussed under the global perspective. Top ranks got the issue data availability and data quality in markets and even more in value chains. Although vast amounts of data are generated access is very restricted and hinders an adequate representation. Highly scored challenges which cover distributional aspect related to food access and hunger, but also international demand developments. Some considerations are given to the role of private entities by defining and controlling standards. The gap between increasing international supply and societal preferred regional provision of food is perceived as important as well as the representation of structural changes in the supply chain which is perceived as induce increasingly asymmetries in the chain.

Under 'social concerns', high priorities were allocated to the analysis the relationship between productivity gains and developments in employment. A number of highly scored challenges were already stated under SDGs and climate change like sustainability; (im)migration ad migrant labour in food chain, climate change, rural versus urban relationships, differentiate income groups, jobs, GHG reduction and employment transition.

Table 2. Priorities identified by stakeholders

SDGs (first 6 items of 14)	points
Income distribution and growth	18
Environmental degradation + feedback to economy (soil, water, biodiversity)	12
SDGs indicators with limited coverage -> model outcomes	12
Future food demand -> trade	10
Water	5
Holistic model approach -> global beyond Europe	3
Climate Change / Low Carbon Econ. (first 6 items of 14)	**points**
Disruptive consumer preferences and behaviour	13
Internalize externalities (positive/negative)	12
Disruptive technologies	8
Technology diffusion, adoption	7
Adaptation -> calibration of new activities (between farms)	7
How to anticipate future shocks -> Policy shock	7

Topic II: Value Chain

Value chain, market, international integration (first 6 items of 27)	points
Bio economy	9
Data quantity + quality	9
Distributional aspect (in relation to hunger)	8
Private entities take the role of public entities	7
Regional vs international production	7
Structural change in the chain	6
Social concerns (first 6 items of 9)	**points**
Productivity gains vs employment	9
Sustainability	9
Immigration, jobs and migrant labour in food chain	7
Climate change	6
Health, nutrition	6
Rural and urban relationships	6

Topic III: Farm risks

Farming challenges: behaviour – markets (first 6 items of 9)	points
Role of consumers with respect to organic, animal welfare	15
Supply chain	12
Spread of innovation	7
Monitoring useful for farmers and policy	5
New Approach integration of choice experiments	3
Monitoring in general	3
Farming risks (first 6 items out of 15)	**points**
Water constraints	18
Adaptation versus mitigation	18
Yield = f (…) e.g. fertilizer, pests, chemicals	14
Feed efficiency	10
Technology	9
Infrastructure, transport costs	9

Source: Deliverable 1.1

However, here the perspective with most challenges is more on the market and supply chain putting additional emphasis on processing. Participants also attribute priorities to health and nutrition concerns in general and the relation between rural and urban areas.

Challenges with respect to farming and supply adaptation comprise new mitigation technologies related to climate change, adoption of new technologies, including remote sensing, robotics as well as restrictions in farming related to environmental regulation. With respect to market and behavioural challenges highest scores were given to capture supply chains and final consumers. His behaviour is perceived as disruptive when it comes to organic, animal welfare and low emission production and difficult to anticipate. Often citizens express a willingness to pay while, in the end, consumers choose differently at the point of sale (stated versus revealed). Diffusion of innovations should be better represented in models and will needs to be studied also with respect to impacts on jobs (supply chain) and adoption issues (global). Additionally, monitoring markets is seen as a challenge for farmers and probably policy makers, but also as, in general, a useful activity.

When farming risks are discussed highest scores were allocated to water constraints and equally important to considerations whether to concentrate on adaptation or mitigation under climate change. Both are already discussed in SDGs and climate change issues. Yields and variables contributing to yield developments gain also high priorities whereas efficiencies in crops (yield = f (…) e.g. fertilizer, pests, chemicals) are placed somewhat higher than for livestock (feed efficiency). Technology which is detailed under SDGs and climate change receives a bit low priority. Newly mentioned are challenges in infrastructure and related transport costs respectively transaction cost.

2.2 Improvements required for “Narratives”

In SUPREMA, we envisage three different respective narratives related to the scenarios: (a) baseline, (b) EU common agricultural policy (CAP) and (c) climate policy which were discussed within the Workshop “Narratives” (see details in Deliverable 1.3 and Deliverable 1.4). Two principle sets of counterfactuals narratives were identified: namely narratives for the Common Agriculture Policy (CAP) with a focus on climate and environment and narratives for the climate and policies. The first will deal with medium-term analysis up to 2030 while the latter will cover a time horizon up to 2050 and optionally to 2070. Bilateral trade issues are covered under the CAP scenario while constraints in land and water, sustainable development goals (SDGs) are considered under the climate change scenario. In principle, supply chain issues are related to all scenarios, but due to the frequencies of upcoming adjustments they will be followed up only in relation with the CAP scenario. In so far supply chain issues related to our scenarios and are not amenable to formal modelling they are captured via stakeholder involvement.

2.2.1 Narratives for CAP with a focus on climate and environment

With respect to the CAP it will operate within the frame of the CAP's "new delivery model", according to which basic rules are set at EU level and substantial flexibility is left to the member states for its implementation. Hence, the member states will be required to develop their draft CAP strategic plans and the Commission will assess those proposals. At its base there will be a new system of "conditionality" which links farmers' income support (and other area-/animal- based payments) to the application of environment- and climate-friendly farming practices. Some features of the current systems of cross-compliance and "greening" will be replaced. Some rules of the new system will be less prescriptive at EU level than current rules, but the requirements will nevertheless imply higher environmental ambition. The second layer consists of "eco-schemes" funded by the CAP's Pillar I budget. There, the member states will be obliged to make provision, but there will be no EU-level rules on their content but schemes need to contribute to the CAP's environment and climate objectives. The member states’ designs have to be in such a way that they complement the other elements of environmental architecture while participation in Pillar I eco-schemes will be voluntary for farmers. The third main layer consists of **payments within support for rural development – CAP Pillar II – for various kinds of management commitments (especially agriculture-environment-climate (AEC) commitments**). The member states will have to offer agriculture-environment-climate (AEC) payments, but again, their uptake will be voluntary for farmers. Like Pillar I eco-schemes, agriculture-environment-climate (AEC) payments can potentially cover a range of agricultural practices without, so far, any restrictions by EU rules. In addition, the EU member states will be able to continue their **rural development (RDP) budgets** to fund support in rural areas which could be relevant for the environment and climate - such as funding for knowledge transfer, eco-friendly investments, innovation and co-operation. Overall, then, the future CAP will address environment- and climate-related objectives in various ways. Within a member state, a range of tools might be addressing a given environmental issue (e.g. biodiversity) in complementary ways, but under the general EU principle "double funding" (i.e. paying twice in respect of a given cost) will remain prohibited.

Under the proposed new CAP, the Farm Sustainability Tool for Nutrients (FaST) will need to be used by each farmer as part of the enhanced conditionality requirement helping to optimise farmers' use of nutrients, while protecting water quality and cutting greenhouse gas emissions. The only related obligation for farmers (laid down in the system of conditionality) will be to use it, i.e. activate it and provide necessary data for the tool to be operational.

To cover the elements of the new CAP three CAP scenarios will be developed:

- Strong sustainability and climate focus (a strict enhanced conditionality, and intensive use of ES and AECMs, limited use of VCS; reallocation of EU budget from direct payments to environmental program payments)
- Balanced sustainability and profitability approach (less strict conditionality, small role of ES and limited extension of AECMs, maximum use of VCS)
- As (ii), but with a consumer demand adjustment due to a diet/preference shift

The proposed new CAP will put the EU member states in a prominent and more responsible role with respect to the targeting on policy objectives and the tailoring of policy measures to these objectives (subsidiarity). This may lead to more heterogeneous policies at member state level in the EU. Also the commitments of the member states towards environmental objectives and agriculture's contribution differ. For this reason it will be considered to conduct in depth-assessments for some member states, provided sufficient information is available and synergies with other work (as the budget under SUPREMA does not allow for detailed CAP scenario analyses). The scenarios will involve different assumptions ac cording

- policy measures (ES, AECM, VCS and enhanced conditionality) and
- associated productivity impacts.

In case of specific analyses for individual EU member states, their respective details in implementation may require further refinements.

2.2.2 Narratives for the climate and policies

With respect to "narratives for the climate and policies", SUPREMA will assess the potential contribution of the EU's agricultural sector to climate change mitigation efforts. We will quantify the impact of various levels of ambition for methane (enteric fermentation, manure management, rice cultivation) and nitrous oxide emission reduction (synthetic fertilizer, manure applied to soils, manure left on pasture, manure management, cultivation of organic soils) by implementing a harmonized baseline scenario without mitigation efforts across models and contrast baseline results to a range of climate change mitigation scenarios.

Studied will be different mitigation targets for agriculture in line with a 2°C and 1.5°C target across sectors to capture implications for sectors and sustainability indicators, whereas particular attention will be paid to the 1.5°C target. To emulate the mitigation potentials a carbon price on non-CO2 emissions will be implemented in the models as a tax on agricultural non-CO2 emissions to induce the uptake of emission reduction technologies. Due to international trade regional mitigation policies may impact other regions. Since the EU agriculture is among the most GHG efficient sectors globally, the level of mitigation measures outside the EU is essential to assess the impact of domestic mitigation efforts on EU farmers. To capture the impacts, we will explore first the effect of a unilateral mitigation policy in the EU on the sector by applying mitigation policy only inside the EU while the rest of the world will not apply additional mitigation efforts ("EU"). In a second variant, the whole world will take coordinated efforts across all regions ("World"). In reality, however, some of the non-EU countries took already substantial commitments towards carbon neutrality.

Land based mitigation policies may affect agricultural markets either directly, e.g. through production changes, increased afforestation etc., or indirectly through increased costs for energy and GHG intensive inputs (e.g. synthetic fertilizers) which may trigger environmental and social trade-offs. It will be assessed how increased competition for land related to land based mitigation policies will affect the potential for agricultural non-CO2 mitigation and whether synergies or trade-offs would occur. In a first set of mitigation scenarios, mitigation policy will be implemented only via carbon price on agricultural non-CO2 emissions ("agriculture") while in a second scenario variant, increased biomass use for energy sourced from agricultural land will deliver any synergies or trade-offs with non-CO2 emission reductions ("AFOLU + BE").

Demand side options through reduced consumption of livestock products may contribute to GHG savings with potential co-benefits for health and food security. To test the effect of a shift in dietary preferences, different scenarios will be quantified with respect to changes in dietary preferences and food waste. One scenario assuming business-as-usual (SSP2 diet projections = "None") while in a second scenario a diet shift of total livestock calorie consumption to recommended levels and a 50% reduction in food waste is assumed ("Diet+Waste") until 2070. Climate change mitigation will potentially lead to further intensification of agricultural production with assumed negative impacts on biodiversity, air and water pollution, and water availability. Carbon pricing would have substantial implications for farm incomes, as well as on food security.

Finally, carbon sequestration and growth in the bioenergy supply will represent new economic opportunities. The suit of models available in SUPREMA is very complementary in terms of regional and SDG coverage, and thus suitable for assessment of climate mitigation implications on other sustainability dimensions within the EU and across the world. These will be systematically explored for the retained scenario narratives.

With respect to challenges parameter uncertainties, realistic mitigation policies and consumer behaviour will be regarded. Most of the technologies in mitigation are not widely adopted and if, data about their adoption rates is missing. Bottom-up engineering approaches may present an alternative but bottom-up marginal abatement cost curves regularly show a large potential for mitigation technologies adoption at negative cost indicating unknown hidden barriers or "forgotten" cost, so that modellers need to reconcile such cost structures with the economic principals of their models. The second issue is that data often represents an average value while the cost distribution within a farm population is required to avoid unrealistic corner solutions, so often expert knowledge is applied. With widespread implementation of the mitigation technologies, their cost is likely to substantially decrease while their effectiveness would increase. Long-term climate change mitigation assessments often relies on a carbon tax trajectory representing the level of mitigation efforts needed and allowed to obtain the cost efficient solution in terms of effort distribution across regions, sectors, and mitigation measures. While carbon tax implementation is potentially feasible, its acceptability within the agricultural sector seems currently limited. In agriculture, it is more likely that mitigation policies will support adoption of GHG efficient and emission reducing measures inducing a different distribution of mitigation efforts with direct implications for other SDGs. Finally, it appears that the ambitious mitigation targets will be impossible to attain without life style change. The SUPREMA toolbox is well equipped to simulate impacts of assumed alternative food consumption; however, it cannot endogenously take into account the consumer response to factors trying to influence food choices. Even responses to monetary instruments, such as fat taxes, are probably outside the “comfort zone” of currently used demand elasticities.

3 Individual model improvements

To enhance the capacity of the SUPREMA toolbox a number of improvements are foreseen. But as already mentioned development of entirely new components are not foreseen. Here discussed improvements intend to reduce possible gaps regarding expectations, limitations and deficiencies which are possible under SUPREMA's limited budget. In the following, a number of additional improvements in addition to the GA are described which fore induced by the results of workshops. Some of those improvements might only be tackled in so far that the progress of the project will allow for it and that required data can be retrieved.

3.1 AGMEMOD (P Salamon, R Jongeneel and M van Leeuwen)

For AGMEMOD, the following improvements will be discussed

- the expansion and improvement of the existing market expert network and related tools for validation;
- the representation of the price transmission mechanism with respect to world market, across regions and selected products;
- a better representation of existing and future agricultural policies;
- an improved representation of environmental regulation/constraints;
- the improvement of yield functions and accounting for climate change issues (CO_2 fertilization) which will depend on the achieved progress;
- the extension of the time horizon of the model to cover the period 2030-2050; as well as its alignment with shared socio-economic pathways (SSP) scenarios.

All improvements are not very strongly interacting with each other; nevertheless, they all are seen as necessary to capture stakeholders' expectations to deal with challenges and to fulfil their needs. The mentioned improvements will be implemented separately and in a non-fixed sequence.

3.1.1 Expanding and improving the existing market expert network and related tools for validation

3.1.1.1 State of the Art

In the current AGMEMOD version 8.2 (March 2019) and its previous version, the baseline outcomes are annually validated with the help of two Market Experts' Workshops (one in Brussels and a regional Workshop in one of the Member States). A starting point for a new baseline is provided by the EU Outlook process, supplying aggregate baseline outcomes for the 28 Member States of the EU (EU-28), the 15 countries that were Member States prior to the accession of 10 candidate countries in 2004 (EU-15), and the 13 Member States that acceded to the EU between 2004 and 2013 (EU-N13). The AGMEMOD baseline takes into account those assumptions used to establish the EU Outlook, including policy assumptions with respect to the CAP and its specific implementation at Member State level. Then, the results of this first run are checked and when implausible figures are obtained the model is debugged and rerun, until a coherent draft of the AGMEMOD baseline projections for the EU Member States is available (details see Salamon et al. (2017), pp. 9).

Draft baseline results are then validated by internal AGMEMOD and external national agricultural market experts, whereas country teams are encouraged to review and improve their country models supported by own national market experts within their respective Member State. This interaction between partners and national market experts is a key element to achieve a plausible baseline and scenario analysis of country-level agricultural commodity markets. One approach is to provide feedback with the help of "country fact sheets" summarising baseline results and inquire for market experts' qualitative feedback ("much too high", "too high", "about right", "too low", "much too low"), as well as for additional information on driving factors and events which might change developments (details see Salamon et al. (2017), pp. 10). Those findings will induce amendments by re-estimations, calibrations or the implementation data.

A long-term aim is to bring together a group of pan-national market experts to provide regular support and assistance in market modelling of individual countries (Salamon et al., 2008). Therefore, the next step in the validation process is the organisation of the AGMEMOD Outlook workshop by the AGMEMOD consortium, the JRC and DG AGRI, which is held in Brussels around the end of February/beginning of March and a smaller regional one in May/June of each year. The workshops gather about 50 policymakers, modelling and market experts from the EU. Experts are taken from an internal list which is constantly extended and revised.

Objectives of the workshop are to present and discuss the preliminary results of the agricultural outlook at EU Member State level. The validation of the model-based outcomes is intended to improve AGMEMOD's capacity to generate plausible and sensible market outlooks and to contribute to impact assessment analysis of different policy options. Therefore, the validation process usually takes place at the final stage of the estimation of the projections. As far as possible, comments made during the workshop about expected market developments and their likelihood are, then, incorporated and model adjustments are made which leading to the final AGMEMOD agri-food projections for EU Member States.

In principle, the list of experts is compiled to comprise market expertise on all commodities of the outlook as well as key Member States for specific commodities under consideration. Those experts that are included on the list receive a "Save the date" notice with respect to the foreseen date of the Workshop, and later on a formal invitation. 7 days in advance, they receive outlook results for the relevant commodities for all Member States and are asked to comment on them in the workshop. At the workshop, a short presentation on the commodity projections for key products is delivered, creating this the opportunity for market experts to provide oral review of the mentioned projected market outcomes. Notes or transcripts of expert remarks are taken, serving as entry points for further improvement of the model and its outcomes by means of re-estimation, calibration of existing equations and the implementation of new or updated data among others.

3.1.1.2 Improvements

Improvements with respect to the market expert network may cover three areas:

- Extending and strengthening the network;
- Easier accessibility of the outlook results;
- To facilitate the process.

To extend and to strengthen the network, two features will be pursued: Both the AGMEMOD website and the SUPREMA website will be extended with a folder for stakeholders. Each stakeholder who perceives him- or herself as market expert can fill-in a form-sheet which will allow him or her to become market expert of the AGMEMOD market expert network (self-registration) which enables the registered person to provide validation on the AGMEMOD outlook. Not all possible experts can be invited to the Validation Workshops due to limited resources; hence, they can be provided with the draft outlook results and can give their feedback written and standardized form.

In addition to the mentioned self-registration process via the website, stakeholders in the supply chain will be activated via known their organisations. They will be directly asked whether they can name experts who might be interested in contributing in such a validation exercise. If necessary, Webinars will be organised to provide required information on their expected roles, on the process of validation and on the way their feedback is needed. This improvement will depend on an easier accessibility to the draft outlook results.

Also a better visualisation of outlook results will be emphasised. In addition to xls-files and oral respectively written comments outlook results will be visualized at the websites as well. A tool will be developed so that market experts can "click on" the items for validation and give their feed-back by "clicking on" as well. This adjusted process will – in principle - enable an aggregation of validation outcomes. Hence, a final aggregation will need further discussion about aggregation rules and treatment of diverting validations. Therefore, under the SUPREMA project only first steps towards a better facilitated processed can be undertaken. Those steps will require additional discussion about how market experts perceive the new approach(es) and how efficient and targeted those adjusted procedures are. Their implementation will follow a trial-error approach which might make several rounds necessary. Each round can only be tested under real-time conditions as the motivation of market experts is usually difficult to attract and even more difficult to keep.

3.1.2 On food supply chain and margin analysis

3.1.2.1 General considerations

Many agricultural sector models are preoccupied with primary agricultural production, even though a demand-side is always present. In this respect CGE models proved to be an exception representing always a demand side. Hence, the demand side may also be structured quite heterogeneously. There are supply chains which link primary agricultural production to final food but also non-food demand (e.g. biofuels) but often the demand side is quite shattered involving different levels of processing which, each in turn, required raw materials and providing output demanded. Those supply chains involve many activities going beyond primary production such as logistics, processing, packaging, marketing, distribution, wholesale and retail activities, requiring additionally inputs and factors. Those are not only important because of their added value, but also because of they depict their own dynamics.

As such more insights into the various stages of supply chains and how they link with primary agricultural product production are important, not the least for a better understanding of the margin-behaviour between farm gate prices of primary agricultural products (e.g. raw milk) and consumer products which are made using those agricultural products as input which are turned into consumer products (e.g. drinking milk, or cheese).

3.1.2.2 Planned improvements

In the context of the SUPREMA project due to resource limitation only some effort can be made with respect to a more in-depth analysis of supply chains. The focus will be on one specific sector (e.g. dairy) which will be studied in few Member States (e.g. Germany and The Netherlands). The effort will cover the following aspects:

- Provision of a brief literature assessment with respect to the selected supply chain;
- Descriptive analysis of the selected supply chain and countries;
- Identification of a methodology and data gaps which hamper a proper supply chain analysis;
- A show case will be pursued as a trial to operationalise the assessment in deriving some price transmission relationships, including agricultural and non-agricultural inputs, which link farm gate prices to prices at a downstream supply chain level.

In the assessment, expert consultations are included, and will be necessary as there are already known information gaps, which cannot be covered by data available in the public domain. Since in SUPREMA both partial equilibrium and CGE models are part of the modelling tool set where the latter in theory already include the full set of economic activities related to supply chains, the link between the case study assessment and CGE modelling will be paid attention to.

The effort aims to achieve two important results:

- To provide first insights into the selected supply chain and margin relationships (e.g. validate equivalent milk price calculation), and if possible integrate this type of price formation into the modelling analysis pursued in SUPREMA;
- Based on lessons learned to prepare recommendations for future research, necessary data compilation or new improved approaches to better account for supply chain phenomena in agricultural sector models.

3.1.2.3 Methodology

There are several ways to represent and model the ”intermediate food industry", comprising the collecting, processing, handling and distribution stages between primary agricultural production and final consumption. The standard approach to model retail/farm price linkages is based on the theory of derived demand, where consumer demand for the commodity at retail level generates a derived demand for the agricultural commodity (Gordon and Hazzledine, 1996; Jongeneel, 2000). The retail price of the commodity will be reflected in the farm price plus the cost of marketing and processing of the commodity from the farm to the retail level. The retail/farm price margin is defined as the difference between the retail and farm price covering all other activities. The interest of this study is to determine the impact on the retail price and on the marketing margin resulting from shocks to either the retail or farm sectors. To make such a determination it is necessary to impose structure on the general model.

Several studies use a one output/two inputs framework (e.g. Gardner (1975), Heien (1980), Wohlgenant (1989)). The farm-retail linkage is, then, modelled as a single sector, with one final product output and an agricultural and a non-agricultural “marketing” input. A simple condition is to impose a fixed relationship between the farm product and the marketing inputs used in processing the product for the retail market.

Moreover, it is often assumed that the supply of marketing inputs is perfectly elastic (Wohlgenant and Haidacher, 1989). For example, Holloway (1996) provided a 3-equation reduced form modelling approach, which was extended by Gordon and Hazzledine (2000). Thus, the modelled supply chain is often assumed to be characterized by perfect competition. Several other authors have added to this literature by accounting for different forms of imperfect competition (e.g. McCorriston et al, 1996) or by extending the number of vertical stages in supply chains (e.g. Zhao et al, 2000).

A specific issue to be considered with respect to the dairy sector is that raw milk is processed into a mix of dairy products, which all contribute to achieving a certain margin (Chavaz and Kim, 2001). Conceptually this phenomenon can be captured by following a hedonic pricing approach which links dairy commodity prices to the value of its underlying components (fat and non-fat solids). The role of component valuation will be paid specific attention too in the raw milk – multiple dairy products-price linkage. In the SUPREMA project this literature will be used to establish and estimate (or calibrate) a simple reduced reform-approach to the farm-retail price spread.

3.1.3 Representation of existing and future agricultural policies

The current policy implementation is described in AGMEMOD Consortium (2016), Erjavec et al. (2011) and Salputra et al. (2016). Although the model can handle the most important aspects of the CAP that are affecting markets, like greening and ecological focus areas(EFAs), and voluntary coupled support (VCS) for its application within the context of SUPREMA extensions are required. In the following AGMEMOD improvements needed for assessing policy scenarios of the future CAP policy are addressed.

With the policy reform new instruments are introduced:

- Enhanced conditionality (EC) which is, in principle, can be captured like the old greening, but potentially at some different rates;
- Eco-schemes (ES); and
- Agri-environment-climate Measures (AECMs).

Those instruments will need some different consideration: On one hand, the EC can be implemented with the current model version but some considerations need to be conducted to establish coefficients for their implementation. To pursue that approach several steps need to be followed:

- Technical implementation of the country and potentially product specific coefficients for ECs;
- Deriving values for ECs based on a literature review and discussions with stakeholders and experts.

In contrast, ESs like AECMs involve two components: first, both types measures need to be offered to be offered by each MS, but each MS can make its own choices which one it will provide, and second, when measures become available, farmers can decide whether they will take up the measure or not (voluntary adoption). With respect to this new approach, the model currently cannot explain voluntary adoption. Moreover, the uptake of ES and AECMs will have two potential impacts: (i) market impacts (e.g. reduction in productivity, constraints imposed on land use), and (ii) environmental and climate benefit. While the latter (ii) are mainly aspects covered in Miterra, the former (i) need to be taken into account in AGMEMOD.

Basically, market impacts depend on two factors: (1) the degree of measure adoption; and (2) the impacts on (land) productivity and/or cost. Generally, adoption of measures for ESs and AECMs will depend on the regulatory environment and market related costs and benefits. Other factors playing a role are policy-related remuneration rates for green services and the available budget involved. For the measures that we would like to simulate in a CAP scenario these aspects have to be integrated into the AGMEMOD model.

To allow for simulation of cost related measures, coefficients that affect cost have to be implemented in all relevant sectors while they are currently only available for few selected products. In addition to the extension of cost coefficients, assumptions on their likely size will be required. That information may either be provided by other model results or by an expert panel conducted with stakeholders.

In order to simulate effects based on downward shifts of productivity another set of coefficients needs to be extended. Currently, the productivity (yields per unit) can be increased and decreased by an annual coefficient. Like in the case of the cost coefficient it is not generally applied, so the set of productivity coefficients is required to be extended to all countries and products. Like before, necessary information may either be provided by other model results or by an expert panel involving stakeholders or a combination of both.

3.1.4 Improved representation of environmental regulation/ constraints

3.1.4.1 State of the art

Environmental legislation is currently often included in an implicit way in AGMEMOD. However, the simulation of a CAP-climate scenario may require a more explicit inclusion of environmental legislation and policies for specific Member States. Especially in terms of animal production sectors, EU environmental policies regarding N and P, as well as national environmental regulations (e.g. animal stock restrictions, animal-land intensity restrictions, etc.), may affect (e.g. due to cost increases) or restrict animal productions (e.g. animal number ceilings). Moreover, the various pieces of legislation can overrule each other, where one of them is most binding (which can change over time). In order to take this phenomenon into account for the SUPREMA project, at least for some Member States (prototype) a methodology will be developed and implemented to account for a better and more realistic representation of environmental legislation affecting agriculture.

3.1.4.2 Planned improvement and methodology

Depending on the specification of the environmental policy measures, their impacts on animal numbers as well as yields (where relevant) will be included. As regards the constraints on animal stocks, the environmental constraints on herd numbers will be explicitly modelled, and included in the herd 'supply' functions, where the observed herd H* will be set to the minimum of the herd (without any constraints) as this is provided by the current herd equation H(.), which is usually specified as a function of economic variables and a trend, and the relationships representing the various environmental constraints (e.g. R1, R2, ...), or

$$H^* (.) = \min(H(p, t), R1(t), R2(t), ...)$$

Information with respect to the environmental constraints will be included in the Policy Input Assumptions file-structure.

3.1.5 Improvement of yield functions and accounting for climate change issues (CO_2 fertilization)

3.1.5.1 State of art

In the current specification of yields, which follows a medium-term orientation, no explicit link is made to climate impacts. Extreme weather impacts related to climate change are difficult to implement in a model which focuses on medium run trends. However, climate change includes also systematic patterns which may affect model variables (especially crop yields) as a consequence of changing CO_2 concentrations in the air.

3.1.5.2 Improvements

As reported in the existing literature (Jaggard et al., 2010), free-air CO_2 enrichment (FACE) experiments indicate that certain crops will benefit from higher GHG concentrations. Although there is substantial uncertainty regarding the impact and size of this phenomenon, we will revise the specification of some yield equations to account for some of the key findings of the existing literature.

With regards to climate change and the effect of CO_2 enrichment, additional factors such a water requirements/availability and temperature should be mentioned. Leaving aside the occurrence of extreme weather events such as droughts, FACE experiments have revealed rising yields accompanied by reduction in water requirements (Magliulo et al., 2003; Manderscheid et al., 2010). This increase in crop efficiency (Olesen and Bindi, 2002) could permit yield increases under unfavourable conditions characterised by lower availability of water resources. Nevertheless, there is no certainty regarding the extent to which the decrease in water requirements could partially offset the negative consequences of water scarcity. Temperature increases could also impose additional challenges to yield evolution.

However, the existing literature on the impact of climate change on agriculture suggests a positive increase of yields in some areas in Northern Europe (European Environment Agency, 2016). Using the HadGEM2 model,[1] the European Environment Agency (op. cit.) simulates the effects of climate change on crop production when no CO_2 fertilisation effect is included. The results of the simulation indicate a decrease in wheat yields over most of Europe with the exception of some areas in Northern Europe. Parallel, an additional modelling exercise in which CO_2 fertilisation was considered. In this case, the model shows yield increases in most areas, with the exception of Central Europe. The conclusions of the European Environment Agency's study are in line with previous contributions such as Olesen and Bindi (2002) that suggest an increase in cereal productivity in North-Western Europe, accompanied by a decline in cereal productivity in the Mediterranean Region for the upcoming period.

If the progress of the project will allow it the CO_2 fertilisation effect will be implemented in the AGMEMOD model via annual shifts in the yield equation. Values will be drawn from the existing literature. Similarly, the integration of rain fall or rain fall pattern could be considered, either as shifters in the yield equation or as distinct variable.

3.1.6 Extension of the time horizon and SSP scenario alignment

3.1.6.1 State of art

Within the standard version of the AGMEMOD model, i.e. 2030 version, the exogenous assumptions regarding macroeconomic drivers are consistent with the assumptions of the AGLINK model or specific data regarding GDP and population growth as derived from the EU Commission's projections. However, there is no additional data from the AGLINK framework that can be used for updating the AGMEMOD's assumptions for the period 2030-2050. When using the AGMEMOD model in conjunction or comparison with other models for climate related scenario assessment the macroeconomic and world market price projections should align with the standardized scenario's as they are used in this field.

3.1.6.2 Improvements

In this context, we proceed to generate time series for the period 2030-2050 by relying on the Shared Socio - Economic Pathways (SSPs) that have been extensively used in climate studies. More specifically, the baseline for this study is consistent with the rates of growth for GDP and population that are projected in the case of SSP2 'middle of the road' scenario.

For the period 1973-2030, world prices for key commodities are based on the projections of the AGLINK model. From 2030 onwards, time series for key products were extrapolated by using the average of the annual rate of growth projected by AGLINK for the period 2027-2030. The SSP scenarios are included in the Assumption Input files.

[1] Further details on HadGEM2 are available at: https://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadgem2.

3.2 CAPRI (P Witzke, M Kesting, T Heckelei)

For CAPRI the following model improvements have been envisaged as particularly urgent in view of meeting future challenges and successfully running the test case scenarios of WP3:

- To improve the integration across spatial scales;
- To undertake further steps to broaden activity and land-use representation in non-EU countries;
- To improve mitigation modelling;
- To represent better adoption of new technologies by farmers;

The first two are effectively closely related as "CAPRI-internal" improvements because they refer to a more symmetric land use representation between the supply models for European NUTS2 regions and in the global market model of CAPRI. A better integration across spatial scales is of course also achieved with improved linkages of CAPRI to IFM-CAP, MAGNET, and GLOBIOM, but these are not addressed in this deliverable.

3.2.1 More symmetric land use modelling in regional supply models and the global market model

As a background for an explanation of the revisions in CAPRI's global land use modelling it is useful to recap the pre-SUPREMA situation in CAPRI. Land use modelling and the related LULUCF carbon accounting have been extended recently under the study "CAPRI GHG emission accounting and Ecampa-III" (No 154208.x35 under the Engage II FWC) which focussed on the supply models for Europe. The EU focus of CAPRI is both strength and a weakness of CAPRI as it permits to zoom into European regions with a rich modelling output while being more aggregate for non-European regions. The supply models feature the following land related elements.

- Land demand is derived from explicit (primal) maximisation of representative farmers with detailed activities for permanent and non-permanent crops and permanent grassland.
- Land supply of cropland and permanent grassland is represented by a hierarchical system of behavioural function for land supply, considering regional land "availability".
- Non-agricultural land use that complements farm land to give the total region area is disaggregated into forestry, built up areas (urban or "artificial" land) and a remaining "other land" category. This disaggregation uses an ad-hoc scaling mechanism plus some assumptions on the responsiveness of areas (increasing in the sequence urban – forest – other).
- For carbon accounting CAPRI relies on the six UNFCCC categories of cropland, grassland, forest land, settlements, wetlands, and residual. These are mapped to the decision maker activity levels using historical shares from the CAPRI database. Most importantly the UNFCCC category grassland is the sum of the productive grassland explicitly modelled plus some fraction of the "other land".
- Identifying the 6 UNFCCC categories also permits to estimate a 6x6 transition matrix based on a statistical approach: The simulated transitions are those transitions that maximise a Gamma density while being consistent with the simulated land use in the UNFCCC classification. As the mode values for the land transitions are taken from the historical database this implies that CAPRI takes those land transitions as most likely that are most similar to historical patterns while being consistent with changing land use totals.
- Based on the transition matrix CAPRI performs carbon accounting relying strongly on IPCC default values, but for cropland and grassland in the remaining category the carbon effects

are computed using a dedicated carbon balance tool (currently relying on the "century" model).

Land treatment in the global market model shows some similarities and differences.

- Land demand is conceptually also derived from maximising farmers, but there is a dual representation with a normalised quadratic profit function which generates demand for total agricultural land. This is allocated to single crops using yield elasticities.
- Land supply is represented with a function that links supply to agricultural land rents with an elasticity. This is conceptually fully in line with land supply in the regional supply models of CAPRI but certainly more ad hoc regarding the functional form.
- Non-agricultural land use that complements farm land to give the total region area is disaggregated into forestry, built up areas (urban or "artificial" land) and a remaining "other land" category, using the same approach as in the supply models.
- There is no mapping of land use categories in the market model (temporary and permanent (non-fodder) crops, fodder crops including permanent grassland, forest land, urban, other land) to the UNFCCC categories
- There is no modelling of the transition matrix.
- There is no area based carbon accounting. However, there is a product based carbon accounting. But this suffers from missing data (carbon effects from grassland conversion only covered in Latin America).

The last three points are critical limitations that will be overcome under SUPREMA. Otherwise they preclude that CAPRI runs global GHG mitigation scenarios including both non-CO2 as well as CO2 emissions, exactly as is foreseen in the "AFOLU+BE" scenarios described in Milestone 9 related to WP3.3.

3.2.1.1 Revision of land use modelling in global market model

Point 3 in the previous summary on land modelling in CAPRI mentioned both for the regional supply models as well as for the global market model the same ad-hoc scaling mechanism that generates together with some assumptions on responsiveness the current results on non-agricultural areas forest, urban and other. In spite of full consistency we will change this specification under SUPREMA:

- It is difficult to reconcile with welfare accounting
- It turned out that the scaling mechanism may dominate the planned responsiveness of land types
- The asymmetric specifications for supply of agricultural and non-agricultural land is ad-hoc and intransparent
- It does not link to standard empirical parameter estimation.

The pre-SUPREMA specification may be described as follows. Agricultural outputs i (barley, wheat, beef ...) have land requirements LV_i derived from production of these outputs (via yields that respond to prices according to yield elasticities). Adding up all land requirements gives total agricultural land (LT_{ag}).

$$LT_{ag} = \sum_i LV_i(\boldsymbol{P}, R_{ag})$$

Land demand depends on a vector of prices and the agricultural and rent R_{ag} (treated separately). Total agricultural land is just one of several land types (l) that play a role:
l = {ag, tc, pc, fd, no, fr, ur, ot, iw}, where

ag = total agricultural land
tc = temporary (non-fodder) crops
pc = permanent crops
fd = temporary fodder, permanent grassland and fallow land
no = non-agricultural land
fr = forest land
ur = settlements, industrial, built up md any other artificial areas
ot = other land
iw = inland waters (exogenous)

Matching with land demand there is a land supply function for total agricultural land

$$LT_{ag} = \alpha {R_{ag}}^{\beta}$$

Given agricultural land and an exogenous region area as well as exogenous inland waters permits to compute total non-agricultural land residually:

$$LT_{no} = T - LT_{ag} - LT_{iw}$$

This total non-agricultural land (beyond inland waters) is currently allocated to non-agricultural land types n = { fr, ur, ot} according to the shares of "intermediate" areas for non-agricultural land types:

$$LT_n = LT_{no} * \widehat{LT}_n / \sum_n \widehat{LT}_n$$

The "intermediate" areas in turn result from the change in the non-agricultural area against the baseline, considering elasticities that reflect the responsiveness of land types to imbalances:

$$\widehat{LT}_n = LT_n^0 * \left(\frac{LT_{no}}{LT_{no}^0}\right)^{\gamma_n}$$

The concept of elasticities of land types to imbalances expresses the expectation that any disequilibrium in the land balance is very unlikely to be removed by changes in settlement area, and probably only to a small extent by changes in forest land and therefore most of all by changes in other land category. This has worked in recent CAPRI applications but it not very attractive for the reasons mentioned above. Instead we will use a multinomial logit form for land supply of all major endogenous land types f = g = h = m = {ag, fr, ur, ot} and thereby integrate and replace the above separate treatment of land supply for agricultural and non-agricultural land:

$$LT_m = SH_m * T$$

where the area share of land type m is

$$SH_g = \frac{exp\left(\delta_{g0} + \sum_f \delta_{gf} R_f\right)}{\sum_m exp\left(\delta_{m0} + \sum_f \delta_{mf} R_f\right)}$$

and the elasticity of share g (and due to constant region area also land type LT_g) with respect to rent R_h may be derived as

$$\varepsilon_{gh} = \frac{\partial SH_g}{\partial R_h}\frac{R_h}{SH_g} = R_h\left(\delta_{gh} - \sum_m \delta_{mh} SH_m\right)$$

which permits to make use of the same empirical information (on elasticities of agricultural land supply) and assumptions (on the ranking of responsiveness of non-agricultural areas) that have been used so far in the pre-SUPREMA version. For this purpose a calibration problem has been set up that minimises weighted squared differences to the starting values by modifying parameters δ_{mh}. Due to its symmetric treatment of all major land uses the system also includes supply elasticities for non-

agricultural areas but these are unlikely to be ever used. The key parameters are the "cross-rent" elasticities of non-agricultural areas with respect to agricultural rents as these are steering now which non-agricultural areas are increasing if agricultural area declines and vice versa.
The code for the revised calibration has been developed but not yet fully tested as this would have disturbed the testing of the supply model improvements regarding carbon. However, the approach has been implemented in a "play model" in Excel to confirm its feasibility.

3.2.1.2 LUC modelling as a stochastic process in the global market model

The revision explained in the previous section is a limited but useful improvement in conceptual and theoretical terms. However the critical limitations of land use modelling in the CAPRI global market model are the gaps in elements 4 to 6 mentioned above: no mapping from CAPRI land types to UNFCCC land types, no transition matrices and hence no carbon accounting according to IPCC default values. Fortunately the Ecampa-III study has prepared the key data work already such that we may make with rather limited coding work a great leap forward in terms of analytical power.

The mapping of market model land types LT_l to UNFCCC land use LU_k will rely on the most recent historical shares φ_{kl} of UNFCCC land use k in CAPRI land type l:

$$LU_k = \sum_l \varphi_{kl} LT_l$$

These shares are trivially zero or one in case that certain land types like "temporary non-fodder crops" (tc) and permanent crops (pc) are exclusively mapped to one UNFCCC category (cropland). The remainder to total cropland derives from temporary fodder and fallow land which is a fraction of total fodder area with the remainder being (productive) permanent grassland. The allocation of "other land" (ot) to grassland (φ_{glot}), wetland (φ_{wlot}) and residual land (φ_{rlot}) may occur as in the European database but requires that some programs in use for the supply models be modified to initialise the extended global market model. This is part of the preparation for the scenarios foreseen under WP3.3.

Step 5 on the path to global carbon modelling and accounting is the land transition matrix describing how an initial allocation of land uses (either from the base year or from an intermediate simulation year) is transformed into the currently simulated one. The transition matrix may be expressed in terms of absolute areas from land use LU_j in the initial year converted into another land use LU_k in the final year or in terms of an annual transition matrix T_{jk} giving the share (probability in a Markov chain) of land use LU_j converted each year into LU_k :

$$LU_{k,t} = \sum_j T_{jk} LU_{j,t-1}$$

Where probabilities have to add up to one:

$$1 = \sum_k T_{jk}, \forall j$$

And the most likely land transitions maximise a Gamma density (current choice), giving for each transition probability a corresponding FOC:

$$(\lambda_{jk} - 1) T_{jk}^{-1} - \mu_{jk} + \tau_k + \tau_j^{initial} = 0$$

Where λ_{jk} and μ_{jk} are parameters related to the mode (determined from the database or baseline projection) and standard deviation (assumed = 1) of the Gamma density. The variables τ_k and τ_j are

shadow values paired with the final year land use accounting from transition probabilities and the adding up condition for probabilities.
It should be acknowledged that the future global market model will include more equations and variables for the extended land use modelling that could increase solution time. This was also the case when introducing the same equations in the regional programming models, but the global market model will have these equations multiplied with the number of regions with agents (about 80). Whether this is critical will be explored in the coming tests.

3.2.2 Improve mitigation modelling

Relying on a completed step 5 we may move to the final step towards global carbon accounting which is to transfer the existing carbon accounting equations from the supply model to the global market model. The equations concerned are, indicated with their present "CAPRI names" in the supply models:

Table 3:

GWPLUC_	"LULUCF contributions GLUC (in global warming potentials)"
GWPCO2HIS_	"CO2 emissions from the cultivation of histosols"
GWPCO2BIO_	"carbon effects from LUC and FM concerning biomass and litter"
GWPCO2SOI_	"carbon effects from land use change concerning soil organic carbon"
GWPCH4BUR_	"methane emissions from burning"
GWPN2OSOI_	"nitrous oxide emissions from land use change related to soils"
GWPN2OBUR_	"nitrous oxide emissions from burning"
GWPN2OHIS_	"N2O emissions from the cultivation of histosols"
LANDSHARE_	"Share of some land types in cropland or grassland in UNFCCC sense: 3 eqs"
bioMassPerHa_	"CO2BIO per unit for Crop and grslnd: 2 eqs"
socGrslnd_	"SOC for grassland as average of GRAS and shrubland: 1x max 9 climzone eqs"
SOCFactor_	"SOC factor depending on landuse and climate class: 2x max 9 climzone eqs"

As most CAPRI regions combine only a small number of climate zones we may assume for an illustrative calculation three (out of 9). In this case we would have 22 additional equations for carbon accounting per region and 1738 equations in total (on top of those for land use modelling mentioned above), give that the CAPRI global market model has already now about 80000 equations and variables this should not involve technical problems.

The technical coefficients may rely on the FAO data compiled for the implementation of LULUCF accounting in the supply models. Here they served often only a fall back solution in case that some European dataset was missing, but for the global market model these are often the only source of data available. The preparations are therefore made but in the technical implementation up to the WP3.3 scenario some surprises cannot be excluded.

There is one new element required for the planned implementation of a carbon tax deriving from land use and land use changes: In the supply models the tax is simply added as a cost element in the existing income accounting for the regional farms to make it effective. In the global market model there is no explicit income accounting. The carbon tax levied so far on non-CO2 emissions has been translated therefore into a tax on outputs, depending on the product based non-CO2 emission factors of outputs that may be changed implicitly. For LULUCF an explicit tax on land use would be more transparent, but the envisaged land allocation system as presented above has currently only an aggregate supply of land (rather than with breakdown into temporary and permanent crops and fodder). At this point it is thus not entirely decided if the "LULUCF tax" may be levied on some agricultural land subcategories or whether they need to be allocated to products (giving more equations in the system).

3.2.3 Better representation of adoption

The present status to represent the adoption of mitigation technologies is still well described by Section 4.3 in Perez-Dominguez et al. 2016 (Ignacio Pérez Domínguez, Thomas Fellmann, Franz Weiss, Peter Witzke, Jesús Barreiro-Hurlé, Mihaly Himics, Torbjörn Jansson, Adrian Leip (2016): An economic assessment of GHG mitigation policy options for EU agriculture - EcAMPA 2 -, Final Report, JRC) which underlies the introduction to this section.

The general modelling approach for the specification of cost functions in the CAPRI model is also used for the specification of costs involved in the adoption of a mitigation technology. The CAPRI supply equations are nonlinear inter alia because the cost function C^O is nonlinear. It is so because CAPRI considers that there may be other costs, known to farmers but not included in the pure accounting cost statistics, which increase more than proportionally if production of a certain commodity (e.g. maize) is expanded. These other costs may appear due to bottlenecks of labour and machinery, but potentially also risk premiums. Due to these non-linear costs, farmers will not suddenly and to a large extent switch from barley to maize production even if in a scenario net revenues of maize may happen to increase beyond those of barley. A sudden and large switch to the production of a more profitable commodity (like maize instead of barley) would be the outcome of a linear programming model and depicts a problem known as 'over-specialization'. This is not observed in statistics and, therefore, CAPRI uses nonlinear costs to reflect the rather smooth responsiveness to incentives that actually favour the switch to the production of a different commodity. These nonlinear costs are known in literature as "calibration costs" and are a well-established and commonly used modelling approach (Howitt 1995; Heckelei and Britz 2005; Heckelei et al. 2012).

For activity levels (e.g. production of a certain crop), the “responsiveness” to economic and political incentives is expressed in terms of elasticities, which give for example the percentage increase in an activity level (production of wheat) if the output price for wheat is increasing by 1 %. For technological mitigation measures responsiveness is not captured with elasticities, because most rates of adoption (relying on the GAINS database) of the mitigation technologies are zero in the base year, and therefore elasticities cannot be defined (because the uptake of a technology would then remain zero also in the scenario). Instead the responsiveness to apply a certain mitigation technology is measured in terms of the increase in the mitigation share of this technology if a certain subsidy is granted for mitigation. For the cost function calibration, we consider the choice of the mitigation share for a single fixed activity where mitigation receives a subsidy S (which is zero in the observed situation). The problem is thus to minimise net cost N:

$$\min_{mshar} N(mshar_{a,m,e}) = C^m(mshar_{a,m,e}) - S_{a,m,e} \cdot mshar_{a,m,e}$$

where

mshar vector of mitigation shares. Typical element $mshar_{a,m,e}$
a set of production activities (e.g. dairy cows)
m set of mitigation technologies (including “no mitigation”)
e emission type (e.g. CH4 from manure management)
N net cost function, equal to cost net of the subsidy
C^m mitigation cost per activity level for mitigation option *m*, which depends on mitigation share $mshar_{a,m,e}$ for activity a, mitigation option *m*, and targeting emission type *e*
S subsidy for implementation of the mitigation option *mshar*.

The proposed specification splits the CAPRI mitigation cost function *C(.)* into a part coming from GAINS and other costs not accounted for in GAINS. These cost that are not accounted for in GAINS reflect the costs that are related to the determinants for technology adoption going beyond pure profitability considerations (see previous section):

$$C^{m}(mshar_{a,m,e}) = \left(\kappa_{a,m,e} + \beta_{a,m,e}\right) \cdot mshar_{a,m,e} + 0.5\gamma_{a,m,e} \cdot \left(mshar_{a,m,e}\right)^{2}$$

where

$\kappa_{a,m,e}$ cost per activity level for a full implementation of a certain mitigation option as given in the GAINS database; emission type *e* from activity *a*, if a mitigation technology *m* is used

$\beta_{a,m,e}$, $\gamma_{a,m,e}$ (additional) cost parameters not covered by GAINS

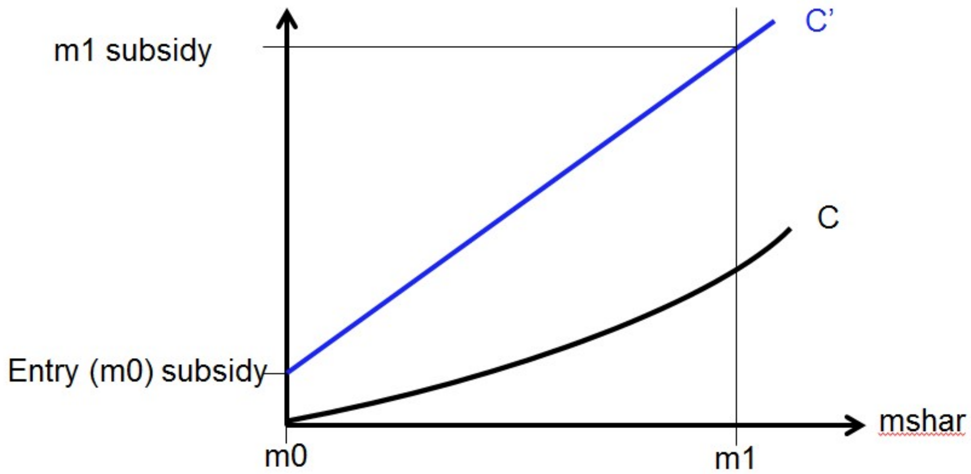

Figure 1: Representation of mitigation cost curves in CAPRI

Source: Adapted from Fig 19 in Perez-Dominguez et al 2016

For the parameter specification, two cases have to be distinguished, depending whether or not the mitigation technology is already applied in the initial situation according to the GAINS database).

Parameter specification when the mitigation technology is already adopted in the base year

To specify the cost parameters that are not depicted in the GAINS database (i.e. the ones relating to the above outlined determinants for technology adoption), we use two conditions, the first one being the first order condition for cost minimisation at the observed mitigation share (assumed > 0 here, the case of zero initial shares is discussed below):

$$\partial C^{m}(mshar^{0}_{a,m,e}) / \partial mshar^{0}_{a,m,e} = 0$$

$mshar^{0}_{a,m,e}$ Current mitigation share according to the GAINS database (m0 in the figure above)

The second condition is an assumption related to responsiveness. For a certain subsidy S the optimal solution would be the implementation of a mitigation technology up to the technical limit (which is given in the GAINS database):

$mshar^{1}_{a,m,e} = mshar^{\max}_{a,m,e}$ (m1 in the figure above)

We assume for the time being that the implementation of a mitigation technology would be at its maximum if a relative subsidy of $S^{1}_{a,m,e}$ = 80% of the accounting costs from GAINS $\kappa_{a,m,e}$ is paid. The assumption of 80% explicitly renders responsiveness of applying the technology. If a lower relative subsidy would be assumed (e.g. only 10%) this would mean that farmers would quickly adopt the technology completely. However, this would be unrealistic, following the determinants of technology adoption outlined in the previous section. If a higher relative subsidy would be assumed (e.g. >100%), this would mean that for those farmers that are "late followers" of adopting the technology, there would be near zero benefits of applying the technology. By definition then, the first order condition for minimisation of the net cost N(.) should be zero at the maximum implementation share

$$\partial N^{m}(mshar_{a,m,e}^{1}) / \partial mshar_{a,m,e}^{1} = \kappa_{a,m,e} + \beta_{a,m,e} + \gamma_{a,m,e} \cdot mshar_{a,m,e}^{1} - s_{a,m,e} \cdot \kappa_{a,m,e} = 0$$

This is the second condition needed to specify a nonlinear cost function with smooth behaviour of uptake of the technological mitigation options.

Parameter specification when the mitigation technology is not adopted in the base year

There are several technological mitigation technologies, where the GAINS database indicates that they are currently not applied by the farmers, i.e. the uptake of these technologies is zero in the base year. This implies that it is currently not attractive for farmers to apply the technology. To model the cases with zero uptake in the base year, we assume that a relative subsidy of $S^{0}_{a,m,e}$ = 20% of the accounting costs from GAINS would be needed to make the technology almost attractive for the first adopter. Furthermore, as the technological mitigation options with observed zero shares in the base year are apparently less attractive to farmers, a full implementation also by “late followers” may only be expected at a higher subsidy rate. Our assumption for these cases is 120% (rather than the assumed 80% for those technologies already applied in the base year), which implies that the uptake of the mitigation technology by “late followers” is more heavily constrained by (some of) the non-economic determinants for technology adoption outlined in the previous section. Thus we assume that a higher incentive is needed to achieve a full adoption of the mitigation technology by all farmers.

Sensitivity of our modelling approach for the uptake of mitigation technologies

It has to be stressed that there is no empirical evidence for the specification of the threshold values for the relative subsidies assumed in our modelling approach. Apparently, such evidence is difficult to come by when considering the nature of future mitigation options. Even though the approach may have a weak empirical basis, the alternative to only use the cost depicted in the GAINS database is known to be further away from reality. It would imply, for example, that farmers are homogeneous in a region and would happily switch from one economic or production option to the next if the latter increases regional income by one Euro. Such jumpiness in farmers' behaviour contradicts all anecdotal evidence and also the determinants for technology adoption outlined in the section on the (non-) adoption of technologies by farmers.

3.3 GLOBIOM (S Frank, P Havlik)

For GLOBIOM the following model improvements have been conducted in coordination with other ongoing research activities:

- To expanded representation of SDGs in GLOBIOM;
- To improve the capacity of the model to cover extreme weather events;

3.3.1 Expanded representation of SDGs

The Sustainable Development Goals (SDGs) set an agenda for the sustainable management of social, physical, and ecological elements of the Earth system and attempt to guide and monitor progress across along 17 goals and 169 specific targets [1]. Many of the SDGs are interrelated and can be in fact connected to land use, in particular SDG2 Zero Hunger, SDG6 Clean Water and Sanitation, SDG12 Responsible Consumption and Production, SDG13 Climate Change, and SDG15 Life on Land.
While SDGs related to land based climate change mitigation policies (SDG13) are well covered in GLOBIOM, other SDG targets were covered only to a smaller extent. This was recently expanded to also cover additional land related SDGs such as food security (SDG2), diet change and food waste (SDG12), irrigation water consumption (SDG6), and biodiversity protection (SDG15). The present status of the SDG representation is well described in section B – lookup table documentation in Frank et al. (Stefan Frank, Petr Havlík, Mykola Gusti, Hugo Valin, Nicklas Forsell, Fulvio DiFulvio, Amanda Palazzo, Pekka Lauri, and Michael Obersteiner (2018): Final report, Reproducing land-use patterns in energy models, JRC) which underlies most of this section.

3.3.1.1 Food security (SDG2)

To achieve the SDG target of zero undernourishment by 2030, we apply a food security constraint in GLOBIOM to ensure certain calorie intake levels and for example, avoid strong decreases in calorie intake (especially in developing countries) under high carbon price scenarios which usually tend to increase agricultural prices for GHG intensive products such as ruminant meat, milk, or rice. The constraint ensures that by 2030 the population at risk of hunger is reduced to at most 1% in food insecure countries in line with SDG2 Zero Hunger. Currently around 10% of the global population was undernourished in 2016 according to FAOSTAT. To estimate the population at risk of hunger we apply the FAO approach[2] as described in detail in Hasegawa et al. (2015). The method considers the mean food caloric intake per person per day, the mean minimum dietary energy requirement, and the coefficient of variation of food distribution of the dietary energy consumption in a country. If food insecure countries exceed this calorie intake threshold over time e.g. related to GDP per capita growth, they may reduce their consumption levels in response to the carbon price signal to that threshold; however they may not consume less (see Figure 2) illustrates the food security constraint for the Western Africa region.

[2] FAO Methodology for the measurement of food deprivation: updating the minimum dietary energy requirements, 2008 http://www.fao.org/fileadmin/templates/ess/documents/food_security_statistics/metadata/undernourishment_methodology.pdf

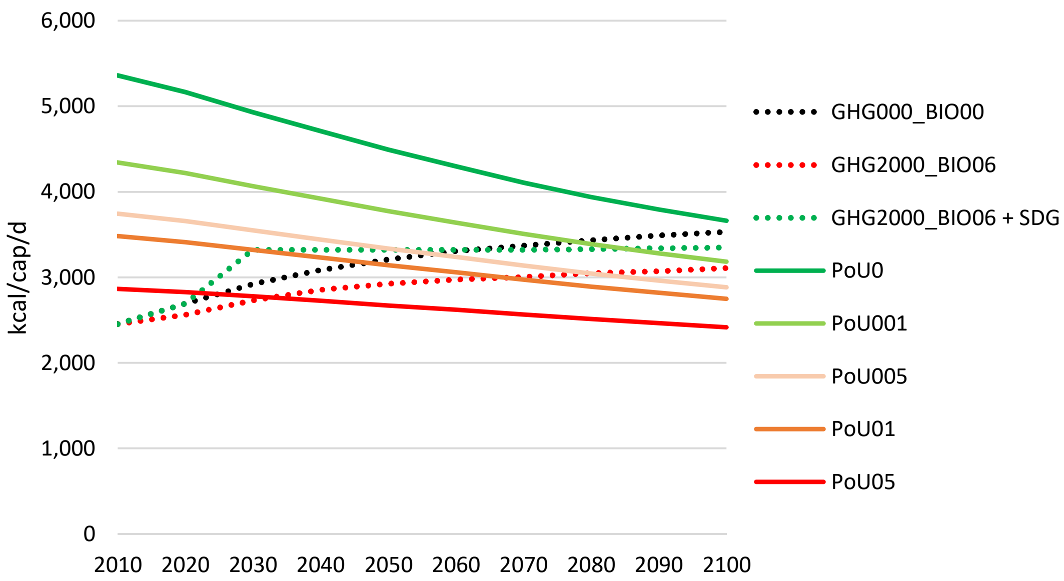

Figure 2: Food security constraint in the SDG set-up in Western Africa region.

Solid lines (PoU) respresent the calorie intake levels which correspond to a certain level of undernourishment i.e. PoU01 - 1%, PoU5 – 5%. The pointed lines represent GLOBIOM results for the baseline scenario (GHG000_BIO00) and two mitigation scenarios without (GHG2000_BIO06) and with (GHG2000_BIO06 + SDG) consideration of the food security constraint.
Source: Frank et al. (2018)

3.3.1.2 Healthy diets and food waste (SDG12)

To mimic SDG12 which aims to ensure sustainable consumption (& production) patterns, we use the healthy diet assumptions developed in the AgCLIM50-2 project in GLOBIOM. We assume a change in dietary preferences for livestock products based on the USDA recommendations for healthy diets (https://www.cnpp.usda.gov/USDAFoodPatterns) where animal calorie intake is decreased to 430 kcal/capita/day by 2030 in countries exceeding this threshold. In addition, we also assume a halving of current food waste by 2030 in line with the SDGs. Moreover, additional health and diet indicators beyond calorie consumption per capita were implemented in GLOBIOM recently which allow reporting on nutritional aspects of different diets. Two food and nutrient based indicators (Nutrient Rich Diet (NRD) 9 & 12 – score indicators based on maximum/minimum intake level of key nutrients in a diet, and G7NS – a score indicator based on recommend maximum/minimum intake levels of certain food items e.g. red meat etc. in a diet) were based on the GENUS database and calculated as described in more detail in Zurek et al. (Monika Zurek et al. (2017): Sustainability metrics for the EU food system: a review across economic, environmental and social considerations, SUSFANS Deliverable No. 1.3).

3.3.1.3 Irrigation water consumption (SDG6)

To translate SDG6 (sustainable water use) into GLOBIOM we limit irrigation water use in agriculture to sustainable removal rates that do not jeopardize ecosystem services and environmental flow requirement Pastor et al (2019) . Water use in other sectors i.e. household consumption and industry, is given priority over irrigation water demands. Projections from Wada et al. (2016) are used to represent future developments in the demand from these sectors and water availability is provided by the HadGEM2-ES model and assumed to remain constant over time. The water balance is accounted at grid level and with monthly resolution. Currently no irrigation of energy crops is considered, only conventional crops.

3.3.1.4 Biodiversity protection (SDG15)

With respect to biodiversity protection and SDG15 (Life on land) we assume achieving the AICHI target 11 and increase the land surface under protection to 17% by 2030. We use the World Database on Protected Areas (WDPA) from IUCN[3] to identify areas currently under protection. To meet the target we assume an increase of land under protection and hence not eligible for land use change and conversion to manged forests or agricultural areas included dedicated energy plantations. The expansion of protected areas is applied to all categories (I – VI) reported in the WDPA proportionally. In total, around 1700 Mha of land are being classified as protected in the database, around 530 Mha within the highly protected classes I (strict nature reserve, wilderness area), II (national park), and III (natural monument or feature). The other categories IV (habitat/species management area), V (protected landscape/seascape), and VI (protected area with sustainable use of natural resources) may allow a certain degree of sustainable management practises. In addition, we use the UNEP-WCMC Carbon and Biodiversity Report to identify highly biodiverse areas and prevent their conversion to agriculture or forest management from 2030 onwards. We consider as highly biodiverse where three or more biodiversity priority schemes overlap (Conservation International's Hotspots, WWF Global 200 terrestrial and freshwater eco-regions, Birdlife International Endemic Bird Areas, WWF/IUCN Centres of Plant Diversity and Amphibian Diversity Areas).

3.3.2 Extreme weather events

A GLOBIOM model version that is able to deal with yield variability related to climate change (but also other stochastic shocks) is currently being developed at IIASA. The present status of this module is well described in Boere et al. (Esther Boere, Petr Havlik, Franziska Gaupp, Tatiana Ermolieva (2018): Models for designing policies aimed at market stabilization, SUSFANS Deliverable No. 8.6) which underlies this section.

Climate change and weather variability may lead to short-term variability and shocks to agricultural yields. This may not only impact agricultural supply, but the entire food system and pose threats to global food security. To assess the impact of these stochastic shocks and their interdependent demand and supply impacts a framework is required that can take stock of both the climate-induced deviations between expected and observed prices and yields, the impacts on the food commodity market, as well as to analyse different adaptation mechanisms that may serve as market stabilisation policies, such as storage. The GLOBIOM was adapted to integrate these new elements and to analyse the impact of different market stabilization measures on agricultural production and consumption, resource use and trade within the SUSFANS project.

GLOBIOM's default objective function is the maximization of global consumer and producer surplus, defined as the integral under the demand functions minus the sum of all production, resource and trading costs (Havlik et al., 2014). However, a producer bases his production decisions on expected instead of actual prices and on expected yields. To accommodate for the differences between expected and realized prices and yields, the default objective function is adapted by replacing the part of the constant elasticity demand function belonging to crop production with the expected revenues obtained from crop production. Subsequently, the allocation of cropland by crop is fixed and the default objective function is re-run. This two-step system implies that within an agricultural season, an unanticipated change in yields will lead to a change in supply of products, which will lead to a change in the corresponding prices and demand of the product. Only in the next period, a change in resource costs will allow producers to shift the supply and reconsider their crop allocation decisions. Annual weather variability and climatic shocks are implemented based on a model-chain of climate and process-based crop models and will result in deviations from expected prices and yields. Storage is

[3] www.iucn.org

implemented as a potential adaptation mechanism to mitigate price-shocks resulting from unexpected yield fluctuations.

The Figure 3 schematically shows the steps and intermediate and final outputs.

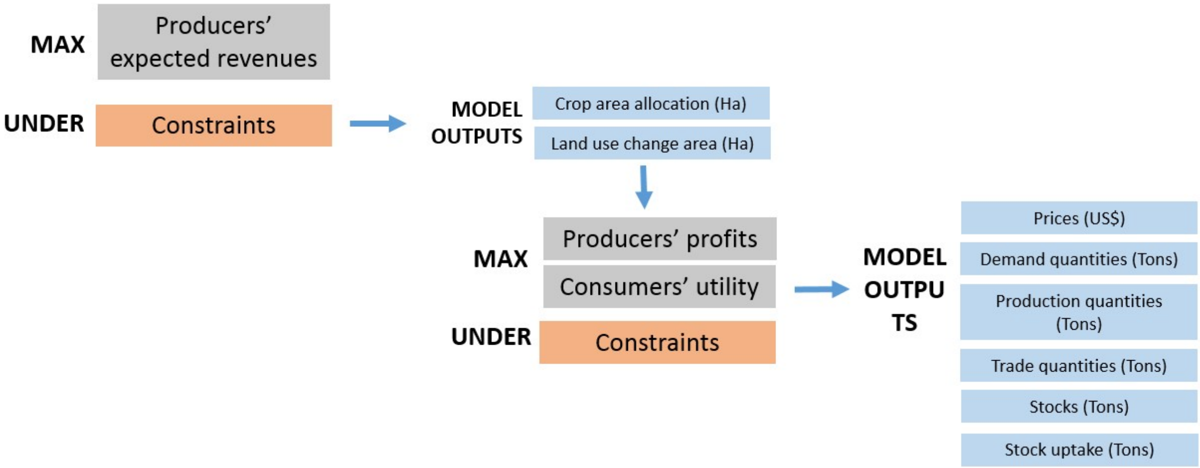

Figure 3: Schematic overview of steps in GLOBIOM-X
Source: Boere et al. (2018)

To test how disturbances in yields affect the severity and duration of disruptions to supply, demand, prices, trade and the use of natural resources, we implement climate-induced yield shocks. Results show that this 'locked in' state, where production levels are different from expectations, leads to significant price spikes and subsequent adjustments in supply, demand, trade and natural resources that overcompensate for the losses incurred. Depending on the sign of the yield shock, an over- or under-production of wheat will occur in the year of the shock. The change in production forces the market to move away from its previous equilibrium state, leading to a change in prices, consumption and trade. The new equilibrium is however a temporary one, as the new equilibrium prices are artificially high (low) due to the large drop (rise) in prices. This leads to oscillation patterns in production and consumption of the base scenario production for the implemented shocks. This need for additional policy measures such as storage capacity under a large negative yield shock is indicative for the region-specific ex-ante policy evaluation that can be performed using the model developed in this study. While the tool is geared towards analysis of ongoing stabilization policies as present under the EU's Common Agricultural Policy, it also lays a basis for future evolution of the model's capability towards capturing management options for other events that destabilise EU's agricultural commodity markets, such as food safety scares or animal disease outbreaks.

3.4 MAGNET (H van Meijl, A Tabeau, M-L Rau)

In MAGNET, the improvements are made on the following topics:

- To expanded representation of SDGs; focus on SDGs related to socio-economic issues;
- To cover extreme weather events;
- To improved land use change representation and to widen the representation of existing agriculture and other land use activities;
- To better implement the adoption of technologies so as to account for innovation;

The aforementioned improvements are elaborated in this section by presenting the state of the art and the further development and implementation. Note that the improvements on the one hand comprise changes in the model, thereby further developing the model. On the other hand, and equally important, the improvements relate to the data as well as implementation of modelling approaches that were developed for certain specific cases, thereby generalising approaches and making them available for research question about the agri-food sector in general. For the improvements, we build on the latest state of the art and go beyond by improving the modelling approaches, the data and the implementation in MAGNET and beyond.

The model improvement in SUPREMA brings together and proliferates the work of the MAGNET team, referring to the specific modules in the modular set-up of the model. The specific modelling approaches relevant for the model improvement are looked after by the following MAGNET team members: SDGs (David Cui, Andrzej Tabeau), extreme weather events (Jason Levin-Koopman, Andrzej Tabeau), land use change (Andrzej Tabeau) and adoption of technologies and R&D (Zuzana Smeets-Kriskova, Hans van Meijl).

3.4.1 Representation of SDGs related to socio-economic issues

In MAGNET, indicators of the SDGs are calculated in a post-calculation. Specifically, the MAGNET results are translated into SDGs indicators that have become the formal language of international impact assessment, following their establishment on 1st January 2016. While the millennium development goals (MDGs) only address developing countries, the SDGs are for both developing and developed countries and are thus relevant for all policy analyses with policy makers being interested in making the link to the SDGs. The SDGs will be valid until 2030.

The SDGs cover 17 topics whereby for each sub-goals are defined and hence made explicit for specific targets. In total, the SDGs comprise 169 associated targets. The 17 SDGs are illustrated in the official UN classification, see Figure 4 The European Commission has fully acknowledged and adopted the SDGs in their internal and external policies and strategies, as outlined in "Key European action supporting the 2030 Agenda and the Sustainable Development Goals" (SWD, 2016).

Figure 4: UN SDGs – overview of the 17 Sustainable Development Goals.
Source: UN (2016).

MAGNET covers the SDGs in a MAGNET module called SDG Indicators. Being an economic model, SDG indicators for 12 socio-economic related SDGs are derived using the variables that are available in the MAGNET model. The following are not covered so far: SDG 3, SDG 5, SDG 11 and SDG 16

While some details on the SDGs covered are presented below, the general set-up of the indicators contains information, as elaborated in the report "Enhancements for bioeconomy and SDGs analysis in Magnet", page 52: 1) levels that refer to calories per day or other reference indicators, 2) shares that provide the insights in terms of a proportion of an specific indicator, for example skilled labour, income etc. and/or 3) indices with 100 usually referring to the base year and the indices hence accumulating in the consecutive years in the simulation. The indices can be weighted by value weighted, price weighted and quantity (constant price) weighted.

The reports "Enhancements for bioeconomy and SDGs analysis in Magnet" (January 2017) and "Sustainable Development Goal Indicators - scenarios for bioeconomy and indicators" (December 2017), both deliverables of projects commissioned by EC-JRC, provide the details of the calculation of the SDG indicators in the MAGNET model. The SDG indicators available in MAGNET are provided in the appendix.

For improvements, we focus on those on socio-economic issues so as to better cover inclusiveness issues, decent work and economic growth. They are particularly relevant for impact assessments of agricultural policies with macro-level economic models, like MAGNET. The details of the SDGs considered are as follows, for details see the deliverables of projects commissioned by EC-JRC (mentioned above):

GOAL 4: Quality education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

- Share of skilled labour

The share of skilled labour in total quantity of labour is introduced as a lagged educational variable, as follows:

$$SDG4_{"ShSkilled",r} = \left[\frac{VFA\_TOTSK\_Q_{reg}}{VFA\_TOTSK\_Q_{reg} + VFA\_TOTUSK\_Q_{reg}}\right]$$

where VFA_TOTSK_Q and VFA_TOTUSK_Q are the total of skilled (denoted by SK) and unskilled labour (denoted by USK) in each region in constant prices.

Goal 8: Decent work and economic growth: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work

- Annual growth rate of GDP per capita

$$SDG8_{"AnGDPpc",r} = \left[\left(\frac{GDP_r/RPOP_r}{GDP0_r/RPOP0_r}\right)^{1/time}\right]\text{-1}$$

where RPOP is the population consistent with PPP real GDP and GDP0 and RPOP0 are initial values at the start of the period, computed outside of the POSTSIM part of the module. Time is the number of years in the simulation period.

- Net trade position

$$SDG8_{"NetTrade",r} = VXWREGION_r - VIWREGION_r$$

where VXWREGION is the value of exports by region r at FOB prices and VIWREGION is the value of commodity imports by region r at CIF prices.

- Revealed Comparative Advantage (currently commented out due to long solve times)

This indicator is the Balassa index of Revealed Comparative Advantage (RCA). If the RCA for region r is greater than 1, then the region exports, as a share of its portfolio, more of tradable i than the global average:

$$RCA_{i,r} = \frac{\sum_s VXWD_{i,r,s} / \sum_i \sum_s VXWD_{i,r,s}}{\sum_s \sum_r VXWD_{i,r,s} / \sum_i \sum_s \sum_r VXWD_{i,r,s}}$$

For example, if 10% of Brazil's exports are soybeans and the world average is 1%, then the RCA for soybeans in Brazil is 10 as it exports 10 times its 'fair share', revealing a comparative advantage in soybeans.

The indicator is computed for five aggregate commodity groups,*i* : AgriFeed, FishForest, Food, FosFuelEner, BioRenewEner, Ely, Manu and Servs (specified by the mapping in header T2AC in the sets file). All groups except FishForest are currently reported. The reported indicators can be changed by commenting in/out the relevant parts of the code given in the example below and altering the SDG8Set.

$$SDG8_{"RCAAgriFeed",r} = RCA_{"AgriFeed",r}$$

$$SDG8_{"RCAFood",r} = RCA_{"Food",r} \quad \text{etc.}$$

Note that the set of regions here all includes all regions in the simulation and an aggregate EU28 region.

- Diversification index:

This indicator is a Balassa-style index of diversification. The index is computed for value added in production in each region, compared to the world average. This shows the global pattern of production avoiding aggregation bias. If the diversification index for aggregate sector, *j*, is greater than 1, then the region's sectoral value added, as a share of its total value added, is greater than the global average:

$$DIV_{j,r} = \frac{\sum_e VFA\_L_{e,j,r} / \sum_e \sum_j VFA\_L_{e,j,r}}{\sum_e \sum_r VFA\_L_{e,j,r} / \sum_e \sum_j \sum_r VFA\_L_{e,j,r}}$$

For example, if 10% of Brazil's value added is engaged in agricultural production and the world average is 2%, then the diversification index for agriculture in Brazil is 5. Brazil engages 5 times its 'fair share' of value added in this sector, revealing a concentration of resources in the agricultural sector.

The indicator is computed for five aggregate commodity groups,*i* : AgriFeed, FishForest, Food, FosFuelEner, BioRenewEner, Ely, Manu and Servs (specified by the mapping in header T2AC in the sets file). All groups except FishForest are currently reported. The reported indicators can be changed by commenting in/out the relevant parts of the code given in the example below and altering the SDG8Set.

$$SDG8_{\text{"DIVAgriFeed"},r} = DIV_{\text{"AgriFeed"},r}$$

$$SDG8_{\text{"DIVFood"},r} = DIV_{\text{"Food"},r} \quad \text{etc.}$$

Note that the set of regions here all includes all regions in the simulation and an aggregate EU28 region.

-
- Share of fossil fuels in GDP

This indicator computes value added (including factor taxes) used in energy sectors as a share of total value added:

$$SDG8_{\text{"ShFosFuelGD "},r} = \frac{\sum_{j,ENFOS\_SECT} VOM_{j,r}}{GDP_r}$$

where VOM is the value of fossil fuel output in region r.

- Annual growth rate of real GDP per employed person (Indicator 8.2.1)

This official indicator is included as an index of the annual growth in real GDP per employed worker. In the first instance, workers approximated by the quantity of labour in constant prices. This can be adjusted when data on number of workers are introduced.

$$SDG8_{\text{"RealGDPwkr"},r} = \left[\left(\frac{RGDP_r / VFA\_TOTL\_Q_r}{RGDP\ \ _r / VFA\_TOTL\_Q0_r}\right)^{1/time}\right]\text{-1}$$

Goal 9: Industry, innovation and infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

- Manufacturing value added as a share of total value

Manufacturing includes food processing, beverages and tobacco, pellet and other standard manufacturing sectors. It excludes primary agriculture, fishing, forestry, extraction, gas distribution, energycrops, residues, aviation, transport, food services and other services. This follows the categorisation available at https://www.bls.gov/iag/tgs/iag311.htm. The set is built from IND_COMM and PROC_FOOD by removing by-products and extraction from IND_COMM and then adding in processed food from PROC_FOOD. Note that changes in the definition of the underlying sets will alter the definition of manufacturing used in this indicator.

$$SDG9_{"ManVA\quad",r} = \frac{\sum_{\substack{i=EN\quad\_COMM \\ j=MAN\_SECT}} EVFA_{i,j,r}}{\sum_{\substack{i=END\quad\_COMM \\ j=PRO\quad\_SECT}} EVFA_{i,j,r}}$$

where EVFA is producer expenditure on i by j in r at agent's prices.

This indicator is computed as a share of total value added due to difficulties computing value added at the sectoral level consistent with GDP definition.

- Manufacturing value added per capita

Manufacturing expenditure on value added divided by total population.

$$SDG9_{"ManVAShGDP",r} = \frac{\sum_{\substack{i=END\quad\_COMM \\ j=MAN\_SECT}} EVFA_{i,j,r}}{RPOP_r}$$

The MAN_SECT set is constructed by removing by-products and extraction from IND_COMM and adding in processed food from PROC_FOOD. Note that changes in the definition of the underlying sets will therefore alter the definition of manufacturing used in this indicator.

- Manufacturing employment as a percentage of total employment

The share of manufacturing employment as a share of total employment is defined as:

$$SDG9_{"ShManEmp",r} = \frac{VFA\_MANUL\_Q_r}{VFA\_TOTL\_Q_r}$$

where VFA_MANUL_Q and VFA_TOTL_Q are the values of payments to labour in the base year in manufacturing and the total economy respectively, updated with quantity changes:

$$VFA\_MANUL\_Q * qfmanempl\_r = \sum\nolimits_{e=END\qquad\_COM} \sum\nolimits_{j=MAN\_SECT} VFA\_Q_{e,j,r} * qf_{e,j,r}$$

$$VFA\_TOTL\_Q_r * qftotempl\_r = \sum\nolimits_{e=ENDWLAB\_COM} \sum\nolimits_{j=PROD\_SECT} VFA\_Q_{e,j,r} * qf_{e,j,r}$$

- CO2 emissions (tons per unit of value added)

The indicator is computed for CO_2, combustion and non-combustion emissions from five aggregate sectors, *j*: crops, livestock, natres, manu and servs. The AGFUELSECT set and mapping are defined in the AGFUEL _CH matrix in _ModelDefinition> 2_ModelStructure>Results>ModelChoices.har. The header can be user-specified by including the relevant headers (GCAT) in the user’s ini file.

Combustion emissions are all emission sources except fertilizer, chemicals and activity (ACT) which are non-combustion emissions. Value added is specified in market prices to remove tax distortions and better represent the underlying patterns of factor use. Note that the indicators are given in tons of

CO2 equivalent emissions per unit of value added (million USD) to avoid small numbers, whereas emissions are given in million tons.

$$SHEMISVA_{"CO2",j,r} = \frac{\sum_{i=FUE} \left(QGHGX_{"CO2",i,j,r} * 1000000\right)}{\sum_{e=END\_COMM} VFM_{e,j,r}}$$

$$SHEMISVA_{"Combn",j,r} = \frac{\sum_{g=GAS}\sum_{i=COMBU}\left(QGHGX_{g,i,j,r} * 1000000\right)}{\sum_{e=END\_COMM} VFM_{e,j,r}}$$

$$SHEMISVA_{"NonCombn",j,r} = \frac{\sum_{g=GAS}\sum_{i=NONCOMBU}\left(QGHGX_{g,i,j,r} * 1000000\right)}{\sum_{e=END\_COMM} VFM_{e,j,r}}$$

Currently the emissions per unit of value added is report for CO2, combustion and non-combustion emissions for crops and livestock. The reporting can easily be extended to other sectors by extending the following code for the desired sectors:

CO2 emissions per unit of value added in crop and livestock sectors:

$$SDG9_{"CrpsCO2VaS",r} = SHEMISVA_{"CO2","Crops"r}$$

$$SDG9_{"LvStCO2Va\ ",r} = SHEMISVA_{"CO2","Livestock"r}$$

Combustion emissions per unit of value added in crop and livestock sectors:

$$SDG9_{"CrpsCombVaS",r} = SHEMISVA_{"Combn","Crops"r}$$

$$SDG9_{"LvStCombVaS",r} = SHEMISVA_{"Combn","Livestock"r}$$

Non-Combustion emissions per unit of value added in crop and livestock sectors:

$$SDG9_{"CrpsNCombVaS",r} = SHEMISVA_{"NonCombn","Crops"r}$$

$$SDG9_{"LvStNCombVaS",r} = SHEMISVA_{"NonCombn","Livestock"r}$$

- Trade levels

$$SDG9_{"TotalImports",r} = VIMS\_TOT\_Q_r$$
$$SDG9_{"TotalExports",r} = VXMD\_TOT\_Q_r$$

The trade level indicators are given in constant prices. The indicator equals the value of imports/exports in the base year, updated with quantity changes in subsequent steps/time periods:

$$VIMS\_TOT\_Q_r * qtotimpr_r = \sum_{i=TRADCOMM}\sum_{s=REG} VIMS_{Q\,i,s,r} * qxs_{i,s,r}$$

$$VXMD\_TOT\_Q_r * qexptotr_r = \sum_{i=TRADCOMM}\sum_{s=REG} VXMD\_Q_{i,r,s} * qxs_{i,r,s}$$

- Trade openness

Trade openness is measured as the sum of exports and imports of goods and services as a share of gross domestic product:

$$SDG9_{"TradeOpen",r} = \frac{\sum_{i=TRAD\_COMM} \sum_{s=REG} VXMD_{i,r,s} + \sum_{i=TRA\ \_COMM} \sum_{s=REG} VIMS_{i,s,r}}{GDP_r}$$

3.4.2 Modelling extreme weather events

Within the SUPREMA project, we envision to model extreme weather events by applying synergise across models and modelling approaches applied elsewhere. One approach makes use of the work by Willenbockel (2012). In essence, for modelling extreme weather events, yields corresponding to extreme weather events are superimposed in 2030, 2050 and possible 2070 projections made by the model. Then, one-year comparative static simulation experiments are run to calculate effects of extreme yield shocks under the following conditions:

- Supply side variables related to production process, e.g. land use and capital will be kept unchanged as they will not respond to the unanticipated shock.
- Long-run supply side elasticities for agricultural production will be lowered to capture short-run supply change effect.
- Agricultural stocks will be implemented exogenously

3.4.3 Representation of land use changes by considering existing agriculture and other land use activities

Land use activities are closely related to societal, environmental, institutional, and economic processes and hence modelled by incorporating the human−environment system by large. In MAGNET, this involves modelling sectors such as agriculture, forestry, transport, or energy, and being an economic model, MAGNET by large considers the economic decision of for what activity or which sector land is used. Apart from some decision constraints, like total land area available, biophysical conditions are not taken into account in MAGNET.

For modelling land use changes (LUC), the elasticity of aggregate land supply is key, i.e. the response to the land price (land rent), since it determines the land supply impacts of economic shocks and policies and the resulting impacts on food prices and food and nutrition security etc. However, values for land supply elasticities are rarely available in the literature. Due to lack of reliable time series data on land prices and concerns about the quality of utilised agricultural area data, they are only available estimated for some countries of the world. In general, one can state that land supply elasticities with regard to the own price tend to be rather inelastic, implying limits of changes and depending on the initial land use.

Tabeau et al. (2017) provides details on the method of calculating the land supply elasticities for several world regions and countries used for the MAGNET elasticities. The original MAGNET land supply functional form is used for calculating land supply elasticities as follows: L = A−B/P , where L is land supply, P is the real land price, A is the maximum available agricultural land area (the land asymptote), and B is a positive parameter that is calculated, given the data is available. These new estimates update the previous MAGNET land elasticities that were based on other information and expert knowledge. The new land supply elasticities calculated are introduced into new AgriFood2030 model version called MAGNET_3_09_AgriFood2030D committed on the svn sever.

Other more detailed new approaches in MAGNET take into account 1) that land supply is restricted and 2) that there is an additional demand for (forestry) land. They are thus more distinct and geared towards specific policy questions, e.g. effect of afforestation. The implementation into MAGNET is explained as follows :

Restricted (agricultural) land supply (see figure 5)
In the baseline, there is no distinction between Agricultural land supply (ALSB) and Total land supply (TLS). In count of growth in forest area.

both are shown by the same yellow curve. Land demand is denoted by LD. The baseline equilibrium is determined by the point of intersection of the two curves, giving total land supply (and demand) at LS. The land price is P_B.

In order to implement afforestation scenario, we now distinguish the Agricultural land supply (ALSS) and Total Land Supply (TLS), where the difference is accounted for by forests. From IMAGE input, we know the desired reduction in Agricultural Land use in order to accommodate afforestation. This information is used to restrict the agricultural land supply in the afforestation scenario. This restricted agricultural land supply is shown by ALS. Restricted Agricultural supply however means that the land price now increases to PS. At a higher price (PS), agricultural land demand falls accommodates the supply restriction. At the same time total land supply at price PS, is given by TLS. The difference between the total and agricultural land supply (TLS - ALS) is the forest. With afforestation we see higher land prices, lower land use in agriculture but higher total land demand on account of growth in forest area.

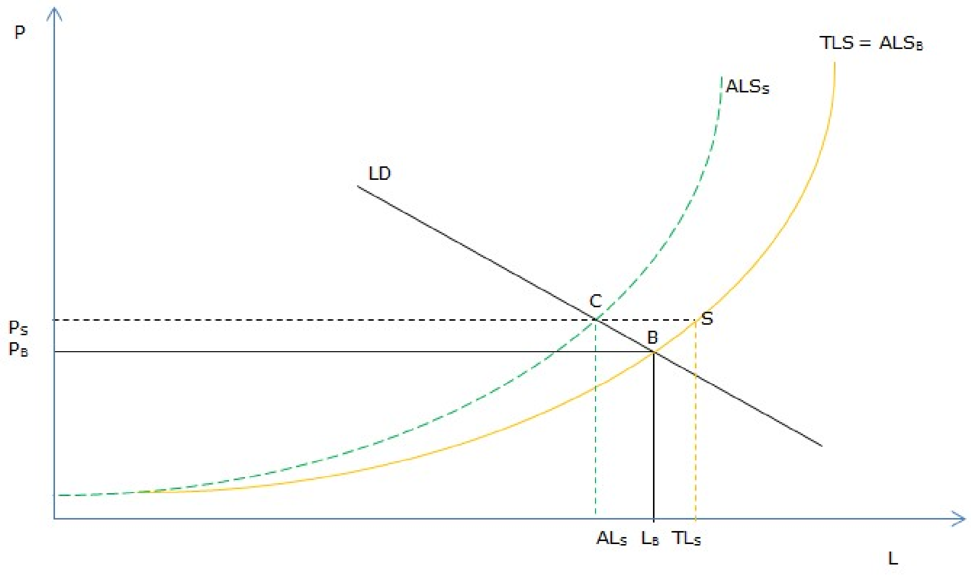

Figure 5: The Land Market with and without Afforestation (land supply approach)
Source: Tabeau et al (2017)

Additional demand for (forest) land ((see figure 6)

An alternative way to implement the forest growth in the modelling is to introduce changes on the demand side in the land market. Instead of distinguishing between agricultural land supply and total land supply, agricultural land demand and total land demand, the difference being the forest land is differentiated. In the baseline, the equilibrium point B provides the land price PB and the land supply/demand LB. At this initial equilibrium price, we now need to sequester land for forests. Again the information from IMAGE is used to calculate this demand for forest land (in km sq.). Graphically this means that the total demand (TLDS) for land is agricultural demand (ALDS) plus the demand for forest (distance BF). The new demand curve intersects the land supply curve (TLS) and generates the new land price (PS). A higher price also means higher land supply (TLS), of which a part (illustrated by the distance CS) is set aside for forests and the remaining (ALS) is used as agricultural land.

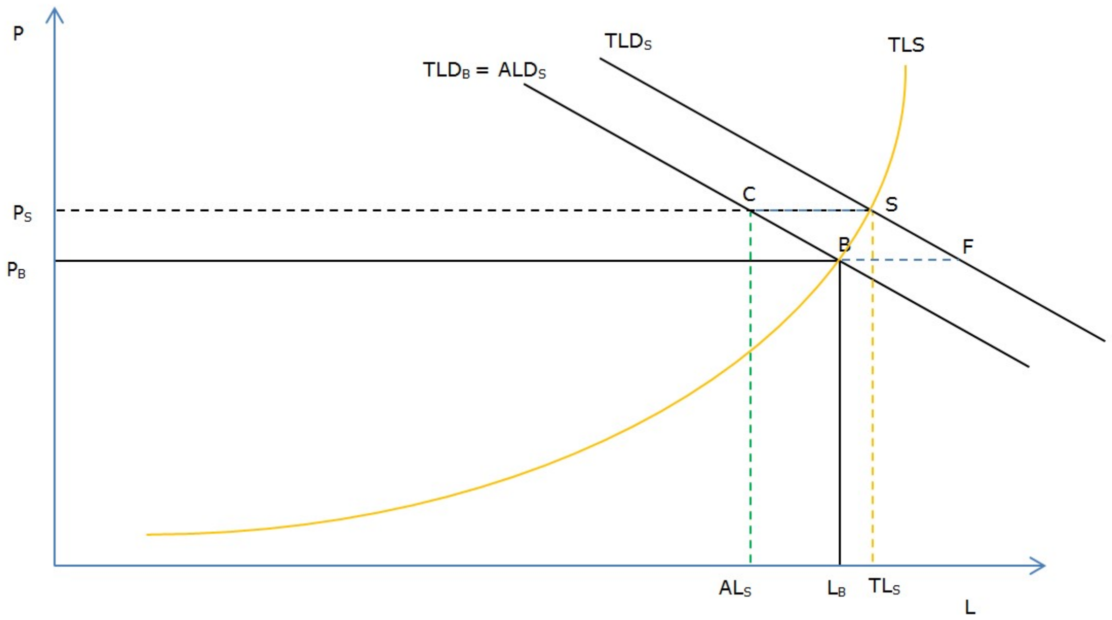

Figure 6: The Land Market with and without Afforestation (land demand approach)
Source: Tabeau et al (2017)

Like in other approach, we get higher land price and lower agricultural land use with afforestation. However, the magnitude of these changes differ across the two approaches. The difference is illustrated in figure 7. Without any forests, we start with a land supply curve S and land demand curve D; land price is P_B and land demand and supply is L_B. At this initial price we can introduce forests in two ways by restricting land supply to agriculture by a given amount or by introducing the demand for forests as a new source of demand. To be able to compare we construct the figure in a way such that the increase in forest demand (BM) at the initial equilibrium price P_B is the same as the reduction in agricultural land supply (NB) at the same price. Following the forest demand approach, land demand at initial price increases to M (shift of demand curve D to D_A). However this is more than the land supply available at that price, so market forces drive up land price and new equilibrium is found at point A. Even at the new price the forest land set aside remains the same (AD=BM) and the remaining supply (D) goes to agriculture. The equilibrium moves from B to A through M. The approach can be seen as finding a new equilibrium in land market and dictating the forest demand and residual is agricultural land. With the agricultural land supply restriction (A_L) approach (shift and twist agricultural land supply curve from S to S_L), the new equilibrium is found at point L (moving from B to N to L). With this approach the forests are determined as residual supply after agricultural market reaches an equilibrium at point L. Note that with this approach we see a greater reduction in agricultural land use and higher land prices. This in turn implies that forest area with this approach (LC) exceeds that with the demand approach (DA) (in which forest demand is hocked.

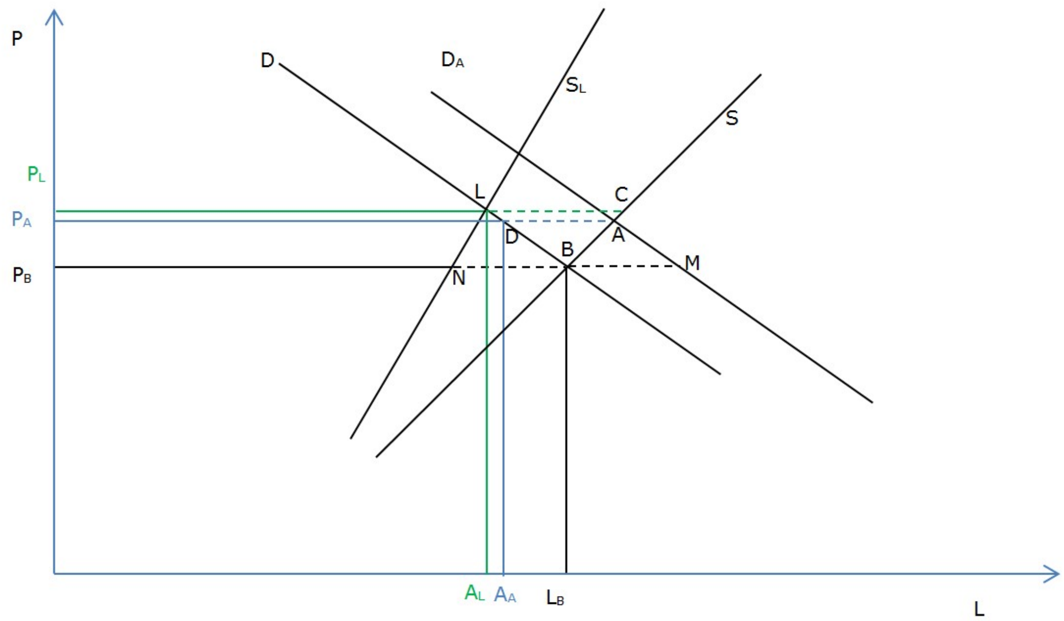

Figure 7: Difference between the approaches
Source: Tabeau et al (2017).

3.4.4 Representation on technologies adoption to capture innovations

Modelling technology adoption has become an important feature since upgrading and taking-up new technologies are related to economic growth, more specifically fostering productivity growth which in turn leads to economic growth. Di Comite and Kancs (2015) provide an overview and comparison of modelling research and development (R&D) in four macroeconomic models that the European Commission uses for ex-ante policy impact assessment. The models captures the dynamic and spatial dimensions of R&D investment decisions and technology transmission mechanisms in the context of polices.

MAGNET does not provide dynamic stochastic features. Following the approach developed by van Meijl et al (2012), the modelling approach introduces into the MAGNET model a new technology as an alternative to the incumbent technology, here new bio-based technologies to produce bio-energy, pellets, bioethanol and bio-based chemicals as an alternative to fossil resources-based technologies.

More specifically, van Meijl et al (2012) distinguish between three technologies for producing one unit of output. In the case of ethanol, the unit of output is 1 litre of gasoline equivalent in the Malaysian petroleum products industry in 2030, as follows: Technology 1 is the baseline technology that is the vector of inputs required per unit of output in the baseline run based on fossil resources such as oil and coal; Technology 2 depicts the newly developed bio-based technology to produce the same unit of output; Technology 3 is based on a combination of technology 1 and technology 2, whereby the weighting factor between technology 1 and 2 are determined by the amount of fossil-based input that can be replaced by the bio-based alternative and this is dependent on the amount of biomass provided by the Biomass Strategy (the National Biomass Strategy, 2011) and the efficiency of biomass conversion.

In the modelling approach, the important determinants that drive the investment decision and hence the decision whether the new technology is taken up are the technological improvements related to the conversion of palm biomass to a point at which it can act as a substitute, and the price of competing fossil resources based substitutes. Next to constraints in conversion possibilities, the approach is based on the details of the cost structure of the bio-based technologies and alternatives, both are investigated in details, with the profitability of using biomass products as substitutes for fossil fuel inputs, for example, being crucial.

Fully endogenous technical change within the field of agriculture within MAGNET has been developed in an experimental set up in Smeets-Kristkova (2017a and 2017b). R&D is introduced as a separate sector that uses resources and produces technical change. Endogenous R&D stocks determine tech change (e.g. yields). This innovative approach has to be developed further but given the resources needed cannot be done within this project.

3.4.5 Exploring options for a soft link between AGMEMOD and MAGNET for a supply chain case

As foreseen in SUPREMA, we will explore options for model linkages, more specially here the link between AGMEMOD and MAGNET. Given the experiences with previous model linkages, see deliverable D1.5 on the tool box of SUPREMA models, the model link between AGMEMOD and MAGNET will be a soft link that will be applied in a supply chain case study explored in AGMEMOD. As a case, the dairy supply chain has been chosen, with supply chain issues being identified by the stakeholders as an important topic. More general work on supply chain issues will be taken up in the SUPREMA recommendation of the road map for future research. For the modelling in SUPREMA, the case study of the EU dairy supply chain will be explored, and subsequently implemented in AGMEMOD with the link to MAGNET.

4 Conclusions

For each model with the exception of MITERRA we will conduct a number of improvements to the individual models. They will cover a wide range of activities which are necessary to enable the planned narrative scenarios and to take-up some of the priorities identified by stakeholders. Hence, not all priorities can be implemented as data, time for implementation, or pertinent findings from research are lacking. Nevertheless, the plan is quite ambitious and it realisation in some cases will depend on the speed of progress and the access to data.

In all models the time scope and related model extensions will be prolonged towards the year 2050 or the year 2070. In addition the following improved are planned

- In AGMEMOD the following improvements are envisaged:
  - the expansion and improvement of the existing market expert network and related tools for validation;
  - the representation of the price transmission mechanism with respect to world market, across regions and selected products;
  - a better representation of existing and future agricultural policies;
  - an improved representation of environmental regulation/constraints;
  - the improvement of yield functions and accounting for climate change issues (CO2 fertilization) which will depend on the achieved progress;
  - its alignment with shared socio-economic pathways (SSP) scenarios until 2050.
- In CAPRI it is planned
  - To improve the integration across spatial scales;
  - To undertake further steps to broaden activity and land-use representation in non-EU countries;
  - To improve mitigation modelling;
  - To represent better adoption of new technologies by farmers;
- In GLOBIOM it is foreseen
  - To expanded representation of SDGs; focus on SDGs related to the environment and production
  - To cover extreme weather events;
- In MAGNET, it is foreseen:
  - To expanded representation of SDGs; focus on SDGs related to socio-economic issues;
  - To cover extreme weather events;
  - To improved land use change representation and to widen the representation of existing agriculture and other land use activities;
  - To better implement the adoption of technologies so as to account for innovation.

With these improvements the narrative scenarios developed at the Workshop "Narratives" can be conducted. Also a number of priorities identified by stakeholders at the Workshop "Needs" can be, at least partly, captured. A full consideration of mentioned priorities was not expected under the project SUPREMA and this would require more efforts, additional data, additional research and extended project duration to align activities. The match between priorities containing a long wish list with planned improvements are shortly discussed:

- The scope of some models is extended to reach a global coverage especially the land use coverage is extended to not currently included areas. This will enable a much better representation of sustainability and production. Other models, with a global coverage, will conduct scenarios with globally relevant assumptions. To operationalize SDGs better a number of activities are planned, hence not all SDGs are readily quantifiable and their complete implementation in models in all their dimensions requires more investments. Some SDG efforts will allow to have first insights into the representation of the relationship between health-nutrition. Distributional aspect in their relation to hunger will be addressed only on specific cases.

- Emphasis is given to implement dietary changes but shifts of preferences as well as in the representation of disruptive developments in demand behaviour can, so far, only be addressed by scenarios.
- In line with identified need some activities are invested in a better representation of technology diffusion and adoption as well as in adaptation of new activities on farms. But also here adoption might need further refinements to achieve a better representation and scenario outcomes for empirical based policy decisions.
- Partly issues like environmental degradation and feedback to the economy are addressed; however these improvements do not achieve full feedback loops. Some steps are taken to better capture biodiversity; but its coverage is still rather limited.
- Also the implementation of the factor water will receive additional attention, but this nonetheless leaves ample room for further improvements.
- Efforts are also put in an internalization of selected externalities but this is only achieved in a case wise manner and in view of the planned scenarios, and not as a general effort targeting all externalities as some stakeholders may have wished.. Selected improvements are targeted to better represent farming risks which will deal with water constraints and yield formation.
- Other challenges like a better coverage of the bio-economy are already considered in a number of other projects, so they are not really addressed under SUPREMA itself but will be followed up by collaboration in those projects that will indirectly benefit from SUPREMA improvements.
- Improvements with respect to data access, data availability, and data quality within the value chain would overburden the SUPREMA project. Therefore in a case study the existing problems will be fathomed and possible steps for future actions will be defined. Consideration of structural change in the value chain will require data availability and access and will be studied on the selected case study as well. Conclusions from the case study will frame future research.
- Also monitoring of markets and value chains cannot be ensured by the SUPREMA project; hence, the project can develop ideas how to achieve a better monitoring. Extension in data provisions will also allow later on to analyse regional compared to international value chains.
- Treatment of infrastructure, transport and transaction costs will require very diverse actions; stylized representations are partly included in some models of the SUPREMA toolbox but any detailed implementation will depend on future activities not covered under SUPREMA.
- Currently not covered are approaches to anticipate future policy shocks. Effects of immigration as such, on employments and migrant labour in food chain reaching beyond current modelling activities will likewise not be part of the current project.

The previous wish list covers almost all conceivable improvements for future quantitative economic research with an emphasis on agriculture and the environment. Identifying the most promising and urgent areas for improvements is the purpose of another deliverable (D1.6). One conclusion that might emerge is that complex topics should be addressed with several models of the toolbox, which need to align assumptions and where possible, models should be linked.

A second strategy to bridge the gaps to stakeholder expectations (apart from additional research efforts) is better communication. From this viewpoint more emphasis should be put on 'story telling' including communication and interaction with stakeholders, presentation of harmonized and easy understandable, short papers with additional annexes providing detailed outcomes.

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5 References

- AGMEMOD Consortium (2016) Update of AGMEMOD database and baseline projections, with a focus on the pig meat sector. Final Report (Deliverable 4), Braunschweig, Germany.
- Boere, E., Havlik, P., Gaupp, F.and Ermolieva, T. (2018): Models for designing policies aimed at market stabilization, SUSFANS Deliverable No. 8.6.
- Chavaz, J.P. , and Kim, K. (2001) Hedonic Pricing of Components and Cointegration Relationships: A Dynamic Analysis of Dairy Product Prices. Maddison, Department of Agricultural and Applied Economics, University of Wisconsin, Food System Research Group, Working paper FSWP 2001-1.
- Di Comite, F., Kancs,d'A. (2015). Macro-Economic Models for R&D and Innovation Policies. IPTS Working Papers on Corporate R&D and Innovation – No 02/2015.
- Domínguez, I. P., Fellmann, T., Weiss, F., Witzke, P., Barreiro-Hurlé, J., Himics, M., Jansson, T. and Leip, A. (2016): An economic assessment of GHG mitigation policy options for EU agriculture - EcAMPA 2 -, Final Report, JRC.
- European Environment Agency. (2016). Water-limited crop yield. Available at: https://www.eea.europa.eu/data-and-maps/indicators/crop-yield-variability-2/assessment.
- Erjavec, E., Chantreuil, F., Hanrahan, K., Donnellan, T, Salputra, G., Kožar, M., van Leeuwen, M. (2011) Policy assessment of an EU wide flat area CAP payments system. Economic Modelling 28 (2011) 1550–1558.
- Frank, S., Havlík, P., Gusti, M., Valin, H., Forsell, N., DiFulvio, F., Palazzo, A., Lauri, P. and Obersteiner, M. (2018): Final report, Reproducing land-use patterns in energy models, JRC.
- Gordon, D.V. and Hazzledine, T. (1996) Modelling farm-retail price linkage for eight agricultural commodities. Agriculture and Agri-Food Canada Policy Branch, Economic and Policy Analysis Directorate, Technical Report #1/96.
- Hasegawa, T., S. Fujimori, K. Takahashi and T. Masui (2015). Scenarios for the risk of hunger in the twenty-first century using Shared Socioeconomic Pathways. Environmental Research Letters 10(1): 014010.
- Havlík, P., H. Valin, M. Herrero, M. Obersteiner, E. Schmid, M. C. Rufino, A. Mosnier, P. K. Thornton, H. Böttcher, R. T. Conant, S. Frank, S. Fritz, S. Fuss, F. Kraxner and A. Notenbaert (2014). Climate change mitigation through livestock system transitions. Proceedings of the National Academy of Sciences 111(10): 3709-3714.
- Heien, D. (1980) Markup pricing in a dynamic model of the food industry. American Journal of Agricultural Economics, 62: 10-18.
- Holloway, G. J. (1991) The Farm-Retail Price Spread in an Imperfectly Competitive Food Industry. American Journal of Agricultural Economics 73:979-989.
- Howitt R.E. (1995) Positive Mathematical Programming, American Journal of Agricultural Economics 77: 329-342.
- Heckelei, T., Britz, W. (2005): Models based on Positive Mathematical Programming: State of the Art and Further Extensions. In Arfini, F. (ed.), Modelling Agricultural Policies: State of the Art and New Challenges. Proceedings of the 89th European seminar of the European Association of Agricultural Economics. Parma, Italy: University of Parma, 48–73.
- Heckelei T., Britz W., and Zhang Y. (2012): Positive Mathematical Programming Approaches – Recent Developments in Literature and Applied Modelling. Bio-based and Applied Economics 1(1): 109-124

- Jaggard, K.W., Qi, A. and Ober, E.S. (2010). Possible changes to arable crop yields by 2050. *Philosophical Transactions*, 365: 2835–2851; doi:10.1098/rstb.2010.0153.
- Jongeneel, R. (2000) The EU's grains, oilseeds, livestock and feed-related market complex: welfare measurement, modelling and policy analysis. Wageningen, Department of Social Sciences, Wageningen University (PhD-thesis).
- McCorriston, S. (1996) Price transmission in vertically related markets under imperfect competition. Exeter: University of Exeter, Agricultural Economics Unit (Paper presented to the German Association of Agricultural Economists Congress, Kiel).
- Olesen, J.E. and Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy, 16, 239–262.
- Pastor, A. V., A. Palazzo, P. Havlik, H. Biemans, Y. Wada, M. Obersteiner, P. Kabat and F. Ludwig (2019). The global nexus of food–trade–water sustaining environmental flows by 2050. Nature Sustainability.
- Salamon, P., Chantreuil, F., Donnellan, T., Erjavec, E., Esposti, R., Hanrahan, K., van Leeuwen, M., Bouma, F., Dol, W., Salputra, G. (2008), 'How to deal with challenges of linking a large number of individual national models: the case of the AGMEMOD partnership', Agrarwirtschaft, Vol. 57, No 8, pp. 373-378.
- Salamon, P., Banse, M., Barreiro-Hurlé, J., Chaloupka, O., Donnellan, T., Erjavec, E., Fellmann, F., Hanrahan, K., Hass, M., Jongeneel, R., Laquai, V., van Leeuwen, M., Molnár, A., Pechrová, M., Salputra, G., Baltussen, W., Efken, J., Hélaine, S., Jungehülsing, J., von Ledebur, O., Rac, I., Santini, F (2017), Unveiling diversity in agricultural markets projections: from EU to Member States. A medium-term outlook with the AGMEMOD model. JRC Technical Report, 29025 EUR, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-77335-8, doi:10.2760/363389.
- Salputra, G., Chantreuil, F., Hanrahan, K., Donnellan, T., Leeuwen van, M., Erjavec, E. (2011), 'Policy harmonized approach for the EU agricultural sector modelling', Agricultural and Food Science, Vol. 20, pp. 119-130.
- Smeets-Kriskova, Z., van Dijk, M., Gardebroek, K., van Meijl, H. (2017). The impact of R&D on factor-augmenting technical change – an empirical assessment at the sector level, Economic Systems Research, Vol. 29 , 3, p.: 385-417.
- Smeets-Kriskova, Z., van Dijk, M., van Meijl, H. (2017), Assessing the impact of agricultural R&D investments on long-term projections of food security, Frontiers of Economics and Globalization, 17, p.: 1 - 17.
- Tabeau, A., Helming, J., Philippidis, G., Land Supply Elasticities, Overview of available estimates and recommended values for MAGNET, EUR 28626 EN, Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-69102-7, doi:10.2760/852141, JRC106592
- van Meijl, H., Smeets, E., van Dijk, M., Powell, J., Tabeau, A. (2012). Macro-economic Impact Study for Biobased Malaysia. LEI report 2012-042. May 2012. Then Hague/Netherlands.
- Wada et al. (2016)
- Willenbockel, D. (2012). Extreme Weather Events and Crop Price Spikes in a Changing Climate. Oxfam research reports, Oxfam GB, Oxford, UK.
- Wohlgenant, M. K. (1989) Demand for Farm Output in a Complete System of Demand Functions. American Journal of Agricultural Economics 71: 241-252.

- Wohlgenant, M. K. and R. C. Haidacher (1989) Retail to Farm Linkage for a Complete Demand system of Food Commodities. U.S. Department of Agriculture, Technical Bulletin No. 1775, 47p.
- Zhao, X., Mullen, J.D., Griffith, G.R., Griffiths, W.E. and Piggott, R.R. (2000), An Equilibrium Displacement Model of the Australian Beef Industry, Economic Research Report, No. 4, NSW Agriculture, Orange.
- Zurek, M. et al. (2017): Sustainability metrics for the EU food system: a review across economic, environmental and social considerations, SUSFANS Deliverable No. 1.3