D1.10: THE SUPREMA ROADMAP EXPLORING FUTURE DIRECTIONS FOR AGRICULTURAL MODELLING IN THE EU

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Executive summary

Changes with respect to the DoA

No changes.

Dissemination and uptake

This report presents an overview of the key topics and needs that the SUPREMA modellers will face in the future when assessing agriculture policy. This document builds on the outcomes of the different WP that comprise the SUPREMA project.

Short Summary of results (<250 words)

The increasing need for impact assessments in the field of agriculture that are (partly) based on forward-looking outcomes delivered by models has led to (even more) frequent maintenance and development tasks. These maintenance and development tasks are not a trivial issue and might require a considerable amount of resources in terms of labour, time, sector knowledge, computing capacity, etc. In this context, SUPREMA have try to identify the upcoming needs in the research/policy agenda, while exploring the feasibility of those potential modelling exercises by using the existing tools. This assessment has pointed out certain necessities regarding model extensions and development of new tools. At the same time, it has also revealed the potential of model integration and collaboration as a way to supplement the outcomes of individual models. With regard to the scope of the models that were considered, the focus is mainly on large scale models that are well suited for EU policy assessment at macro or meso level. In terms of the thematic coverage, the selected topics are based on the outcome of three stakeholder workshops that took place in WP1. Therefore, a comprehensive assessment of the existing literature on modelling goes beyond the scope of this report. This document also builds on the outcomes of WP2 for which some model improvements were developed; as well as on the results of WP3 for which some scenarios to assess EU agricultural policy were simulated.

Evidence of accomplishment

The present report.

Glossary / Acronyms

ABM	AGENT-BASED MODEL
AECMS	AGRI-ENVIRONMENTAL AND CLIMATE SCHEMES
AFOLU	AGRICULTURE, FORESTRY AND OTHER LAND USE
AGMEMOD	AGRICULTURAL MEMBER STATES MODELLING
AMNE	ACTIVITY OF MULTINATIONAL ENTERPRISES
ASF	AFRICAN SWINE FEVER
CAP	COMMON AGRICULTURAL POLICY
CBA	COST-BENEFIT ASSESSMENTS
CGE	COMPUTABLE GENERAL EQUILIBRIUM
COVID-19	CORONAVIRUS DISEASE 2019
CAPRI	COMMON AGRICULTURAL MODELLING POLICY REGIONALISED IMPACT MODELLING SYSTEM
EAB	EXECUTIVE ADVISORY BOARD
EC	EUROPEAN COMMISSION
ECAMPA	ECONOMIC ASSESSMENT OF GHG MITIGATION POLICY OPTIONS FOR EU AGRICULTURE
EDM	EQUILIBRIUM DISPLACEMENT MODEL
EFI-GTM	EFI FOREST SECTOR GLOBA TRADE MODEL
ESR	EFFORT SHARING REGULATION
EU	EUROPEAN UNION
FAO	FOOD AND AGRICULTURE ORGANISATION
FNS	FOOD AND NUTRITION SECURITY
GFPM	GLOBAL FOREST PRODUCT MODEL
GHG	GREENHOUSE GASES
GIS	GEOGRAPHICAL INFORMATION SYSTEM
GLOBIOM	GLOBAL BIOSPHERE MANAGEMENT MODEL
GVC	GLOBAL VALUE CHAIN

IFM-CAP	INDIVIDUAL FARM MODEL FOR COMMON AGRICULTURAL POLICY
IIASA	INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
ILUC	INDIRECT LAND USE CHANGE
IMAGE	INTEGRATED MODEL TO ASSESS THE GLOBAL ENVIRONMENT
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
JRC	JOINT RESEARCH CENTRE
LCA	LIFE CYCLE ASSESSMENT
LDC	LEAST DEVELOPED COUNTRIES
MACC	MARGINAL ABATAMENT COST CURVE
MAGNET	MODULAR APPLIED GENERAL EQUILIBRIUM TOOL
MITERRA	MITERRA-EUROPE
NGO	NON-GOVERNMENTAL ORGANIZATION
NRS	NATURAL RESOURCE SECURITY
NTM	NON-TARIFF MEASURE
NUTS2	NOMENCLATURE OF TERRITORIAL UNITS FOR STATISTICS 2
OECD	ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
PDO	PROTECTED DESIGNATION OF ORIGIN
PE	PARTIAL EQUILIBRIUM
PGI	PROTECTED GEOGRAPHICAL INDICATION
RACER	RELEVANT, ACCEPTABLE, CREDIBLE, EASY AND ROBUST
R&D	RESEARCH AND DEVELOPMENT
SDG	SUSTAINABLE DEVELOPMENT GOAL
SUPREMA	SUPPORT FOR POLICY RELEVANT MODELLING OF AGRICULTURE
TBT	TECHNICAL BARRIERS TO TRADE
TiVA	TRADE IN VALUE-ADDED
WP	WORK PACKAGE
WUR	WAGENINGEN UNIVERSITY AND RESEARCH

1 Introduction

1.1 Objective of the report

Policies related to agriculture are supposed to address an increasing number of objectives as demanded by society. As a result, agricultural policies, like the European Union (EU) Common Agricultural Policy (CAP), increase their scope to incorporate for example objectives of the Paris climate agreement and the Sustainability Development Goals (SDGs). In line with this development, the European Commission's (EC) Communication on The Future of Food and Farming (November 2017) and the Farm to Fork strategy, address several key challenges for the CAP, trying to redesign this key agricultural policy. Central challenges for the future CAP are the promotion of research and innovation in agricultural and food production, the fostering of a smart and resilient agricultural sector, the enhancing of environmental care and climate action, the strengthening of the socio-economic conditions of rural areas, while addressing the citizens' concerns in the areas of health, nutrition, food waste and animal welfare. The increasing need for impact assessments in the field of agriculture that are (partly) based on forward-looking outcomes delivered by models has led to (even more) frequent maintenance and development tasks. Nowadays, modellers should keep their tools well prepared for assessing (sometimes at a very short notice) a broad range of issues, including: (i) the impact of upcoming policies, e.g. the new CAP reform, SDGs, Paris climate agreement and the Green deal; (ii) the effects of disease outbreaks, e.g. the African Swine Fever (ASF) disease, the Covid-19 syndrome; (ii) the consequences of changes in the existing body of legislation, e.g. the so-called 'N' problem in the Netherlands etc. These maintenance and development tasks are not a trivial issue and might require a considerable amount of resources in terms of labour, time, sector knowledge, computing capacity, etc. Bearing this background in mind, SUPREMA identifies the upcoming needs in the research/policy agenda, while exploring the feasibility of those potential modelling exercises by using the existing tools. This assessment has pointed out certain necessities regarding model extensions and development of new tools. At the same time, it has also revealed the potential of model integration and collaboration as a way to supplement the outcomes of individual models.

In short, this report presents a roadmap for future suggestions for agricultural modelling in the EU, building on the outcomes of the SUPREMA (SUpport for Policy RElevant Modelling of Agriculture) project. The Roadmap provides directions for future modelling needs, improving existing models and their interlinkages, data management and requirements, as well as insights on governance structures for models and modelling platforms. This document also includes some suggestions to close the gap between expectations of policy-makers and model capacity on a permanent basis. Therefore, this Roadmap can be considered as a 'sketch' of possible modelling requests and future 'action plans' for their execution, using as a starting point the existing modelling capacity. In other words, this document has raised awareness on future challenges that modelling teams will have to face, creating at the same time an opportunity to anticipate to them.

Table 1 presents an overview of the different topics that will be discussed later in this report (Chapters 2-10). These set of topics provides a good description of the elements that will shape the context in which agricultural modellers will have to perform their activities in the future, focusing on the main challenges that the agri-food sector will face in the coming years.

Table 1. Summary of topics covered in the Roadmap

Topic	Description
Recent policy developments and policy needs	The notion of a food system approach, the shifting nature of global food challenges, as well as the main policies that affecting EU agriculture will be discussed in Chapter 2.

Primary production	A list of sectoral issues that would be priority for policy-makers in the future, a proposal for their modelling, as well as some insights on the need for new indicators will be discussed in Chapter 3. Other topics that will be addressed in this chapter are the role of social and technical innovation, fair and proper prices for farmers, as well as budgetary issues within the CAP.
Land use	Keeping in mind the ultimate objective of achieving climate neutrality, the potential role of forestry, together with appropriate land use practices are discussed in Chapter 4.
Modelling of environmental impacts	Issues related to biodiversity, soil quality, landscape preservation, extreme weather events, climate change and mitigation technologies, etc. are complex phenomena that cannot be fully captured within a single model. Therefore, the focus of Chapter 5 is on the needs and improvements that are required for models to offer a proper representation of the environmental impacts, including biodiversity aspects, the cooperation of agronomic, economic and biophysical models, etc.
Climate change and mitigation options	The assessment of the effects derived from climate change, as well as the modelling of the potential impact of implementing several mitigation options is the focus of Chapter 6.
Representation of supply chains	Several gaps that have been identified in the existing models with regard to the representation of supply chains, as well as potential approaches to overcome them are presented in Chapter 7.
Modelling of trade flows	The international dimension of economic relations, i.e. international trade, is from to time 'shocked' by trade wars, import bans, creation or abolition of trade agreements, etc., These developments should be better captured as explained Chapter 8.
The role of food from a broader perspective	Chapter 9 looks at food from a broader perspective, covering issues such as health outcomes, animal welfare and circularity.
Integrated model use, model maintenance and model network	Needs (and follow-up actions) for benefiting from model interlinkages, the efforts for maintaining the quality of the models, the importance of reconciling sectoral and farm level, as well as key lessons from SUPREMA regarding data management and governance are elaborated on Chapter 10.

1.2 Scope

With regard to the scope of the models, the focus of this project is mainly on large scale models that are well suited for EU policy assessment at macro or meso level. Therefore, they do not properly take into account the micro dimension and cannot offer the level of detail that could be delivered by a national or sub-sector model, e.g. in terms of impacts that at are observed evenly through the country territory, when productive activities are geographically concentrated on an province, etc. Nevertheless, the existence of these detailed models create room for some kind of cooperation between them. This is so in the sense that some of the information that they contain could be used by large scale models, for example by using 'reduced-form equations' of those models that have a narrower/localised focus. In this context, an interesting exercise is to compare the outcomes of pan-European and national/regional models for getting insights on how 'accurate' is the concept of the 'representative' farm that is included in a large scale model.

In terms of the topics that have been covered in this report, the focus of SUPREMA is on the modelling needs that the different tools will have to overcome when simulating a number of aspects of the agricultural policy in the EU. The selected topics are based on the outcome of three stakeholder workshops that took place in the context of WP1. Therefore, a comprehensive assessment of the existing literature on modelling goes beyond the scope of this report. This document also builds on the outcomes of WP2 for which some model improvements were developed; as well as on the results of WP3 for which some scenarios to assess EU agricultural policy were simulated. Furthermore, this document also incorporates elements from several discussions within the team members, the outcomes of the meetings with the Executive Advisory Board (EAB) of SUPREMA, as well as additional input provided bv the RUR-04 projects.

Along with the need of model improvement and interlinkages in the context of specific topics, the remainder of this report will also elaborate on the necessity of extensions of existing models as well as on developing new (supplementary) models in those cases in which the existing tools are not well-fitted for the analysis. This is the issue when studying supply chains that are not well represented in the existing sector models, being a solution the combination of a sector model with a targeted equilibrium displacement model (EDM).

As an output of this project, an overview of the main characteristics of the SUPREMA models in relation with the key topics that are discussed in this report is presented in Table 2.

Table 2. Key characteristics of SUPREMA models

	CAPRI	GLOBIOM	MAGNET	AGMEMOD	IMF-CAP	MITERRA
Model type	Partial equilibrium	Partial equilibrium	Computable general equilibrium	Partial equilibrium	Partial equilibrium/micro-simulation	Partial equilibrium
Trade representation	Armington spatial equilibrium of quality differentiation, heterogenous goods	Takayama-Judge spatial equilibrium, homogenous goods	Armington spatial equilibrium of quality differentiation, heterogenous goods	Net trade	Not available	Not available
Demand side representation	Explicit price and cross-price elasticities, exogenous income elasticities	Explicit price elasticities, exogenous income elasticities	Explicit price and income elasticities	Explicit price and income elasticities	Consumer demand is not available. Farm income and distributional aspects are covered	Not available. It can be taken from an economic model.
Supply side representation	NUTS2 level non-linear programming models in the EU. Linear system of supply functions in the ROW	Spatially explicit Leontief production systems Leontief covering alternative production systems	Regional/country level multilevel nested constant elasticity of substitution production technology	EU MS / commodity level	NUTS 2/ farm level/14 different farm types. Detailed representation of intermediate inputs, including resource endowments	EU MS / NUTS2 / Representation of 40 crops (including perennial/energy crops) and 10 livestock categories
Land representation	Explicit link to agri. activities in the EU, land supply and demand functions in the ROW, allocated to products	Explicit link to agri. and forestry activities	Land supply function	Total agricultural land, including harvested area at commodity level	Functions for land use, land allocation by activity within the farm	Explicit representation of agriculture land/activities
Agricultural emissions	Product specific emission factors globally, consistent with activity-based accounting in EU	Spatially explicit emission factors for the different production systems	Product and region-specific emission factors	Not available	Not available	GHG and nutrient emissions at NUTS-2 or country level or on a product basis (farm gate LCA)

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Mitigation options	Technical options, changes in composition of regional activity or product aggregates; international trade	Technical options, changes in production systems, composition of regional activity or product aggregates; international trade	Technical options, GHG taxes, changes in composition of regional activity or product aggregates; international trade; diet changes	Not available. It could be implemented on project basis in the context of scenario analysis	Technical options (changes in feed composition, specific feed requirements, etc.)	The impact of mitigation options can be modelled in the context of scenario simulation in combination with an economic model.
Representation of bio-diversity aspects	Land use/abandonment; irrigation shares per crop	Land use/abandonment; water use	Land use/abandonment	Not available	Land use/abandonment	Land use/abandonment; critical N load and surface water quality indicators
Agricultural policy representation	Premiums/activities; Set-aside (obligatory and voluntary); Intervention Prices; Quotas (milk, sugar); Border Measures; WTO Limits; Import tariffs, TRQs; Decoupling (on arable and grassland for hybrid decoupling systems)	In combination with CAPRI, using CAPRI'S projections of the agricultural sector in EU as an input	CAP budget; Subsidies; Quotas; Border Measures; Tariffs; Tax rates; TRQs; Decoupling; Second Pillar technology effects;	Intervention prices; Subsidies on products including grants for crops and headage premiums; Subsidies on production , including for land set/aside and for cattle premiums; Quantitative restrictions, including quotas for milk and for numbers of animals eligible for headage payments; SFP; SAPS; Subsidised export limits and TRQ levels	Farm in-quota prices; Subsidies (coupled and decoupled payments); In-quota production quantity; Set-aside; Policy rights; Greening, Capping, Modulation, Regional ceiling for premiums	Nitrates Directive, Greening and mitigation options related to climate change and air quality

Source: Based on deliverable D3.3 of the SUPREMA project and others, including model manuals.

1.3 Structure of the document

After this introduction, this report is structured in the following chapters:

- Chapter 2 elaborates on the recent developments of agricultural policy at EU level, introduces the notion of 'food system approach' and identifies key modelling needs;
- Chapter 3 focuses on primary production and the key issues that should be addressed regarding this topic;
- Chapter 4 discusses the aspects of modelling land use that are relevant in the context of SUPREMA;
- Chapter 5 draws attention to the assessment of environmental impacts, including how model interlinkages could improve this modelling exercise;
- Chapter 6 concentrates on the modelling of climate change and mitigation options, as in the case of the other topics a discussion on the needs for further improvement of the tools is presented;
- Chapter 7 refers to the representation of supply chains in the existing models, including a proposal for improving the existing approaches;
- Chapter 8 concentrates on the modelling of trade flows within the SUPREMA models;
- Chapter 9 explores the role of food in terms of health outcomes and environmental impacts;
- Chapter 10 discusses how to use the different models in an integrated manner, as well as other aspects related to data management, network development and model maintenance.
- Chapter 11 presents the conclusions of this report as well as a set of recommendations for policy-makers and modelling teams; and
- Chapter 12 displays the list of references that were quoted through the report.

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2 Recent policy developments and modelling needs

2.1 Introduction

The objective of this chapter is to present the rationale for the modelling needs that have been identified in the context of SUPREMA. First of all, some discussion on the food challenges that the World will face in the coming years is presented (Section 2.2). Secondly, a description of the agricultural policy context at EU level is provided (Section 2.3). Thirdly, it is important to familiarise the reader with the concept of 'food systems' since food is a complex element that goes beyond its production at primary level and its use by end consumers (Section 2.4). Then, the focus on this chapter is on the SUPREMA workshops that were a key element to collect relevant insights from all the actors involved in the agri-food system (Section 2.5) . Finally, some concluding remarks are provided in Section 2.6.

2.2 Shifting nature of global food challenges

Over the past 50 years, food production has significantly grown. However, the agricultural sector should continue increasing its production by 70-100% by 2050 in order to provide sufficient food without significant price increases (University of Essex, 2010). This task is not a trivial one since at the same time that the agriculture sector is challenged to increase its production, a number of elements will force the sector to 'produce smartly'. Climate change, the protection of biodiversity, water stress, energy insecurity, labour scarcity and dietary shifts are among the key challenges and limitations that an increasingly 'globalised' agriculture will need to face in the coming years. Needless to say, in the context of this challenging 'environment', there is no room for the traditional paradigm in which food challenges that were mainly defined as 'increasing the production of cheap food', were solved at the expense of the environment.

All of this is well captured by Haniotis (2020), who states that 'The world food system is rapidly moving from a phase of solving economic and social problems (food productivity and food affordability) at the expense of the environment (soil, air, water, biodiversity) towards a phase of potentially solving both economic and environmental problems (precision farming and digital economy) with potentially increasing social tensions (health, knowledge gaps, digital divide, gaps in urban versus rural jobs and growth) that requires using agriculture's unique potential for net job gains in the food chain to turn this challenge into a growth strategy to produce more with less'. Further discussion of the main features of a global food system is provided in Box 1.

Box 1. Characterising a global food system

Broadly speaking, the main features that characterised a global food system can be summarised as follows:

- There is a need to refer to the major transformation of food supply systems that is already occurring, i.e. food and farming 4.0. This transformation is based on the use of digital technologies, e.g. big data in practices throughout the food chain, which has huge potential to mitigate increases in environmental costs stemming from higher standards but also with significant gaps and monopolisation in the knowledge, applications, access and perceptions around these technologies.
- Changes also affect food demand and are driven by mixed shifts in tastes, preferences and perceptions. It is important to consider that population, income and consumption trends differ worldwide, with some food deficits being identified in certain regions of the world. Looking at dietary patterns, there are also significant differences among developed, emerging and developing countries; while growing expectations for solutions do not always match fact-based analysis, e.g. livestock sector.
- Globalisation and trade has opened up markets and increased economic welfare. However, price volatility also increased which is often driven by exogenous factors, e.g. macro, geopolitical, weather

conditions, diseases, etc. This highlights the need for mechanisms whereby 'winners' compensate 'losers' and the particularity of the EU in being a free-trade environment with such mechanisms in place.

Source: Adapted from Haniotis (2020).

Keeping in mind the above, the first step towards the transition of a sustainable global food system is to raise awareness among all the relevant stakeholders regarding the existence of trade-offs between human beings' needs and perceptions, agricultural supply and natural capital. Then, the next item of this process is the identification of synergies that could open the way to achieved the desired sustainability of the system.

An important item in this discussion is the fact that food systems contribute to Greenhouse Gas (GHG) emissions while at the same time are affected by them. Looking at the contribution of food systems to global GHG emission, The Intergovernmental Panel on Climate Change (IPCC) special report on food security reports that the global food system represents 21-37% of the total anthropogenic emissions, with farms and agricultural land expansion being responsible of around 16-27% of total emissions; and energy, transport and industry related to food processing/distribution contributing to 5-10% of total emissions. Although there are no specific estimates about the GHG emissions related to the EU food system, Garnett (2011) indicates that food could be responsible for around 30% of the EU's total GHG emissions. However, these estimates do not take into account the GHG related to the net-import of agricultural products, and therefore, these figures are underestimating the total volume of emissions that are associated to the EU food system. A detailed analysis of the EU figures indicates that agricultural production is the larger contributor to GHG emissions, while other 'actors' in the food system like storage, processing, transport and retail have a more limited impact.

Drawing attention to the impact of GHG emissions on food systems, it is important to indicate that emissions can affect them in several ways. For example, extreme weather events such as drought and water floods are already threaten yields, with an increasing risk of their presence being more often if climate change is not tackled in a proper manner (IPCC, 2012; WUR-Ecorys, 2020). This element has an important regional aspect, since its negative consequences will not distribute equally through the territory. For example, in the case of Southern Europe it could seriously alter the 'natural' conditions for performing agriculture, reducing the viability of water intensive crops. This negative impact would be mitigated if farmers and plant breeders take appropriate action (Cassman et al., 2010), e.g. modifications of planting date and crop maturity, better heat stress tolerant crops yield losses might be substantially reduced. Nevertheless, the increase in temperature (within certain boundaries) associated to climate change has permitted to extend the growing season in the Northern part of Europe and might allow for tropical cultivations being feasible in non-traditional locations. At the same time, the increase in CO_2 concentrations has led to the so-called 'CO_2 fertilisation' that can increase notably yields in C3 crops (wheat, rice, soya, sunflower, oilseed rape, potato, sugar beet and dry bean).

At this stage, the reader could wonder about the role of policy to facility this transition (see, Box 2 for further details in the case of the Common Agricultural Policy (CAP)). In this regard, at EU level, there is already a comprehensive package of policies that affect the food system. Some of these policies target directly the food system or its specific components, e.g. common agricultural policy, Codex Alimentarius; while others measures affect food systems in an indirect way, e.g. environmental policy, transport policy, biofuel policy, etc. In general terms, these policies are often designed with the goal of tackling sector-specific issues, e.g. animal welfare, or seemingly single, well-defined topics, e.g. nitrate, climate or food safety among others. However, the challenges that emanate from food systems are as complex as the system itself, and therefore, they should be addressed in an integral manner to avoid the introduction of 'undesired' effects such as further fragmentation and incoherencies. In this sense, ignoring this complexity and all potential interactions could lead to the implementation of policy instruments that could be suitable to solve a 'single issue' although might provoke undesirable (side)effects on other policy issues in the long run. Thus, policy coherence and coordination at the level of the food system is crucial to enhance its effectiveness and ensure that trade-offs such as animal welfare versus environment are properly considered (Hoes et al., 2019).

Box 2. The role of the CAP in the transition of the EU agricultural system

As revealed by a public consultation carried out to evaluate the contribution of the CAP to the development and transition of the EU agriculture, an important achievement is the fact that the increase in the EU competitiveness has turned the EU into a net agro-food value-added exporter. The CAP has also had a positive impact on jobs, growth and poverty reduction that has spread in all EU rural areas. In addition, this policy has led to improvements in income stability within a very volatile farm-income and commodity-price environment.

Despite its positive role, the mentioned consultation has also pointed out several aspects that needs to be better addressed in the future. For example, the environmental performance of EU agriculture, the search for solid drivers of productivity growth, changes in expectations about the level of agricultural and commodity prices from CAP post-2013, the shift from a world trade environment towards multilateral to bilateral/regional agreement, as well as new climate change, environmental and sustainability commitments emerging from COP21 and SDGs.

Source: Based on Haniotis (2020).

As will be extensively discussed later in this report, the complex nature of food systems and its interaction with a broad range of policies at EU level have created a challenging environment in which the use of a single model to provide an answer to a particular policy question could become less suitable. This is so in view of the limitations that by definition all models have. On a positive note, the complex nature of food system has opened new opportunities for model collaboration and enhancement of the existing modelling tools (see, Chapter 10).

2.3 Main policies areas affecting EU agriculture

As already introduced in Section 1.2, within the EU there is a variety of (EU and national) policies that affect the agricultural sector. Drawing attention to the transnational level, the EU policy framework regarding agriculture relies on three pillars:

- EU Green Deal Roadmap;
- Farm to Fork Strategy; and
- CAP after 2020.

Box 3. Achieving the SDGs: The potential of the EU policy framework regarding agriculture

Important progress towards the achievement of the SDGs can be expected from the current EU policy framework.

As has been observed in the case of the former CAP, the new CAP is expected to continue stimulating agricultural production, although a stronger focus on sustainability during the production process is now present. Looking at the 2014-2020 CAP, European Commission (2019) estimates that subsidies has led to an increase of about 5-6% of production compared with a situation in which no financial support was in place, eventually contributing to SDG 2. Zero Hunger. This report also provides some policy recommendations based on an evaluation of the policy measures that were implemented for the period 2014-2020. Among the possible recommendations, the authors proposed: greater disciplines on coupled support payments, management measures for not destabilising market prices, further convergence on direct payments, phasing-out decouple payments from income support, as well as improving and facilitating the dialogue with stakeholders regarding issues such as agri-food trade.

In the context of the Farm to Fork Strategy, the emphasis is on sustainable production, processing and consumption in order to facilitate the transition towards a new, healthier, fairer and more sustainable food system. Important aspects that are directly related to the SDGs (mainly 2. Zero hunger; 3. Good health; 10. No inequality; 12. Responsible consumption; and 13. Climate action) are the reduction pesticides, antibiotics and fertilisers; the expansion of organic farming and the reduction of obesity.

From a more broader perspective, the EU Green Deal aims at changing our consumption, production and trade patterns, contributing heavily to the achievement of SGD 12. Responsible consumption among other SGDs. In doing so, it relies on the circular economy package, focusing on promoting sustainable products, reducing primary resource use, encouraging reuse and recycling of materials. Within the Green Deal, current social and environmental challenges are also directly addressed. Moreover, biodiversity deserves a special mention since it is key for the functioning of the environment, society and economy. In this context, is really important to tackle direct and indirect biodiversity loss and creating the necessary conditions for the recovery of nature.

Source: Various.

The EU Green Deal Roadmap is born from the search of an strategy that allows the EU to become 'the world's first climate-neutral continent by 2050', with the ultimate goal of decoupling economic growth from resource use.[1] Earlier this year, the European Parliament adopted a new resolution welcoming the initiative and emphasising the importance of strengthening social dialogue at all levels and sectors in order to ensure a just and inclusive transition towards a climate-neutral economy.[2] The ambition of the European Green deal goes beyond just climate policy, aiming for a coherent and holistic policy framework able to deliver decarbonization, sustainability, protection of natural resources and biodiversity together with economic competitiveness. In doing so, the new EU's flagship framework will need to devote special attention to the territorial dimension, which is crucial for further integration of the EU territory, the utilisation of agricultural resources and the protection of biodiversity.

Box 4. The European Green Deal and the agri-food system

The indicative policy roadmap announced by the EC Communication of 11 December 2019 has the following objectives:

- Designing a fair, healthy and environmentally-friendly food system;
- Resource-efficient, circular and low-carbon economy;
- Protecting, conserving and enhancing natural capital;
- Safeguarding from environmental risks to health and well-being; and
- Trade policy concerns: strengthening sustainable development commitments and compliance with EU food standards.

Source: Adapted from European Parliament (2020).

With regard to the traditional corner stone of the EU agricultural policy, the upcoming new CAP has become a more complex element since it is creating much more room for the Member States to design and implement CAP measures.[3] In this context, the National Strategic Plans has become a crucial element which gives an opportunity for Member States to implement tailor-made and more result-oriented agricultural measures in order to achieve the priorities of the EU Green Deal. The 2018 reform proposals made for the CAP after 2020 address the need to improve the sustainability of agriculture in

[1] For further details, see, With the Communication on the 'European Green Deal', published by the European Commission (EC) on 11 December 2019 (COM (2019) 640).
[2] See, also, European Parliament PA_TA(2020)0005, published on 15 January 2020.
[3] In the preparation for the proposed new CAP, each Member State has to do a SWOT-analysis with respect to the perceived strengths and weaknesses of the current CAP in the context of the local needs and challenges.

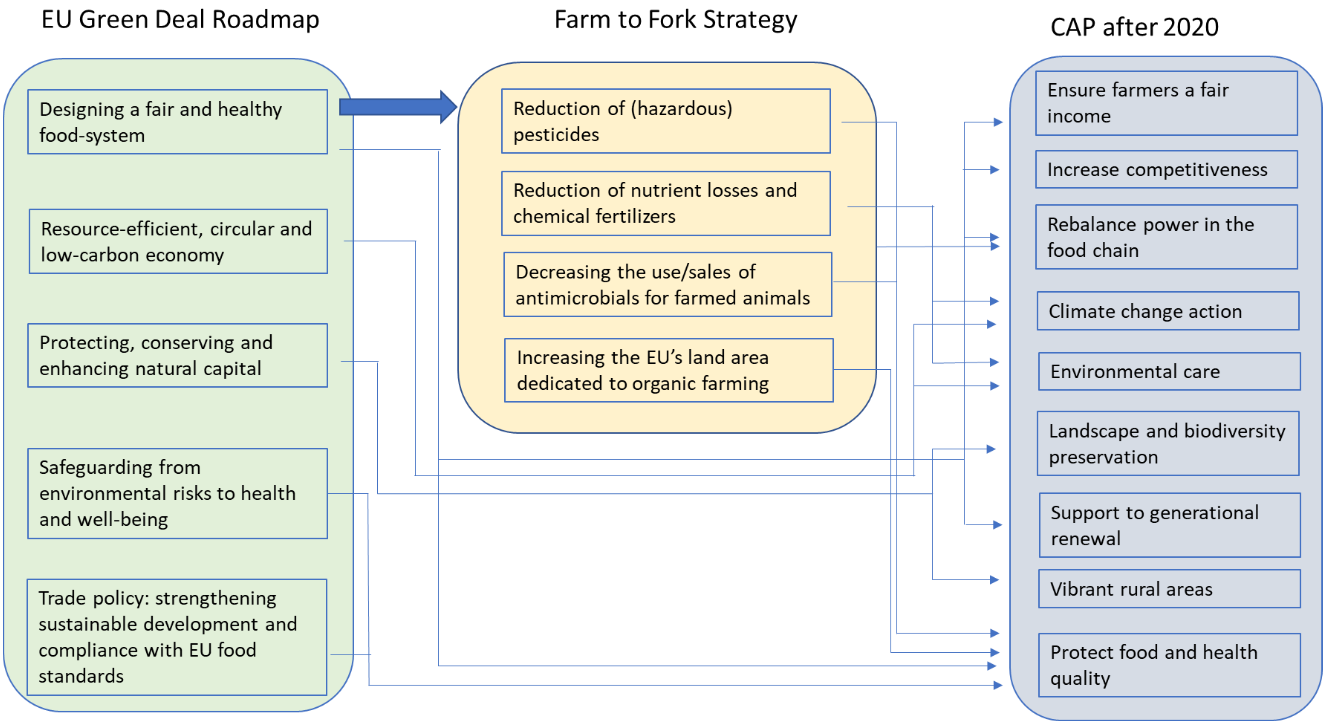
several ways to reflect the new green architecture of the CAP, which is characterised by the following elements:

- Enhanced conditionality is key to establishes and ensures a well-defined baseline. This goes beyond of what may be required outside the EU (public support for farmers outside the EU is also different). The proposed EU baseline now includes the greening requirements (and have these extended to all farms), that are currently supported by a Green Payment, comprising 30% of the Pillar I national envelopes.
- Eco-schemes are now included in the first pillar of the CAP. They are defined as voluntary schemes (for farmers) for the climate and environment and should be specified in greater detail in the National Strategic Plans of the Member States. The allowed compensations for eco-schemes should have a link to the cost of the efforts made by farmers, i.e. the payments can be a fixed amount per hectare, a payment based on a compensation of income forgone or additional costs, etc.
- Agri-environmental and climate-schemes (AECMs) that are included in the second pillar of the CAP. AECMs provide support for management commitments comprising a wide range of activities (which is more extensive that the activities covered by eco-schemes). It may, for example, include organic farming premia for the maintenance of and the conversion to organic land; payments for other types of interventions supporting environmentally friendly production systems such as agro-ecology, conservation agriculture and integrated production; forest environmental and climate services and forest conservation; premia for forests and establishment of agroforestry systems; animal welfare; conservation, sustainable use and development of genetic resources. Member States may develop other schemes under this type of interventions on the basis of their needs.

It should be noted that the timing for discussion the CAP reform and Green Deal is also coincides in with the revision of the EU Bio-economy Strategy. The 'connection' among all these three elements is key since at least half of nine objectives of the post 2020 CAP are directly related to the bio-economy. Needless to say, agriculture and farmers could play a crucial role in improving biomass in order to produce energy and bio-based material and chemicals; eventually contributing to make the European Green Deal a huge success.

Another important aspect for discussion is the major transformation of the food supply systems that is already taking place thanks to new technologies which have the potential to switch the traditional trade-off between productivity and sustainability into a win-win situation. At the same time, there are signs that part of the consumers are actively reflecting on their food consumption styles, especially with respect to animal and vegetable protein consumption. All this proves that the notion of 'food systems' is gaining increasingly importance in different spheres, and therefore, it should have a clear representation within the policy framework. This is the motivation for the 'Farm to Fork Strategy' which has been published in May 2020. More specifically, the 'Farm to Fork Strategy' proposed a food systems approach, which considers primary agriculture (food production), its footprint, and food consumption and healthy dietary choices as interrelated and subject of sustainability-thinking. Within this context, the whole food chain faces the challenge to produce more with less, to decouple growth of output from growth of input. Moreover, the 'Farm to Fork Strategy' creates an opportunity to revisit and update farming policies as well as to reinforce their contribution for the achievement of a fair, healthy and environmentally-friendly agri-food system.

For a better understanding of the inter-linkages among the three pillars of the agricultural policy at EU level, as well as their objectives Figure 1 is presented. Some important conclusions can be drawn from the mentioned figure are as follows. First of all, the Farm to Fork Strategy only covers a limited subset of the Green Deal objectives, with a focus on sustainability/environment and consumer health. The 'reversing obesity' objective of the Farm to Fork Strategy has no direct match with any of the CAP after 2020-objectives. Therefore, there is a 'gap' with respect to the encouragement of healthy lifestyles and consumption patterns in the context of the CAP. Although a bit 'hidden' the link to consumer demand is also present with respect to the objective to increase of the EU's land area dedicated to organic farming, as this, aside other measures, first and foremost will need measures that stimulate demand for organic products. Figure 1 also points out that there are several linkages from all the Green Deal objectives to the general objectives of the CAP. The most indirect one might be the trade-policy objective. However, they establish an important indirect link, since an aligned trade policy will be crucial to ensure that EU farmers will face a level playing field and fair competition with the outside world.[4] Therefore, the 'New Green Deal – CAP' linkage reveals that key issue is not the lack of connections or coverage of topics. Instead, the crucial element is that the CAP after 2020 policy implementation needs to be aligned with the Green Deals priorities and objectives. Moreover, both the Green Deal and the Farm to Fork Strategy indicate a strong ambition with respect to sustainability, environment and climate action.



Source: Jongeneel et al. (2020).

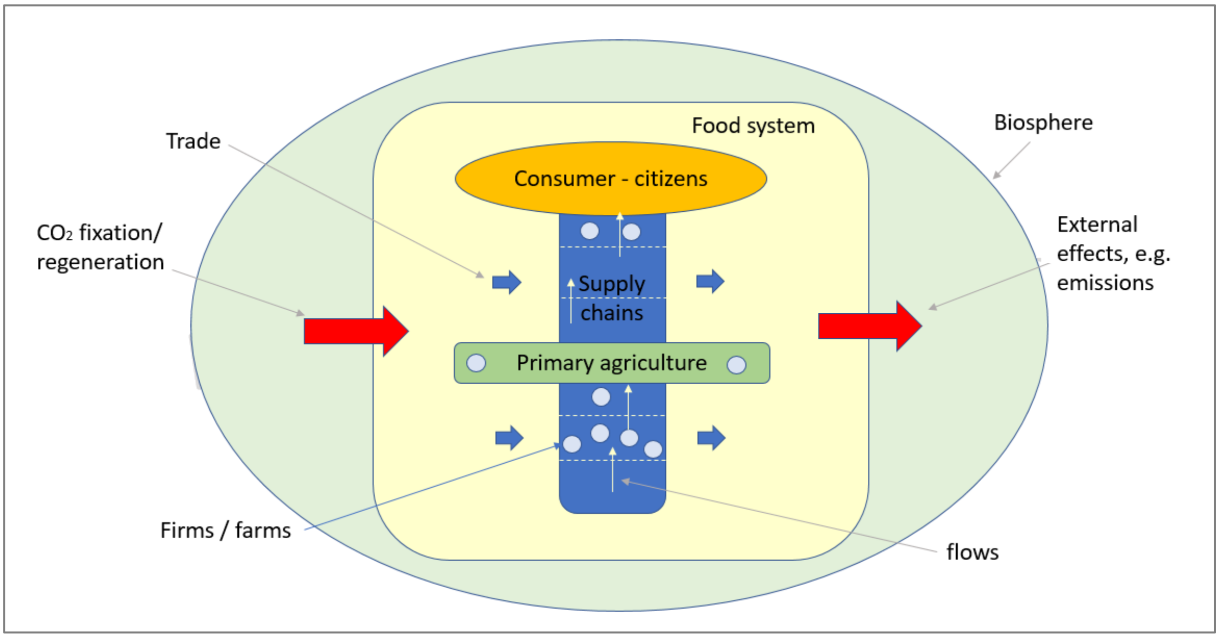
Figure 1. The EU's New Green Deal roadmap, Farm to Fork Strategy, the CAP after 2020 and some main connections

2.4 Food system approach

The notion of 'food system' is gaining importance in the current context in which supply chains are becoming more complex and individuals are asking themselves more questions about the implications of their diets. Within the policy domain, there is increasing interest in seeing agriculture not as a standalone activity, but as contributor to the provision of healthy food supplies that are produced in a

[4] At this point some conflicting views can arise. From the point of view of NGOs, budgetary payments are a means to compensate farmers for obligations and conditions. In contrast, farmers in LDCs and emerging countries are not compensated by their achievements.

sustainable manner. Before moving into a deeper discussion, a clear and comprehensive definition of food systems is needed. HLPE (2017) suggests that food systems are 'all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes'. As explained by Hoes et al. (2019) food systems can be understood as complex webs of actors, hardware, data, food, environments, institutions, etc. that interact with each other. Therefore, the first step in the 'food system' ladder is a primary agricultural sector that can deliver sufficient, safe healthy and affordable food for all (Figure 2).



Source: Authors' elaboration based on various sources.

Figure 2. Food system framework

The geographical dimension is also an important characteristic of a food system. In an increasingly globalised context, such as the pre-covid-19 one, there was a trend for food systems to become broader and delocalised. This trend is in contrast with 'local' food systems which are more present in the case of organic production and 'locally-sourced' products that can act as a 'decoy' for attracting consumers which are concerned about the production process.

A food system framework that takes into consideration not only the activities in the food system but also its socio-economic, environmental and health outcomes is key to understand and define the transformative action to enhance food and nutrition security (FNS) and natural resource security (NRS). As discussed by Hoes et al. (2019), a food system framework considers the interactions and feedback loops between food systems activities (supply and demand) and the ecological and socioeconomic context in which these activities take place. A better knowledge on the interactions and feedback loops provides relevant insights such as:

- Mapping out opportunities for more efficient use of natural resources (beyond one product and/or value chain);
- Highlighting the importance of the food system's socio-economic context;
- Showing the implications of the food system for health, nutrition, livelihoods and the environment;
- Helping shed light on the trade-offs between different intervention strategies; and
- Illustrating non-linear processes and feedback loops in the food system.

Linked to the notion of food systems, a new field of applied research was born. In general terms, the so-called 'food system analysis' focuses on how different types of policy incentives or business innovations can influence the relationships between multiple stakeholders, e.g. input providers, farmers, traders, public officials, processors, retailers), changing the interaction between the different components of the system (consumption, distribution, processing, production). Therefore, all this implies that more attention needs to be paid to the role of food supply chains and diet aspects, as well as on environmental and animal welfare issues. More specifically, food system analysis aims at supporting the design and implementation of policies by:

- Identifying the root that causes a specific problems by considering all the existing interrelationships between actors and flows;
- Spotting particular situations in which interventions might have the most effect, while remembering that these might be found in a very different part of food systems than the place where the issue was initially identified; and
- Identifying relevant trade-offs between different intervention strategies, e.g. food system approaches are considered to be paramount for overcoming trade-offs in agricultural and rural development.

An important example that illustrate the potential of the transforming the food system is the Green Revolution (Third Agricultural Revolution) that took place in 1950s and 1960s. Looking at this event, it is also possible to confirm the potential of policy to make the transition happen.

As already advanced when looking at the sighting nature of global food challenges, the contribution to GHG emissions of the European food system should be made. In a context in climate change threatens the continuation of the 'business as usual' of the European food system, e.g. droughts, water floods, changes in infection diseases for animals and crops, reduction in land availability, etc., there is additional pressure to change the current food system and improve its sustainability and resource intensity. Nevertheless, the role of the European food system goes beyond being an emission contributor since it can also be an important element for achieving climate neutrality, e.g. closing loops in primary production, possibilities for sequestration of CO_2 emissions, providing the basis for a new bio-based economy, etc.

Therefore, with the entire food system contributing to the GHG emissions, climate policy should address the entire food system to reduce its climate impact. In contrast, the focus so far has been on agricultural (primary) production being the main contributor to anthropogenic GHG emissions despite calls for a more integrated approach (Fresco and Poppe, 2016). In particular, consumption which is a key driver of production, needs explicit recognition as high levels of animal protein intake, food waste and overeating at the consumer level contribute to large inefficiencies of global food systems (Garnett, 2011; Alexander et al., 2017).

Moving onto the discussion of the health aspects of the food system, a key reference is the EAT-Lancet report (EAT-Lancet Commission, 2019). This report states that a transition towards a sustainable, safe and nutritious diets by 2050 will require important changes in the current diet, i.e. global consumption of vegetables, fruits, nuts and legumes need to double, while global consumption of foods such as meat/sugar should reduce by more than 50 percent. This confirms that the changes required in the existing EU food systems go beyond primary agriculture. In this context, the EU Green Deal is an excellent opportunity to pursue this objective. At the same time, the EU 'Farm to Fork Strategy' will need to translate the ambitions of the Green Deal into an integrated agriculture and food policy that can be implemented from 2022 onwards.

Designing a fair and healthy food system not only requires policies acting at producer level but also involves targeting other elements in the food system such as consumers. At EU level, the Directorate General for Health and Food Safety is the body in charge of consumer related food policy. There is a wide body of legislation regarding food in the EU, under the umbrella of the General Food Law adopted in 2002. The EU food related legislation has grown over time and addresses food quality and food safety. It includes standards for food safety, animal welfare, agricultural product quality and the environment. There are also rules regarding the labelling of the nutritional value of food as well as health claims. Certification and food safety standards are important instruments to pursue the goals of food safety and quality (Verbeke, 2013). However, the 'health' related part of food policy is less well developed. It is only recently that some programmes have been implemented, e.g. programmes to support the consumption of fruit and vegetables and of milk products at school to promote a more healthy diet among school children. It was only in September 2019 when the 'CuTE: Cultivating the taste of Europe" was launched, being this action the first campaign to promote the consumption of fruit and vegetable among all the European citizens.

Apart from measures that aims at promoting healthy food or diets, another effective 'tool' to steer consumer's behaviour towards a more healthy and sustainable pattern is by means of food policy. Demand for food is generally regarded relatively inelastic, hence raising the prices of products considered less healthy and climate unfriendly may be an effective means of improving diets. In the recent past, some countries have started to implement taxes on certain products that are considered unhealthy (see Dagevos (2018) for further details). An example of this type of intervention are the UK and Swedish experiences. So far, the most well-known examples are sugar, fat and meat taxation. Evidence with regard to the effectiveness of these taxes is mixed since there are only limited experiences and its implementation can be rather complicated. Nevertheless, this instrument should be further explored by policy-makers since while a sugar tax would merely be a health related instrument, a meat tax may also be 'an environmentally friendly policy' (Caillavet et al., 2016). From this perspective, taxation over meat products could be an effective way to internalize the environmental costs.

After acknowledging the importance of a need for food systems perspectives and food system innovations that enable the transformation to a more sustainable and healthier food system on a global scale, some additional remarks in terms of policy making are needed. At this stage the issue of pursing joint efforts and coordination among different stakeholders become more important.[5] Keeping in mind the complexity and interactions within a food system, all the actions implemented by policy-makers in order to favour the transition of the food system towards a new system characterised by sustainability, nature-inclusiveness, provision of food suitable for healthy diets, which at the same time meets societal needs should be aligned and designed in such a manner that they are used in a synergetic rather than conflicting way. In other words, a well-design food policy needs to consist of complementary instruments at international, national and regional level that cover several policy domains such as agriculture, environment, energy, health, education, infrastructure and planning. As proposed by Hoes et al. (2019), policies could: (i) apply a food system approach in order to identify effective intervention points and design appropriate policy measures; (ii) support innovation in food systems via actions such as funding specific R&D activities, targeted investment support and experimentation with promising alternatives; and (iii) adapt institutions like regulations, laws, infrastructure, planning, healthcare and education to enable desirable change to food systems.

The recognition of the importance of a food system approach, as well as having a good understanding of the different elements that are involved in the food system have important consequences in terms of modelling requirements and priorities. In short, priorities for model improvements should aim at:

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[5] As discussed by Hoes et al. (2019), the process of transforming the current food systems to better support nutritious and sustainable food systems outcomes is a difficult task which could be hamper by the absence of sufficient viable and sustainable alternative business models, the status quo characteristics that hinder change, as well as limited steering options.

- Providing a better representation of consumer preferences, which leads to a robust modelling of the demand side of the economy, which from an heterodox point of view is the corner stone of the economic system; and
- Providing a more appropriate representation and understanding of the supply chains which will open new opportunities for the implementation of more efficient and targeted policies, i.e. financially supporting farm production versus subsidising/taxing end consumers, labelling standards, fair distribution of revenues and costs along the chain, economies of scale, imperfect competition, etc.

2.5 Input from SUPREMA workshops

In the course of the SUPREMA project, three workshops were organised as part of WP1 'Challenges, needs and communication – topics for model improvements, applications and dissemination'. The purpose of these seminars was to facilitate the interaction with a variety of stakeholders (economic modellers, European Commission, researchers, ministry officials from several MS, industry, etc.) in order to identify future challenges and related modelling needs that the suite of SUPREMA models will face in the future. The early identification of these modelling needs is highly valuable since it creates room for the modelling teams to further develop their capacities and anticipate to the upcoming challenges. An expected outcome of this further development of models includes model adaptions, enhancements or interlinkages is the possibility of assessing impacts across different spatial scales and layers including upstream and downstream sectors. This list of outcomes should also include a proper representation of decision units like farmers, consumers, processors, traders, policy units in models and their respective behaviours. To achieve deeper and better insights into the interactions among different actors in the supply chain, linkages between models should be employed. Linkages will require efforts for further harmonisation among models and model outcomes. Moreover, additional efforts to solve problems in data requirement, availability and access would be also required. With regard to the policy questions and future topics of interest, this set of workshops have delivered value output too, highlighting with are the thematic priorities that are of interest for several actors in the agri-food business.

As regards the Common Agricultural Policy, relevant needs that were mentioned are income generation and challenges with respect to environmental degradation of soil, water and bio-diversity. Another point that was highlighted during the discussion was the issue that impacts on incomes should not be limited to certain groups. Moreover, the potential consequences of implementing measures for adaptation, introducing mitigation strategies or adopting new technologies was also identified as a key topic associated to cost elements and their transmission along the supply chain to consumers. Water was also mentioned as a separate topic, covering quantity (scarcities and sudden surplus) and quality. Another important item was the modelling of GHG emission reductions, including mitigation and adaptation options towards climate change paying special attention to the long-term perspective. In this context, it was already acknowledged during the workshops the necessity of linking and somehow coupling modelling tools in order to model the complexities associated with these topics.

Technologies, innovation processes and adoption play an important role in agriculture GHG mitigation and, thus, in adjusting to climate change. However, technology and innovation processes are, until now, often or mostly exogenous in models. Therefore, the uptake is potentially restricted over time by some assumed technology adoption rates. Stakeholders requested that models should consider adjustments due to innovation in inputs, input use and in production systems with respect to climate change in more detail to ensure realistic outcomes and to enable technology adjustment to differ between countries. Additional points raised by the stakeholders covered the need to model adoption of new technologies concerning digitalization; micro robots and automated processes at farm level and, in principle in the supply chain and their determining multiple factors.

Sustainability needs to be reflected in its economic, environmental and social dimension and with regard to climate change a good biophysical representation of agricultural production, including its interaction with the biosphere in core. Currently, efforts are on primary production with respect to CO_2-equivalent emissions; however, CO_2 or methane footprints should cover the whole supply chain. A circularity approach should model closing of nutrient cycles and reduce mineral fertilizer use, in particular addressing phosphor, cut losses to the environment by strengthening combination with LCA.

Furthermore, another challenge identified refers to modelling changes in consumer preferences and the behaviour of economic agents. Dietary changes towards more sustainable diets that have a lower content of animal protein might be driven by changes in consumer preferences which eventually could have an important impact on GHG emissions. Therefore, changes in consumer decisions take increasingly into account their perception of production processes with respect to ethical issues and regarding aspects of fairness. To what extent changes might materialize at the point of sale and will depend on the individual circumstances like e.g. availability, labelling, income situation, health concerns, ethical upbringing and environmental reasons, etc. Although demand shifts in society are evolving quite smoothly disruptive changes may occur quite sudden, often in combination with quality, hygienic, diseases or animal welfare problems. Keeping in mind this background, it is clear the need for improving the representation of consumer preferences with the existing models.

Similarly, changes in the political agenda for example due to strategies towards a more bio-based economy were identified as being very important. On this regard, the focus on the discussion was on the strong relation that exists to low carbon and circular economy, particularly in a global context. From the modelling perspective, both challenges would call for a more integrated approach that includes the utilisation of different models in a harmonized way. Since this process is partly unknown and expected interactions are manifold, research is needed for modelling the transition. Within models, bio-economy and, here, in particular bio-materials and bio-chemicals, are only represented to a limited degree. For proper representation of bio-economy, flows of food and feed, bio-material and bio-energy, waste, residues and other uses with substitutions of fossil-based resources data and parameters are scarce, coverage of new technologies and technology adoption is important. To better reflect circularity, a more detailed representation of product-flows (including by-products, intermediate products, re-used products, product waste) is required.

2.6 Concluding remarks

This chapter has set the basis for understanding the priorities for future modelling of different aspects related to the agri-food sector. In particular, this chapter has: (i) elaborated on the current (and upcoming) agricultural policy framework; (ii) introduced the notion of 'food system approach' as an overarching framework that covers the food market from a broad perspective; and (iii) presented an overview of the topics discussed at the SUPREMA workshops. All this discussion have permitted the SUPREMA modelling teams to identify key issues to assess, while an creating an opportunity for the modellers to start thinking about their technical implementation.

At this stage it is important to highlight that models evolve along with policy questions, changing with societal needs and economic development. An illustration of this 'natural' trend is the current shift towards sustainability in the UE policy context and the increased reliance on policy measures addressing individual farms (e.g. 'voluntary-adoption' kind of measures). All these changes create a need to align policy directions and tools for an appropriate model assessment.

In order to provide an illustration of the complexity of the questions that researchers in the field of agricultural economics would need to explore, Table 3 provides some examples of broad topics that could be of interest to investigate. As explained above, this is based on the outcomes of the three SUPREMA workshops that were organised for the purpose of WP1.

Table 3. Overview modelling needs by broad research topic

Topic/subject	Strength	Weakness	Examples
Primary agriculture economy	Response to market signals and trade policies	Explain risk management behaviour and scheme/technology adoption	Technology adoption and eco-schemes
Supply chains (SC)	-	Poor representation of SCs (stages, firms, flows)	C4 of EU dairy processing industry at MS level
Consumer-citizen interests	Consumer demand (apparent cons), other demands	Consumer profiles, consumer age structure, representation of product quality and product attributes (e.g. production systems)	Consumer red meat preference shift
Bio-economy	Bio-energy reasonably covered	Bio materials and chemicals its infancy	Bio-based plastics
Food-system: trade	Trade value well represented (bilateral trade and net trade)	Value added ‘trade’ poorly represented	GTAP involvement, data issues
Sustainability and circularity	Models have set of sustainability indicators, including GHG/climate	Circularity and C-linkages poorly represented, but work ongoing	EU P balance (Nutri2Cycle)

Source: Authors.

3 Primary production

3.1 Introduction

The modelling of primary production is at the core of all the models of the SUPREMA modelling suite. As is shown in an excellent literature review, spanning the developments in primary production modelling throughout the last 30 years (Gohin et al., 2018), production modelling is well advanced and many of the insights and mechanisms gained in the academic literature have been incorporated to sector models. Still from the policy assessment, stakeholder workshops and modelling experts a number of issues were raised which need further consideration. From the policy need assessment it became clear that in addition to the second pillar of the CAP also in the first pillar of the CAP the role of voluntary measures is likely to increase. An important issue in this regard is then to understand, explain and model farmer uptake of such voluntary agri-environmental and climate measures (Pillar 2) and eco-schemes (Pillar 1). As farmer participation and technology adoption can be interpreted as a costs-benefit-evaluation a good representation of the costs and benefits associated which such decisions is also important.

A related issue is that strengthening the linkage between model outcome and policy indicators would be very convenient for policy makers. During the stakeholder workshop also the need for a good representation of fruit and vegetables and Mediterranean products was mentioned as being of importance.

As indicated by the Green Deal roadmap as well as the Farm to Fork strategy, a food systems approach to addressing the current societal challenges is needed. In the Farm to Fork strategy, more in particular, specific objectives with respect to the use of hazardous pesticides, chemical fertilizers and antimicrobials are mentioned. An implication of this for primary production modelling is to pay more attention to the integration of farmers in the food chain (e.g. farmer-supply chain relations such as contracts, linkage between industry and farm-level standards, the position of the farmer in the supply chain) and representation of individual behaviour and decision taking. Another one is that the use of specific farm inputs needs to be well represented in order to asses potential policy impacts and generate relevant policy indicators. Also in the current CAP such issues already got increased prominence, as has been reflected in the policy measures on producer groups and branch organisations.

As it also appeared from the assessment of key policy documents, the EU's emphasis on improving the sustainability of primary agricultural production is clear. This challenges the modelling community to have representations of agricultural production activities that include drivers of production related to environmental constraints.

3.2 Primary production issues

Although the modelling of primary production is one of the core elements of quantitative agricultural economics and has been well-developed in agricultural modelling from the assessment made it appears that there are still a number of challenges to address.

First of all, models differ in the representation of sectors, although a large set of key sectors, comprising large land use shares as well as animal stock, are covered. However, still sectors such as fruit and vegetables as well as Mediterranean products (e.g. olives, citrus fruits) or protein crops and other minor products have a clear policy interest and gain also more prominence from a food systems perspective, since these products play an important role in the healthy diets debate. This also holds with respect to some types of product differentiation, which are important both from a policy (EU quality schemes) as well as a commercial point of view, such as organic produce and PDO- (protected designation of origin) and PGI- (protected geographical indication) products, or other products linked to sustainability of animal welfare labels.

At the heart of production modelling are the costs of production, associated with a wide set of inputs that are used (e.g. fossil fuel, feed, fertilizers, plant protection products, veterinary services, including the costs associated with the use of antibiotics). All models considered account for such costs, however they vary in the detail on costs they provide (e.g. the use of composite cost-indices absolute cost, cost shares, etc.). Moreover, there are limitations to which extent costs are attributed to specific crops of animal production, which also reflect limitations in the data and variable definitions. As became clear from the recent policy document assessment, a more refined representation of the costs of production will be crucial for future policy assessments (e.g. Figure 1 and the key objectives of the Farm to Fork Strategy).

Although farm input use is a core element in agricultural policy modelling the focus has often be on economic issues like the cost of production, competitiveness and impacts on supply behaviour. However, with the changing policy focus a better and detailed understand of feed input use, including its composition and the use and application of organic and artificial fertilizers gets much more attention, since there are important sustainability and climate aspects linked to these inputs. The desired refined representation of these input is often beyond what models currently can offer in a realistic way.

With the increased market orientation of the CAP and the growing impacts of climate change, issues of price and yield risks have become of increasing importance. Policy both in the EU and elsewhere (notably in the US) has responded to this by offering a risk management toolkit. However, irrespective of the growing need as well as the increased availability of risk management measures, the farmer uptake of such measures is much lower than according to expectations. Whereas modelling risk behaviour is already an old topic in agricultural production economics there seems to be still a gap between the way risk in agriculture is studied in the scientific literature and the manner in which farmers actually cope with risk (van Winsen, 2014). Risk perception by farmers together with risk attitude are important to understand a farmer's ideas on acceptability of risk, his risk management strategy (e.g. take up of insurance provisions) and/or farm management measures (e.g. risk spreading by means of adjusting the activity mix). Moreover, the role of policies in risk mitigation might play a role. There is still a clear lack of knowledge here which hampers the assessment of the policy impacts of the offered set of risk management tools to farmers, as well as of their impact on the production (and land-use) decisions farmers make (Ecorys and Wageningen Economic Research, 2018).

Not only the uptake of risk management measures, but also more broadly the uptake of other voluntary measures, as well as the adoption of new technologies (e.g. climate mitigation technologies) is of crucial importance. The models considered in this research were identified to in general be weak with respect to the modelling of agri-environmental and climate schemes adoption. To the extent this is included or simulated it is strongly assumption driven (the CAP scenario simulation in SUPREMA provides an illustration to this; see Deliverable D3.2). Still a significant and increasing part of the policy efforts from the second, but also the first pillars of the CAP is directed to such measures, which challenges the current models.

Here it is important at what level primary production is modelled. Although it are the individual farmers that take production decisions, their behaviour may be approximated in various ways. Several models, implicitly or explicitly rely on a representative farmer-assumption, where such a farmer could even represent the whole agricultural sector. Other models, e.g. CAPRI, create representative 'regional farms', which optimize their profits. The power of such approximations is that they simplify the modelling efforts, which is an important gain as long as it goes not at the cost of missing important trade-offs that are characterizing agricultural reality and farming practices. The advantage of representative farmer approaches is that they ensure that agriculture's output supply and input demand behaviour follows the normal economic behavioural responses with respect to prices and (technology) shifters. Moreover, this behaviour can be empirically validated by econometric estimation of behavioural parameters, e.g. price elasticities. A weakness of representative farmer-approaches is that they often assume a simplified representation of farmer behaviour, e.g. short-run profit maximization, utility maximization, which is highly stylized when comparing it to actual reality. An alternative approach, which tries to compensate for such weaknesses and account for example for farmer heterogeneity with respect to objective functions and interaction effects between farmers, is the agent based modelling approach (ABM, see also Box 5). For understanding certain land market phenomena, a modelling approach accounting for farmer interaction could provide deeper insight into land market behaviour as well as farm structural change. ABM starts from the individual decision maker and allows for a rich structure of the decision-making process, including decision-making adaptation processes (Robert et al., 2016). However, a weakness of such models still is that they easily become computationally complex and that the estimation, or even calibration of the individual's decision behaviour in such a way that it matches with reality is still rather weak. This implies that these model with respect to their behavioural properties, will be strongly driven by assumptions.

Box 5. Modelling individual decision making

With switch from market-based policies to policies that aim to influence farmer decision making and farming practices the understanding of farmer behaviour and the modelling of individual decision making becomes increasingly important. This requires the need for agent-based models (ABMs) which allow to take into account specific behavioural patterns, responses and rules farms follow, as well as for farmer-farmer, farmer-input supplier and farmer processor interactions, as well as farmer compliance behaviour (e.g. Bousquet et al.,1999; Janssen, 2002; Herzfeld and Jongeneel, 2008). ABM models are based on the multi-agent system paradigm that features autonomous entities in a common environment able to act on it , 'communicate' and adapt their behaviour. A key focus of agent-based modelling is the discovery of emergent behaviour, viz. large-scale outcomes that result from simple interactions and learning among individual entities (Kelly et al., 2013). An important modelling project in this regard is MIND STEP, an EC funded 4-year Horizon 2020 research and innovation action, aiming to improve exploitation of available agricultural and biophysical data and will include the individual decision making (IDM) unit in policy models. Other running projects in the same vain are fellow projects AGRICORE and BESTMAP (all three are cooperating in the AGRI-MODELS CLUSTER).

Source: Authors.

Because of the importance to better understand technology and voluntary farm and land management measures, within SUPREMA an in-depth exploration into technological and social innovation has been made (see next section).

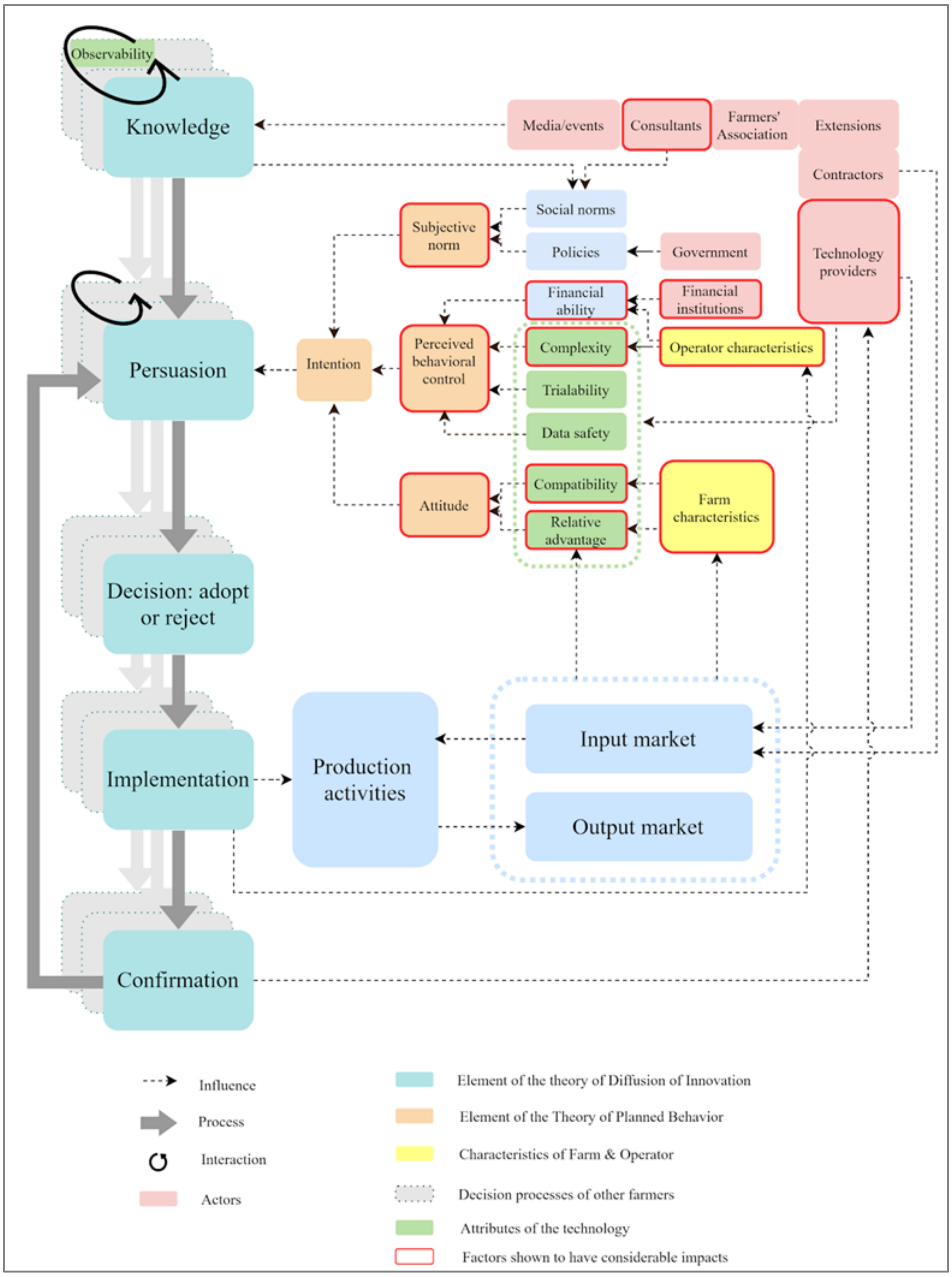
3.3 The role of technological and social innovation

Digital and automated technologies have the potential to be transformative, i.e. a 'game changer' for agricultural production and its environmental footprint in the coming decades (Finger et al., 2019; Miao and Khanna, 2020; Shang et al., 2020). Other technologies such as gene editing or agrovoltaics (Miao and Khanna, 2020) may also have substantial impacts on the trade-offs between yields and non-yield outputs of agricultural production. SUPREMA models have the potential so understand the implications of these new technologies at European or global scale in the context of the whole agri-food system. But the use of empirical knowledge on technology adoption and diffusion processes in SUPREMA model applications is currently rather limited. This section briefly addresses the issue if and how the empirical knowledge for the representation of technological innovation in SUPREMA models can be improved in the long run.

In some way, technological innovations are considered in almost any ex-ante simulation with SUPREMA models. Unless the impact of new technologies is the focus of the analysis itself, technological changes are introduced in the baseline by adjusting input/output coefficients, the parameters of production or processing functions or cost shares in production and processing activities. These parameter adjustments are typically done by assumption or using trend-based forecasts extrapolating past developments into the future, thereby also providing the opportunity to specify the uptake over time. Specific new technologies - for example in CAPRI - can be introduced in the form of alternative production activities or by adjusting the parameters of the crop specific activities. The optimization model will pick preferable activities based on economic conditions, but the relevant model parameters (like non-linear cost function terms) that steer the process are typically calibrated based on some best guess regarding the uptake of such technologies under different economic conditions. An explicit, empirically based modelling of the diffusion of a new technology over space and time is not available for implementation in any of the SUPREMA models and unlikely to be feasible in the foreseeable future due to the comparative static nature of these models and the lack of appropriate approaches for endogenous technology adoption modelling at large scale (Müller et al., 2020). Any progress on this issue for the SUPREMA models will more likely happen by increasing the knowledge used for the definition of technology parameters in baseline and scenarios.

One of the key insights from the recent literature is that adoption is not an event, but a process (Pannell and Zilberman, 2020;). The knowledge on the stages of this learning process is rapidly increasing, and with it the understanding that different determinants matter for each stage (Weersink and Fulton, 2020:73). Relative profitability is only one of many factors relevant for adoption of a new technology at farm level. Non-profit or behavioural determinants are at least as relevant (Dessart et al., 2019). One of the issues with the – by now – vast amount of literature on technology adoption at farm level is that the studies typically relate to a specific technology or practice to be adopted and the focus of attention is operator/farm characteristics or production conditions, but rarely the attributes of the technology (Montes de Oca Munguia and Llewellyn, 2020). Shang et al. (2020) confirm this finding for farm level adoption studies of digital technologies. The key to make progress beyond this limitation is the availability of datasets that span across technologies giving sufficient variation in attributes. Until then, studies that do include technology attributes are typically based on approaches using stated preferences instead of observed adoption behaviour.

Moreover – and this seems to be addressed even less in empirical analysis – the diffusion of new technologies over space and time also depends on system feedbacks at larger scale. These relate to, for example, farm interaction in the learning processes, scale effects in the technology-providing industry, as well as developments of efficient market and service structures (Müller et al., 2020:6). Even though agent-based models are able to analyse elements of such innovation processes with a spatially explicit and dynamic set-up (e.g. Huang et al., 2016), empirical models taking these feedbacks into account seem missing. Figure 3 from Shang et al. (2020) shows a conceptual model currently developed, comprising the complex set of farm level determinants of adoption – including attributes of technology - as well as system interrelations. This conceptual model develops by combining the recent literature on digital farming technologies with insights from the agent-based modelling of technological diffusion processes.



Source: Shang et al. (2020).

Figure 3. Conceptual model for technology adoption and diffusion considering system feedbacks

Increased knowledge on attributes of technology, is exactly what is needed in terms of generalisation, if we want to base ex-ante analysis of technologies in the development stage and not yet used in practice on empirical knowledge. Such knowledge would allow to create informed scenarios on technology adoption. Understanding how certain technology attributes, e.g. labour-saving, CO_2 emission-reducing, decreasing pest pressure, investment cost, etc., affect adoption in specific contexts will allow to transfer this knowledge to new technologies considered in ex-ante assessment. But understanding better the determinants of farm level adoption is not sufficient for defining technology scenarios at larger scale. Here the system feedbacks are relevant as well and, as said above, empirical studies covering this are rare. Dynamic and spatially explicit agent-based models which represent the role of technology attributes for adoption, in principle, are capable to capture the diffusion process over space and time

(Müller et al., 2020). There are research activities going in the right direction for this purpose, but it currently seems too early to develop meaningful recipes for the design of empirically grounded innovation scenarios for SUPREMA models. However, significant progress is expected in this area for the coming years and this should be kept in mind for future research agenda setting.

R&D expenditures are not treated in the models explicitly and technological change (e.g. yield) is a kind of 'manna from heaven', which needs no resources and bares no costs (see, Von Lampe et al. 2014, Robinson et al. 2014). On the sectoral level econometric studies exist to estimate the impact of R&D on factor-augmenting technical change. Smeets-Kriskova et al. (2017a) provides empirical evidence on the speed, sources and direction of technical change for various sectors and production factors. These type of studies provide better insight in the development of technical change and enable enhanced projections in, for example, the global ex-ante assessment models (Smeets Kriskova et al., 2016, 2017b). In these studies factor-augmenting technical change is endogenously driven by R&D investments and impacts are calculated on agricultural production and food security. In this way, technological change is not manna from heaven but resources have to be invested.

3.4 Concluding remarks

With respect to primary production modelling a number of challenges have been identified that need 'solutions' in order for the models to serve the policy makers in their future policy development, implementation and design. Selected aspects that need attention are:

- The representation of production activities and sectors, in particular with respect to fruits and vegetables and Mediterranean products, and with respect to the representation of products under EU quality schemes.
- A refined representation of specific input use (fertilizers, antibiotics) and of the costs of production, where such costs are attributed to the proper production activities and disaggregated to the level needed to better address current and upcoming policy priorities with respect to farm input use (e.g. pesticides, fertilizers, antibiotics).
- The representation of farmer behaviour, which needs to reflect the key trade-offs as these are playing a role in reality, and account for objectives (e.g. profit maximization), decision-making rules (e.g. farming practices, ABM), and relevant farmer interaction effects.
- The adoption of voluntary policy measures, farm management practices and technological innovations.

As was shown in the elaboration with respect to technological and social innovation, adoption practices are complex and still more efforts are needed to better understand these. Before integrating the results into the larger scale sector models, first a number of detailed case study assessment are still welcomed. Results from detailed econometric studies enable the modelling of endogenous technological change, by introducing R&D investments in macroeconomic models. The empirical studies assess the rate of return and factor biasedness of technological change and *ex-ante* models quantify the sustainability impacts of these developments.

4 Land use

4.1 Introduction

As stated by the IPCC Special Report on climate change and land (IPCC, 2019), 'Land provides the principal basis for human livelihoods and well-being including the supply of food, freshwater and multiple other ecosystem services, as well as biodiversity. Human use directly affects more than 70% (likely 69-76%) of the global, ice-free land surface (high confidence). Land also plays an important role in the climate system.' As indicated by IPCC (2019), land is both a source and a sink of GHG emissions, being a key factor in the exchange of energy, water and aerosols between the land surface and atmosphere (see, also Smith et al. (2014) for further discussion on the impact on GHG emission from Agriculture, Forestry, and Other Land Use (AFOLU)).

In the current context in which extreme weather events and climate change can have a strong impact on biodiversity and land ecosystems, the development of sustainable land management practices is an urgent need. According to the official estimates (EPA, 2017), agriculture, forestry and land use are responsible for 24% of the GHG emissions at global level, with a large share coming from land use change and tropical deforestation and degradation. The Nationally Determined Contributions to the Paris Agreement aimed at emissions reductions from land use, land use change and forestry representing a quarter of all planned emissions reductions by 2030 (Grassi et al., 2017).[6] More specifically, Ni et al. (2016) explores the potential for carbon capture and storage from forestry at global level, confirming that carbon harvest from forests and carbon storage in living forests have a considerable potential for carbon capture and sequestration at global level. This study estimates that world's forests have the potential for creating a large carbon sink of about 1 Gt per year, in addition to 11.5 Gt of carbon per year related to reducing CO_2 emissions when substituting wood for fossil fuels.

At EU level, the potential role of an appropriate land use is properly acknowledged within the policy framework, which highlights the relevance of combining productive (e.g. agriculture) and unproductive (e.g. ecological focus areas) land uses. More specifically, the CAP includes the so-called 'green direct payment' that aims at supporting farmers who implement certain farming practices that contribute to the achievement of environmental and climate goals. The 'greening' was designed as an element for rewarding farmers for crop diversification, maintenance of permanent grassland as well as creating areas beneficial for biodiversity, being their associated costs (reductions in expected profits) not covered by market prices. An interesting paper by Zinngrebe et al. (2017) focuses on explaining EFA choices in Germany concluding that administrative and economic considerations have an important role in the decision. The authors also suggest that the conditions for the implementation of EFAs were found to not effectively favour a higher share of biodiversity.

Within the new CAP, a very important element is the eco-schemes (Pillar I) that aims at amongst others the creating of creating buffers zone to promote biodiversity. The mentioned eco-schemes are open to farmers on a voluntary basis, incentivising more sustainable farm and land management practising (see, Lampkin et al. (2020) for further details on the use of the eco-schemes). The new delivery system of the CAP also relies on agri-environment-climate measures (AECM) and the so-called 'enhanced conditionality'.

As introduced earlier, deforestation emanating from changes in the use of land that is made by the agricultural system is responsible of about 8% of CO_2 emissions at global level. At this stage, it is

[6] See, Van Deusen (2010) for a discussion on the potential role of forest land under different carbon sequestration strategies, i.e. management for products and bioenergy versus preservation.

important to distinguish between direct and indirect land use (see, Section 4.2 for details on the latter). Focusing on direct land use, i.e. land that is already used for a particular purpose which will be maintained in the future, there are important contributions such as Marcos-Martinez et al. (2017). This article has highlighted the relevance of having a deep understanding of the socioeconomic, physiographic and climatic elements that determine land allocation among alternative agriculture uses. Having a sufficient knowledge about these interactions is key in order to design a more efficient and targeted land policy.

4.2 Land use and farm-management activity modelling

As highlighted in Carpentier et al. (2018), the modelling of the acreage choices that are made by farmers is part of the core business of agricultural production economists. The important decision of farmers' acreage choices is a key determinant of agricultural supply which eventually also can play an important role in global emissions. In this context, there is a controversial debate on the production of certain crops for energy and other bio-based materials in view of the deforestation that have occurred related to the production of palm oil, soy bean and timber. Therefore, there is a need for models to deliver a proper representation of land use changes that supports this policy debate. Some comments on the existing modelling approaches are presented in Box 6.

Box 6. Approaches for acreage choices and land use modelling

Acreage choice models describe how farmers allocate their farmland to different crops. The modelling of acreage choices has been relying on two main approaches. First of all, we refer to Mathematical Programming models which relies on optimisation problems and calibrated parameters are used for farm management issues and ex ante simulations of agricultural policy impacts. secondly we refer to Multicrop Econometric models which relies on functions with statistically estimated parameters that are applied for ex post analyses of agricultural policy impacts.

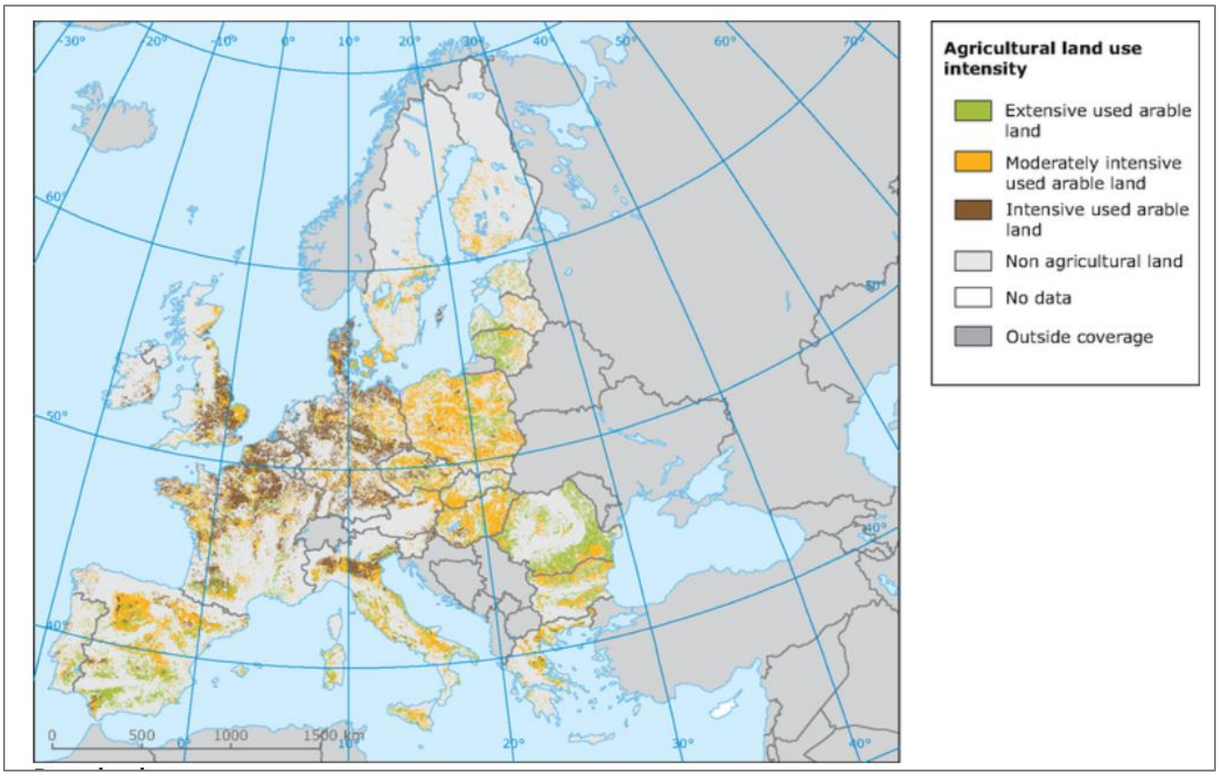
Acreage choice models need to be distinguished from land use models which represent how the decision process in which a land owner decides to allocate a particular piece of land into alternative uses, e.g. crop production pasture, forest, etc. The vast majority of land use models are defined as a standard MultiNomial Logit model or as a variant of this type of modelling. Advantages of this approach is that their parameters are easily estimable by means of a log-linear transformation of the acreage shares, which will add up to 1.

Source: Based on Carpentier et al. (2018.

An illustration of a modelling exercise to better understand the drivers of a multifunctional agriculture system is Jongeneel et al. (2005). This paper studies almost 500 Dutch farms and use the information as the basis for estimation binomial logit models. An important conclusion of this piece of research is that the participation in nature conservation and recreation activities is positively influenced by the trust in the government, and less by the products and services that can be brought to the market.

Apart from that, life cycle assessment (LCA) models deserve to be explicitly mentioned in view of the importance of this approach in the context of assessing the contribution of forestry to climate change. For example, Law et al. (2018) examine the potential of alternative strategies, including afforestation, reforestation, management changes and harvest residue bioenergy use in the Pacific Northwest. The authors demonstrate that reforestation, afforestation, lengthened harvest cycles on private lands, and restricting harvest on public lands increased net ecosystem carbon balance by 56% by 2100, being the latter two interventions playing a mayor contribution. Along the same vein, Mattila et al. (2011) also explore how land use induced environmental impacts can be represented within the life cycle assessment methodology. Another example of the use of LCA methodology is Blonk Consultants (2020) also provides a tools for calculating greenhouse gas emissions from land use change.

Another important item to discuss is land use intensity (Figure 4) and the adoption of different practices at field level. About 80% of Europe's surface area is shaped by land use in cities, agriculture and forestry, with artificial surfaces (including buildings, roads, urban facilities) amounting to less than 5 % of the EU territory and growing despite slowing down in the recent past (European Environment Agency, 2019). Since the current trends in the use of land are not sustainable, policy-makers should focus on land protection to avoid unhealthy and degraded soils. An important element that they should have in mind when extending the built environment is to prioritise 'land recycling' in order to not expand the areas under concrete and asphalt. Drawing attention to agriculture, plant protection products can become an important threat for long-term soil productivity. However, the maintenance of EU healthy soils requires much more than only reducing the use of pesticides. It relies on the use of appropriate agricultural practices, e.g. crop diversification, precising farming, etc., avoiding land abandonment, as well as reducing waste so that 'all can be served, with putting a lower pressure on soils'. Of course, biodiversity protection and climate change mitigation are closely linked to soil quality. Once again, all this emphasizes the role that agriculture can play to the achievement of the SDGs.



Source: European Environment Agency (2017).

Figure 4. Agricultural land use intensity

Within the CAP, Pillar II measures are focused on the achievement of economic, social and environmental objectives in rural areas; involving quite often the implementation of appropriate land management practices. For instance, Schroeder et al. (2014) extend the CAPRI model to estimate the effects of Pillar II in 2006 in the case of Germany. The authors estimate a moderate impact in agricultural income of around 5% increase. In terms of land use, this study points to a marginal agricultural land use increase (0.15%), particularly grassland, and a substitution of arable land with grassland. Private investment seems to be crowd out by farm investment programmes.

A final remark in terms of indirect land use change (ILUC) is also needed. The unintended GHG emissions associated to the expansion of croplands for bio-fuels, together with the reduction in the capacity for capturing CO_2 related to the destruction of grasslands and forests can have a significant impact on global emissions. ILUC is a very complex phenomenon whose impacts go beyond the environmental dimension. Important effects in terms of biodiversity, water and soil quality, food availability and affordability, land tenure, migration and even community stability can be expected from ILUC. Market equilibrium model are able to assess the indirect impacts due to substitution and rebound effects. Equilibrium models can capture how much of the increased demand will be met by agricultural land expansion, agricultural intensification and decreased demand for food (Wicke et al., 2012). Therefore, for the modelling of ILUC, large scale models such as GLOBIOM and MAGNET are the only available tools that could offer a proper assessment of this element. At this stage the reader is referred to Valin et al. (2014) for further details on GLOBIOM and the modelling of ILUC and Banse et al. (2008, 2011) in the case of MAGNET; as well as to Prins et al. (2010) and Wicke et al. (2012) for further discussion on the suitability of several tools that can be used for the modelling of ILUC. Another important effect is the rebound effect, as an increased use of for example biofuels will lower oil prices and therefore result in increased crude oil consumption. This so-called rebound effect offsets the expected GHG emission saving effects of using biofuels, and an energy market model or CGE model (e.g. MAGNET) is able to quantify this effect (Smeets et al., 2012).

4.3 Forestry and bio-economy issues

Forests, forestry and the forest-based sector are the foundations of the bio-economy in the EU, and have a great potential to fight the climate change. At EU level, the future evolution of the forest bio-economy will be closely related to the development of technology, dynamics within the forest-based sector at global level, the evolution of the demand and supply for biomass, the international policy framework as well as the use of forestry resources in a responsible manner. Moreover, the development of the forest bio-economy will depend on a variety of factors, including globalization, the expansion of the digital economy, the evolution of other sectors such as construction, chemicals, textiles and energy, etc.

Within the SUPREMA suite of models, the most comprehensive representation of the forestry sector is provided by GLOBIOM (Global Biosphere Management Model). The model was designed with the objective of contributing to the policy analysis of issues related to the land-use competition between major land-based production sectors. The theoretical framework behind GLOBIOM suggests that the production of food, forest fibre and bioenergy should be designed and evaluated in an integrated manner, i.e. jointly considering agriculture and forestry, forestry, and bioenergy sectors. For example, in the context of the EUCLIMIT project, the model was used to investigate the availability and supply of biomass and the potential effects of its deployment on ecosystems.

Box 7. Key features of GLOBIOM

The structure of the model shows how to available land is allocated into several land cover/use classes according to their output, i.e. production of crops, delivery of raw materials for wood processing, bioenergy processing and livestock feeding. GLOBIOM provides a representation of the existing linkages between elements such as population dynamics, ecosystems, technology and climate that, contribute to the production of agricultural and forestry products. GLOBIOM covers 57 world regions (including 28 EU MS), around 20 most globally important crops, several livestock production activities, forestry commodities, first- and second-generation bioenergy and water. GLOBIOM also includes different energy transformation pathways. Standard outputs of the model are the following ones: (i) demand and supply quantities; (ii) bilateral trade flows, and (iii) prices for commodities and natural resources among others.

Source: Ermolieva et al. (2015).

In this context an interesting application is Ermoliev et al. (2014) which present an exercise for which the regional projections of GLOBIOM were downscaled in order to produce spatially resolved land use and cover change projections. For this exercise, different sources of information were combined, e.g. satellite images, statistics, expert opinions as well as several model outputs. Apart from that, outside SUPREMA, GLOBIOM was used in combination with G4M (Global Forest Model) to compute current and future CO_2 emissions from land use, land use change and forestry sector at EU level (see, Frank et al., 2016).

Moreover, the CGE MAGNET model has an agricultural and a forestry sector. In standard applications the land competition is dealt with within the land supply curve. The MAGNET model depicts sustainable regional supply curves for agricultural land. More specifically, the land conversion between agricultural and forestry land uses is implicitly captured via endogenous land supply function (Meijl et al. 2006, Overmars at al. 2014, Dixon 2014). The forest land is not explicitly included in MAGNET but in post-simulation calculations land use changes between forest, pasture and cropland are calculated under assumption that land converted to or going out of agriculture is a combination of forest and other land suitable for agriculture. Emissions associated with these land use changes are determined. Recently, the model has been extended to identify afforestation as an additional land use category within the land supply curve and afforestation numbers (area) are provided by the IMAGE model (Doelman et al. 2018). The latest development introduces a fully integrated treatment of agricultural and forestry land within the land supply approach as land is also introduced in the forestry sector (Oudendag et al. 2020). In this way demand and supply of both agricultural and forestry products determine the total amount of land needed for both sectors and the land use between sectors. This model extension would improve on the land conversion between forest and agriculture and hence will allow for the socio-economic analysis of policy questions on land use changes. It would also allow for a better (soft) linkage to forest and land use models, which would in turn provide a more detailed and specific insights beyond the economic effects of land use changes.

Outside the SUPREMA project, other models that provides a detailed representation of forestry within the bio-economy are EFI-GTM or GFPM.[7] An important remark regarding land use models is that they need to incorporate a comprehensive modelling of trade flows at global level. This is a key element for them to deliver robust insights in terms of CO_2 emissions and assess the role of forestry when creating a sink that reduces emissions.

Some final considerations in terms of the development of the bio-economy are also due. Early 2000 biofuels entered the agricultural area and the EU biofuel directive of 10% biofuels induced a new policy driven demand category for agricultural products and a direct linkage between the agricultural and energy markets (Banse et al. 2008, 2011, Valin et al. 2014). One effect will be a little drop in fossil fuel prices as fossil is substituted by biomass, and this will create the earlier mentioned rebound effect (also Smeets et al. 2014). In the Macro-economic assessment study for the Dutch bio-based Economy Top sector, a wider range of bio-based products is included such as first and second generation biofuels, bioelectricity and various bio based chemicals in MAGNET (Meijl, et al. 2018). Philippidis et al. (2018, 2019) applied bio-economy assessments to the EU level.

[7] The reader is referred to the H2020 'BioMonitor' project in which a detailed overview of these models is provided in D4.1. See: http://biomonitor.eu/.

4.4 Biodiversity

The intensity of agricultural production has increased over past decades. The intensification of European agriculture has been linked to two main trends: (i) the increase in the application of certain production factors per unit area to increase yields, like agro-chemical (fertilizers, herbicides and pesticides) and machinery (greater intensity and frequency of ploughing and tillage); and (ii) the specialization of land use and crops to maximize the economic return derived from application of production factors, both through a reduction in the number of cropped and husbandry varieties and an spatial differentiation between crops and grassland and increase in plot size (Potter, 1997). The wish to enhance productivity has been a strong and steady driver behind the rationalization and modernisation of agricultural production. A side aspect of this is that landscapes have been moulded to become production-landscapes homogenization. Agriculturally related land use changes include the conversion of complex natural ecosystems to simplified managed ones (Matson et al., 1997). Landscapes are not only important for the amenity values they provide, but also because agricultural landscapes that are composed of a mosaic of well-connected early and late successional habitats may also be more likely to harbour biota that contribute to regulating and supporting services for agriculture, compared to simple landscapes (Bengtsson et al., 2003; Swift et al., 2004; Tscharntke et al. 2005). As such landscape emerges as a fundamental scale to analyse biodiversity in relation to agriculture (Hoffman, 2000). The changes in production intensity and landscape homogenization have been threatening biodiversity. Several indicators indicate a decline in biodiversity, such as a loss of species richness and a decline in meadow bird populations.

Important policy measures for biodiversity protection are the EU Bird and habitat Directives. The CAP aligns to these directives, by including elements from these regulations as requirements farmers should satisfy to be eligible to direct payments (e.g. the current cross-compliance measures and the proposed future enhanced conditionality clauses). In addition, there are several policy instruments in the CAP that directly aim to contribute to agricultural biodiversity preservation (e.g. agri-environmental and climate schemes of the second pillar of the CAP). Moreover, the European Commission has adopted the new EU Biodiversity Strategy for 2030 and an associated Action Plan (annex) in June 2020, which represents a comprehensive, ambitious, long-term plan for protecting nature and reversing the degradation of ecosystems.

Most of the available information on the relationship between agricultural intensification and biodiversity is about birds and vegetation. Also relationships between grazing and vegetation have been well documented. As long as it is causing low to medium disturbance levels, grazing for example determines the relative abundance of plant species in a habitat, thus influencing the competitive abilities of plant species relative to each other, preventing one species to become dominant over the rest. However, there are still knowledge gaps with respect to response of other taxonomic groups, such as invertebrates, earth biodiversity and mammals to changes in farming.

Within the ecological literature significant steps have been made to improve the modelling with respect to biodiversity and landscape. Chopin et al. (2019) reviewed 67 case studies addressing the impact of agriculture on biodiversity in model based scenario approaches, and found a large diversity of approaches, varying from biodiversity based agent based models, expert based exploration of land use change with GIS and to land use approaches of biodiversity with spatially explicit (statistical) simulation models. Whereas there are many specialized biodiversity studies with high complexity in terms of biodiversity modelling with agent-based models or mechanistic models, the bioeconomic simulation models do not consider species' behaviour or landscape configuration, but generally address a large range of socioeconomic and environmental indicators to approximate the state of biodiversity or landscapes.

The models considered in this research are in general weak with respect to the extent that they include biodiversity and landscape issues. There is a tension with respect to the complexity of modelling ecological processes, which often have a strong spatial nature and where localized contexts are important, and the EU wide coverage requirement for EU policy support models. As an example, in the CCAT-project an assessment has been made about the impact of cross-compliance on biodiversity, while focusing on three indicators: the change in share of intensive/extensive land use, the change in density and share of intensive/extensive livestock, and change in land use diversity (evenness). The indicators were calculated at NUTS2 level using a combined CAPRI-MITERRA modelling effort and translated into a pressure-indicator for biodiversity and landscape (Oñate et al., 2008). Moreover, they assessed impacts on habitat quality derived from environmental indicators, including chemical soil quality, ground and surface water quality (e.g. nitrate leaching to ground water) and ammonia emission (NH_3) to air (Oñate et al., 2008).

With the increased policy emphasis on sustainability, including objectives with respect to reduce the use of artificial fertilizers and chemical plant protection products, e.g. Farm to Fork strategy, it becomes urgent to better be able to assess the impact this may have on improving the biodiversity status of agricultural landscapes. For this reason additional efforts are needed to improve the policy impact assessment models, as these are the subject of this research, with insights from the latest results obtained from the ecological literature.

4.5 Concluding remarks

Starting with some references to specific elements within the CAP that affect the sustainability of farming practices, e.g. eco-schemes, this chapter has also provided an overview of the main approaches for land use modelling that are developed by the existing literature. Moreover, it has elaborated on the potential of an appropriate land use (and land management practices) for the achievement of other objectives that will become key in the context of agricultural policy, i.e. biodiversity and climate neutrality. Apart from that, models with a proper representation of land use and forestry are increasingly important for any assessment about the evolution and contribution of the bio-economy. As already introduced in Chapter 3, land use is closely related to the role of technological innovation since the latter can be a driver of the former. The discussion about land use and management practices will be further extended in Chapter 6 in the context of climate change and mitigation options.

Regarding the bio-economy a key challenge is to introduce all potential new bio-economy applications within the modelling framework. Much progress has been achieved for bio-fuels and to a lesser extend bioenergy but the introduction of bio-based materials and especially bio-based chemicals is a huge challenge. The latter is partly caused as bio-based materials\chemicals are very heterogenous and technological change changes fast.

With respect to biodiversity it has been argued that the current status of the models that have been considered is rather weak. Additional efforts are needed to improve the policy impact assessment models and update them using insights from the latest results obtained from the ecological literature.

5 Modelling of environmental aspects

5.1 Introduction

Although in the EU Green Deal climate neutrality is a key objective, reducing greenhouse gas emissions is not the only challenge facing EU agriculture. Sustainability covers a wide range of environmental aspects (European Commission, 2020). Agriculture is a major source of nitrogen losses, with the current nitrogen loss estimated to be 6.5 - 8 million tonnes per year, which represents about 80% of reactive nitrogen emissions from all sources to the EU environment. These nitrogen losses take place mainly in the form of ammonia to the air, of nitrate to ground and surface waters and of nitrous oxide, a powerful greenhouse gas. Around 81-87% of the total emissions related to EU agriculture of ammonia, nitrate and of nitrous oxide are related to livestock production (emissions related to feed production being included) In this context, besides enteric fermentation and manure, feed production is also a main source of emissions. The nitrogen surplus on EU farmland (averaging 50 kg nitrogen/ha) has a negative impact on water quality. Since 1993, levels of nitrates have decreased in rivers, but not in groundwater. Nitrate concentrations are still high in some areas, leading to pollution in many lakes and rivers, mainly in regions with intensive agriculture (Pe'er et al., 2017). Another important pollutant is ammonia, with farming generating almost 95 % of ammonia emissions in Europe. While emissions have decreased by 23% since 1990, they started to increase again in 2012 and by that create additional pressure on biodiversity.

A basic and crucial input for agricultural production is land. About 45% of mineral soils in the EU have low or very low organic carbon content (0-2 %) and 45% have a medium content (2-6 %). Soil trends are difficult to establish due to data gaps, but declining levels of organic carbon content contribute to declining soil fertility and can create risks of desertification. The soil is subjected to erosion, loss of organic matter and pollution by pesticides and heavy metals. All of them are caused by non-sustainable farming practices.

The explicit emphasis to strengthen circularity of nutrient flows (circular economy) imposes also new challenges for modelling since this traditionally has a commodity and input/out product-level approach and not a nutrient-flow focus. Given the prioritized sustainability direction the focus on the modelling of nutrient flows and/or nutrient balances becomes more important (e.g. visualisation in Sankey diagrams).

Together with land, another important input for agricultural production is water. This is a key issue in view of scarcity and quality issues that could seriously affect the production possibilities of certain areas, e.g. tomato production in the Southern EU countries might not be viable in the future, increasing water vulnerabilities in many African countries, etc. Against this background, Iglesias and Garrote (2015) focus on the risk and potential opportunities that climate change and water availability will create in Europe. The authors characterise the main risks across European regions and evaluate adaptation strategies, concluding that improving adaptive capacity and responding to changes in water demands are the most promising areas for intervention. Nevertheless, adequate training to farmers and viable financial instruments are pointed as key element for a successful implementation. In terms of the modelling, hydrological models can be also used to estimate the effect of different operations on water quantity and crop yields. A good example of this is Querner et al. (2014) which use the Soil and Water Assessment Tool (SWAT) to simulate several irrigation scenarios with different options of crop yields and water allocation management practices. However, the representation of water becomes an key area in which there is a pressing need for model collaboration. More specifically, it has been proven as a successful approach the combination of a crop model in which irrigation demand can be a function of the weather; with weather being represented by means of a hydrologic model which also includes other competing uses of water. An example of this approach is the contribution by McNider et al. (2015) which includes a gridded version (GriDSSAT) of the crop modelling system DSSAT. In this exercise, the irrigation demand from GriDSSAT is coupled to a regional hydrologic model (WaSSI). Both models are coupled through the USDA NASS CropScape data to deliver crop acreages in each watershed. Another important contribution on this topic is Li et al. (2019), which presents an integrated model for agricultural water-energy-food nexus management for Northwest China. This model is able to identifying trade-offs among water, energy and land resources for various areas and crops.

5.2 Strengthen the interaction between different types of quantitative models for modelling of environmental elements

As already introduced, environmental aspects are becoming increasingly important in agricultural policies. In the current body of legislation, there are important environmental policies related to agriculture, such as the Nitrates Directive, Birds and Habitat Directives and the clean air policy package. In the proposal for the post 2020 CAP the environmental aspects are clearly visible, with three of the nine main objectives related to the environment, i.e. (i) climate change action; (ii) environmental care and preserve landscapes; and (iii) biodiversity. For achieving these objectives, several elements have been proposed such as a larger share of the budget should be related to climate and environmental objectives, improved conditionality, as well as additional funding for voluntary climate and environment measures (the new Eco-scheme). Moreover, in the recently announced Green deal and Farm to Fork strategy these environmental objectives are important, focusing on tackling climate change, protecting natural resources and enhancing biodiversity. However, most of the agricultural economic models are not able to include these interactions of agricultural and environmental policies in detail.

Box 8. The new Eco-scheme

The Eco-scheme is an integral part of the CAP Strategic Plan's Green Architecture design and implementation. This instrument is envisaged as to serve managing authorities in the process of achieving CAP's specific environmental and climate objectives by giving them more autonomy when establishing the environmental and climate actions supported under Pillar 1. In the context of this instrument, managing authorities must elaborate a 'list of agricultural practices beneficial for the climate change and the environment' based on the needs and priorities they have identified at national and/or regional level.

With regard to the funding allocation, managing authorities can devote the majority of their national envelopes for direct payments to the Eco-scheme as there is no limit to their extent. In this regards, some authors have indicated that their share could increase over time, reaching 100% of direct payments at the end of the 2021-2027 planning period.

The eco-scheme is 100% financed by EU funds, not being necessary for national or regional authorities to allocate additional funding for this instrument. Therefore, managing authorities have more possibilities to use both pillars of the upcoming CAP to invest in solutions that can address the environmental and climate challenges that the agriculture and forestry sector are facing, including the provision of public goods.

The eco-scheme should not be used in isolation, but rather combined with other elements of the Green Architecture such as conditionality, agri-environment-climate commitments, the Farm Advisory Service, and other rural development interventions co-financed by the EU and Member States.

Source: Based on Lampkin et al. (2020).

One of the proposed elements new CAP proposals is also the obligatory use of a nutrient management tool by farmers. The European Commission is working on the development of such a tool. The Farm Sustainability Tool for Nutrients (FaST), proposed in the framework of GAECs, aims to facilitate a sustainable use of fertilisers for all farmers in the EU while boosting the digitisation of the agricultural sector. However, also existing national farm level tools could be used. For example, in the Netherlands all dairy farmers already have to use the 'Annual Nutrient Cycling Assessment (ANCA – KringloopWijzer) tool, which is a management tool for nutrient flows on a dairy farm. The objective for the use of these tools is first of all to create awareness amongst farmers, but the tool might also be used for a more result-based monitoring of the CAP). Instead of regulatory measures to which all farmers have to comply, the use of these tools also allows for the monitoring of more targeted farm specific measures to reduce nutrient losses. The challenge for the agricultural economic models is how to capture and model the variety of measures that are taken on the farms. Some kind of linkage to farm level modelling might therefore be required.

In the context of the SUPREMA project, some first steps have been taken to improve the modelling of the environmental aspects related to agricultural policies. One of the actions was the coupling of the agricultural economic model AGMEMOD with the agricultural emission model MITERRA-Europe. So far, a one-way coupling has been developed, in which activity data from AGMEMOD are linked to MITERRA. This exercise permits to assess the impacts on emissions as a result of changes in activity data. The outcomes of the mentioned exercise are reported In Deliverable 3.2 in which scenarios for changes in consumption pattern and potential effects of the post 2020 CAP have been assessed with the combination of AGMEMOD and MITERRA. In the future a two-way linkage is envisaged in order to take account of feedbacks between different components of the two models. This could be done in a full iterative model linkage, but there might also be alternative approaches, where an optimisation model can be used.

Box 9. Future pathways for Dutch agriculture

In order to assist the 2019 climate discussion in the Netherlands, the Climate Table commissioned a scenario study that was carried out jointly by the AGMEMOD and MITERRA modelling teams. In this study, four different scenarios were simulated focusing on the future pathways for agriculture and land use by 2050. These are hypothetical scenarios for the Dutch agricultural sector, in which a key assumption is that all farmers in the country will follow a specific direction and apply all associated measures. The purpose of the scenarios is to provide a starting point for a substantiated discussion about the future of Dutch agriculture. The expected effects of scenarios in the field of the environment and the economy have been determined as concretely as possible by using models and expert knowledge. In the four scenarios, a distinction is made between: (i) the expected pathway for agriculture, i.e. productivity-driven versus nature-inclusive management; and (ii) environmental usage space, i.e. intended versus stricter environmental policy objectives. For each scenario, a package of (technical) measures that is suitable for moving agriculture towards a certain direction. The effects of the scenarios have quantified by a large set of quantitative environmental and economic indicators, as well as qualitative elements regarding farmers' revenues, biodiversity, animal welfare and resilience to climate change.

Source: Lesschen et al. (2020).

Coming back to the content of Section 4.3, agriculture and forestry are often treated separately in modelling exercises so far. Nevertheless, as policies are becoming more integrated the tools for analysis should do so, e.g. the inclusion of the LULUCF sector in the Climate and Energy Framework with a no-debit target and flexibilities to the sectors under the Effort Sharing Regulation (ESR), the increasing integration for land use, etc. In this context, there is potential for linking economic models with forest growth models, such as the Carbon Budget Model (CBM) used by the JRC (Pilli et al., 2018) or the forest resource model EFISCEN (Verkerk et al., 2016).

5.3 Modelling issues with regard to the rural environment

This section elaborates on a number of selected modelling issues with respect to the rural environment that are important in the context of previously defined policy needs. The focus is on biodiversity, although the topic of animal welfare is also introduced.

There is an increasing awareness of the complexity of evaluating policy measures and processes governing the actors in the rural environment. Back in the 1980s, Lakshmanan (1982) already defined rural development as system defined by the outcome of interactions among its components, i.e. pattern of asset distribution, organizations and institutions, incentive structure in the region, and the external relations to the outside world, etc. As discussed by Hodge and Midmore (2008), there are some specific barriers for analysing and evaluating policies affecting the rural environment. One of this barriers relates to the objectives of rural development which is in the past was consider a sectoral element although it has been progressively shifted to a territorial or local policy. This change in the policy focus adds to the complexity of clearly identifying a clear definition regarding the nature, scope and definition of the notion of 'rural territory'. Against this background, it is clear the need for assessments or models that systematically integrate knowledge developed across a broad range of fields (such as economics, ecology, psychology and sociology, hydrology and agronomy) in order to understand and evaluate the nature and trade-offs of rural decision making. Therefore, an integrated approach that links issues, processes, disciplines and scales is needed. When creating this integrated approach, modellers should also create room for favouring the interaction with stakeholders. This would be key to ensure the employed modelling tools are able to deliver indicators that match with those used for policy evaluation and that are satisfying the RACER criteria (Relevant, Acceptable, Credible, Easy and Robust). Apart from, the interaction with stakeholders will be highly valuable to engage them within the policy/research process, improve the model assumptions and provide further validation of the modelling results.

Looking at biodiversity, knowledge on ecology and the understanding of ecological processes seems to provide an appropriate basis for initiating the process of modelling. Some inherent characteristics of biodiversity are the local nature and the importance for including a proper time perspective as it may take years for biodiversity to recover as a response to policy interventions or to deteriorate as a result of harmful actions in the local or even surrounding area. Nevertheless, the interesting on biodiversity from a broader perspective is also gaining attraction over time. For example, Lammerant et al. (2018) emphasise the need for new natural capital metrics that permit a proper assessment of biodiversity. These authors also highlights the lack of proper methodologies for business and financial institutions to measure and assess the their impact and dependencies on ecosystem services.

Policy efforts are often aimed at preserving or improving habitat conditions (e.g. the EU's Bird and Habitat Directives), but there is often not a simple link between habitat quality and the biodiversity 'output' (e.g. an improved habitat may be good for a certain meadow bird species, but its population may still not increase very much due to the expansion of the number of predators). For an illustration of the complexity of the interaction between policy and biodiversity, we refer to the assessment by Hellmann and Verburg (2010) in the case of the EU Biofuel Directive, as well as the policy documents on the EU Biodiversity Strategy to 2020 (European Commission, 2011).

Modelling of biodiversity impacts related to agriculture is so far not very well established and only indirectly included in the current models (see also previous chapter). Most of the modelling of biodiversity impacts has so far been linked to the proxy indicators such as the intensity of land use (see, the biodiversity monitor that has been developed for the Dutch dairy sector as a reference[8]). Turning back to the SUPREMA models, some of the key characteristics of agricultural management that might effect biodiversity, such as crop shares, stocking densities, yields, mineral and organic fertilizer application rates, are available in models such as CAPRI and AGMEMOD-MITERRA. The interaction between environmental indicators and biodiversity is still an issue that deserves further study (see also previous chapter).

Animal welfare is also an important concern, both for farmers, consumers and society, being an important item in this discussion the trade of live animal trade (see, also Chapter 8) and long distance transport of animals. From the Farm to Fork perspective, the main issue is the use of antibiotics and impacts that the reduction of its use may have on animals, their performance as well as their welfare. Models usually do not allow for taking into account the impacts of antibiotics use reductions since this is not measured as a separate input. The reader is referred to Section 9.3 which further elaborates on the topic of animal welfare.

5.4 Concluding remarks

Environmental aspects are becoming increasingly important in agricultural policies. Besides climate change mitigation, more focus will be set on the preservation and enhancing of biodiversity. However, modelling of biodiversity impacts, is only to a rather limited extent included in the current agricultural and economic models (see also previous chapter). This weak modelling status does not reflect the importance attached to biodiversity objectives in the CAP. Often only indirect aspects of biodiversity have been modelled, such as changes in land use, and modelling of emissions, which can be seen as an indicator for the risk of loss of biodiversity. Direct impacts on the impacts of species, e.g. number of red list species in a region or effects on population sizes of certain key species, etc., cannot be modelled yet.

[8] Available at: http://biodiversiteitsmonitormelkveehouderij.nl/.

6 Dealing with climate change

6.1 Introduction

Achieving climate neutrality in the EU by 2050 is a key objective of the EU Green Deal, thereby creating a serious challenge for EU agriculture to strongly reduce its greenhouse gas emissions. Looking at 2017, GHG emissions from EU agriculture accounted for 10.3% of EU emissions and nearly 70% of those come from the animal sector. Although these emissions decreased by 20% between 1990 and 2013 they started to rise again since 2014. Moreover, net removals from land use, land use change and forestry offset around 7% of all EU GHG emissions in 2015.

Climate action has progressively been integrated into the CAP over time, which is due to the growing importance of the EU agenda on climate action and of developments of the international climate negotiations. The 'sustainable management of natural resources and climate action' can be achieved through the combined effects of a number of different CAP measures, encompassing cross-compliance, direct payments under the European Agricultural Guarantee Fund (EAGF), rural development policy under the European Agricultural Fund for Rural Development (EAFRD) and accompanied by support from the Farm Advisory Service, and the activities of the European Innovation Partnership for Agriculture and the national Operational Groups.

The climate objective challenges agricultural models with respect to the greenhouse gas emission indicators they provide. An important aspect for policy assessments is that models have a realistic representation of mitigation measures (e.g. cover crops, crop rotation, different tillage practices, manure management, stable adaptations, feed management, grazing management, fertilizer applications, riparian buffer strips, agroforestry, nitrification inhibitors, etc.), as well as about the conditions under which such measures will be adopted (e.g. in the form of marginal abatement cost curves). This implies not only a stronger focus on measure/technology adoption and innovative sustainable farming practices, but also includes the role of non-productive investments and their responsiveness to policy signals. Related aspects are input-related footprints, estimating lost/gained carbon sequestration related to changes in land use and soil carbon modelling.

6.2 How agriculture is coping with climate change

Countries have made their National Energy and Climate Plans, which were submitted to the EC by most Member States[9]. However, these plan are often not yet very specific on the proposed mitigation actions in agriculture and also sub-sector targets under the Effort Sharing Regulation (ESR) are not clear yet.

Focusing on adaptation measures, Rotter et al. (2018) highlight that modelling is a key tool to explore the agricultural impacts of climate change, as well as several possibilities for the adaptation of the sector. More specifically, this contribution focuses on the outcomes of MACSUR and AgMIP projects. A key conclusion of the study is that there is a pressing need for integrated crop and economic modelling. In particular, the authors emphasise that a more mechanistic understanding of climate impacts and management options for adaptation and mitigation is required, as well as the need for multi-scale assessments instead of single season and individual crops models. Overall, more realism in the

[9] See, for further details: https://ec.europa.eu/info/energy-climate-change-environment/overall- New input is added targets/national-energy-and-climate-plans-necps_en.

modelling of climate change and the different strategies that are available to adapt to/mitigate its effects is needed. A key issue in this respect is improving the representation of cost-side elements, whose modelling is extremely weak or even lacking in the case of adaptation options.

Moreover, the achievements of climate neutrality by the agricultural sector in 2050 will require the implementation of mitigation options to reduce GHG emissions, but also practices in land use that can sequester carbon in the soil and biomass. Here the key main challenge for agricultural modelling is to have a wide set of mitigation measures (and their adoption) well represented within the models. Examples of mitigation measures that should be incorporated in the models are technical coefficients for modelling reductions in fertilizer use, adaptation of feed rations, change in supplemental/compound feed, e.g. reduced protein-rates, representation of low-emission stables, constraints or ceilings for modelling reductions in herd numbers with no change in animal yields, and planting forestry, i.e. woodlots, on parcels of farm land.

A reference system in the context the impacts of climate change on agriculture is MOSAICC (Modelling System for Agricultural Impacts of Climate Change) as developed by FAO, which combines climate data processing tools, crop models, a hydrological model and an economic model.[10] Moreover, mitigation potential for several of these options have been assessed with models such as MITERRA-Europe (e.g. in the PICCMAT, NitroEurope and AnimalChange projects) and CAPRI (e.g. in the ECAMPA projects). However, key to the mitigation potential is the rate of implementation, which is very much dependent on how mitigation options are stimulated (regulatory policies, subsidies, voluntary incentives) and the economic cost. Therefore, a coupling of economic and emission models is required to get a more realistic insight in the uptake of the measures. At this stage the reader is referred back to Section 3.3 for the modelling of technology adoption, as well as Box 9 (and source publication) for an example in the case of the system AGMEMOD-MITERRA and a discussion of several mitigation measures that could be applied in the Dutch agricultural sector and extended elsewhere.

Box 10. The contribution of CAPRI to the EcAMPA projects

In the context of the three EcAMPA projects (2013-2018), the CAPRI model has been modified for providing an endogenous representation of several mitigation choices that were already included in the model (EcAMPA-I), as well as further improved in terms of technological GHG mitigation options and emission accounting (EcAMPA-II). More specifically, the EcAMPA-II study explores potential options for reducing non-CO2 emissions from EU agriculture, highlighting issues related to production effects, the importance of technological mitigation options and the need to consider emission leakage for an effective reduction of global agricultural GHG emissions. In the course of EcAMPA-III, the accounting and mitigation of CO_2 effects were fully integrated within the CAPRI supply models. Moreover, a large set of scenarios focusing on different individual mitigation measures were modelled in order to determine marginal abatement cost curves with a potentially simultaneous use of all mitigation options.

Source: http://www.eurocare-bonn.de/projects/ghg_carbon/ghg_ecampa/ghg_ecampa.htm.

Yields are also an interesting item to consider when talking about agriculture and climate change since they can be heavily affected by irregular/extreme weather.[11] On a positive note, CO_2 fertilisation could positively affect the yield of C3 crops. An example of econometrically estimation of yield responses for several crops and regions combining economic and agronomic information is provided by Jongeneel and Gonzalez-Martinez (2020).

[10] See: http://www.fao.org/climatechange/mosaicc/66705/en/.

[11] See, Garcia-Cueto and Sotos (2012) for an example of the modelling of extreme weather events using Mexico as a case study.

Some remarks regarding abatement cost curves are also needed. The marginal abatement cost curve (MACC) approach is a well-known framework to summarise information regarding potential mitigation effort which can help to identify the most cost-effective managerial and technological GHG mitigation options. In order to explore the possibilities that agriculture offers to mitigate GHG emissions and utilise carbon sink potentials, several countries have developed national agricultural MACCs. An interesting contribution in this field is Eory et al. (2018) who emphasise the value added of MACCs as a coherent approach to consolidate (and facilitate) the complex discussion about agricultural GHG mitigation, as well as a tool identify key opportunities. In contrast, Kesicki and Ekins (2012) identify several limitations of MACCs, being the main ones: (i) they do not capture ancillary benefits of GHG emission abatement; (ii) they present a very limited treatment of uncertainty; (iii) they usually exclude intertemporal dynamics; and (iv) there is some lack of transparency regarding their assumptions. MACCs are based on individual measures considered in isolation, not representing the interactions (and sometimes the additionality) among different measures. Other limitations are a possible inconsistent baseline, double counting and limited treatment of behavioural aspects and non-financial costs. This limitations are particularly relevant when trying to represent within a MACC emission reductions from deforestation and forest degradation. With a particular focus on agriculture, a study that should be mentioned is Donellan et al. (2018), in which a MAAC for the Irish agricultural sector is developed.

Box 11. Theoretical approaches for promoting actions to fight climate change

In order to incentivise behavioural changes, there are two approaches that policy-makers could consider when designing their interventions regardless the level of action, e.g. farmers, consumers, retailers, etc.: taxes and subsidies:

- **Polluter pays** – Instrumented by means of a Pigouvian tax, the basic idea is to implement a tax on a market activity that generates negative externalities, by capturing the costs that are not included in the market price. A traditional example in the context of climate change is the so-called 'carbon tax'. As discussed by World Bank (2019), 'a price on carbon helps shift the burden for the damage back to those who are responsible for it, and who can reduce it'. This instrument acts as an economic signal to polluters, who can freely decide whether to discontinue their polluting activity, reduce emissions, or continue polluting and pay for it.
- **Provider gets** – An alternative instrument could be to use a subside to 'reward' those who have a private initiative who delivers additional value to society, e.g. farmers investing in clean technology, private actions to protect biodiversity, investments in lower carbon options, small subsidies to promote reusing/recycling at consumer level, etc. This latter approach fits well in the CAP context (e.g. agri-environmental and climate payment schemes being part of the second pillar of the CAP) and in agriculture's double role in emitting greenhouse gases while at the same time sequestering carbon and having a potential for increased carbon fixation.

Environmental taxes are instruments that make the cost of environmental impact visible to actors in society and thus serve as an incentive to producers or consumers to take environmental aspects of their behaviour into account. Such taxes have been applied in several climate studies. In practice, however, environmental concerns are weighed against other interests, such as competitiveness, regional policy and employment. Environmental subsidies provide a positive incentive to environmentally friendly ways of production and provide a compensation for the extra costs of production. A subsidy policy may not always result in lower net emissions than a tax policy because the tax policy's pass-through effect curbs total production emissions, while the subsidy policy does not (Bian and Xuan, 2020). As is know from the literature there are equivalence properties under which subsidies can achieve the same emission reduction targets than taxes (Nault, 1996). The increased emphasis on sustainability could proliferate the use of targeted incentive policies. In order to assess the impact of such policies the empirical validity of the way farmer, food industry and supply chain behaviour is modelled is becoming increasingly important.

Source: Authors.

From a policy perspective, Fellmann et al. (2018) focus on the EU case and simulate the outcomes of implementing non-uniform national mitigation targets to achieve a sectoral reduction in agricultural CO_2 and GHG emissions. The simulations points out considerable impacts on EU agricultural production mainly in the livestock sector. The study highlights four major challenges for the general integration of agriculture into national and global climate change mitigation policies, being this key challenges: (1) the implementation of a targeted but flexible mitigation obligations at national and global level; (2) the need for a wider consideration of technological mitigation options; (3) the necessity for multilateral commitments for agriculture to limit emission leakage; and (4) the possibility for implementing options that tackle the GHG emission reductions from the consumption side.

Therefore, several aspects that should be taken into account in the modelling of climate interventions are:

- The need for more national specific mitigation actions, as climate targets under the Effort Sharing Regulation differ strongly among EU member states. It might be the case that targets vary per member state in the ESR;
- The contribution of agriculture to total emissions is different among countries, e.g. Ireland and Denmark have a much higher share compared to other member states, which will require more pressure on the agriculture sector to reduce its emissions. Also the possibilities for offsetting emissions by carbon sinks in land use differ among countries;
- In certain cases, sector initiatives or targets can be stronger compared to national targets. For example, many companies are currently setting science-based targets to comply with the Paris Agreement;
- The possibility of using (voluntary) payments for climate action, i.e. carbon credits. These can also offset emissions due to sequestrating CO_2 in soils or biomass (forests, hedges, agroforestry); and
- More flexibility for the farmer regarding the choice of measures to that can be put in place.

Regarding the modelling of all these elements, it seems that there is room for more specific modelling of farm a management practices, e.g. exploring options for further improvements of IFM-CAP, development of agent based modelling tools.

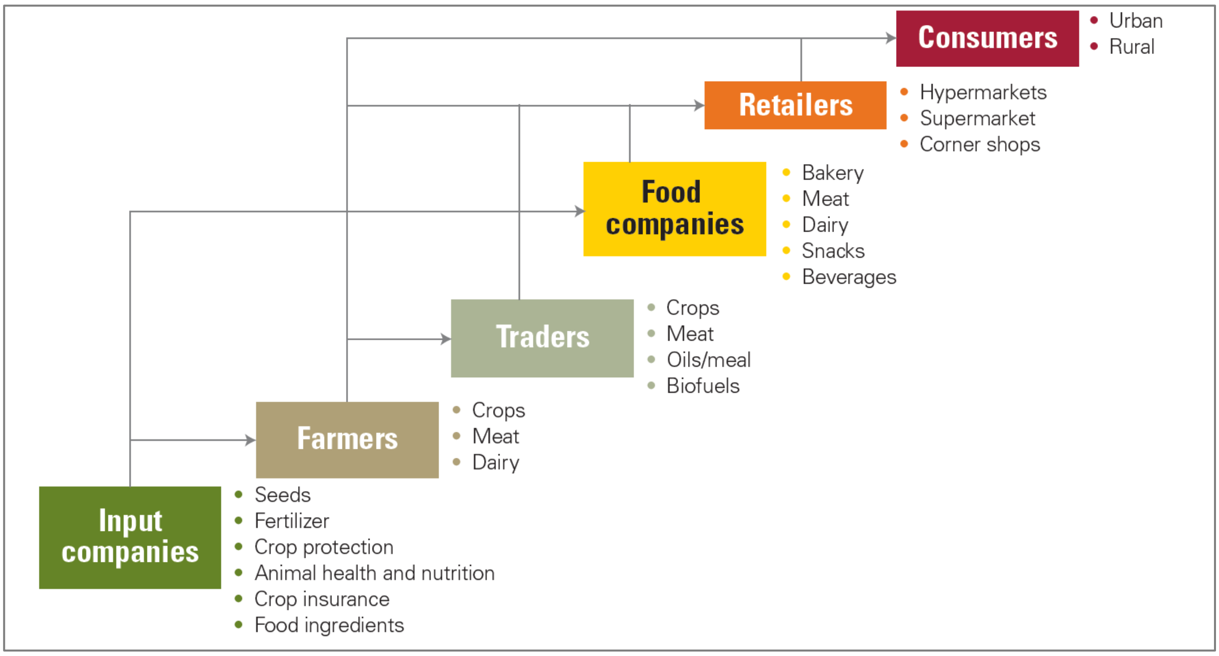
6.3 Concluding remarks

Within the EU Green Deal, achieving climate neutrality by 2050 is a key objective which is encouraging agricultural models to provide a better representation of adaptation and mitigation measures, leading to improved quantification of GHG emissions. The representation of measures as such should be also accompanied with an appropriate modelling of their adoption and diffusion through the agricultural sector. Insight into marginal abatement costs curves, associated with the mitigation measures, could help to provide cost-effective solutions to climate policy objectives with respect to agriuclture. The CAPRI experienced gained through the EcAMPA projects could provide a set of good practices and lessons learnt which could be used when thinking of potential model improvements and further developments for the rest of the SUPREMA models.

7 Representation of supply chains

7.1 Introduction

As was discussed in Chapter 2, the EU Green Deal roadmap and the Farm to Fork strategy advocate a food systems approach to address the challenges of the future. As was already remarked before (see, Chapter 3) this requires a proper accounting for the role of supply chains. Increasing attention given to position of the farmer in the supply chain.



Source: KPMG (2013).

Figure 5. Food supply chain

The agri-food supply or value chains are complex and span input companies, farmers, traders, food companies and retailers, all of whom must ultimately satisfy the varying demands of the consumer in a sustainable manner. The sector encompasses huge diversity and variety at each stage, from R&D-based input companies to generic manufacturers, multifunctional and specialized farmers, small farm holdings to large high-tech farms, small and medium-sized enterprises (SMEs) to multinational corporations (see Figure 5 and KPMG, 2013). At the same time there are short supply chains, characterized by a reduced numbers of intermediaries between the farmer or food producer, and the consumer. The growing interest in SFSCs reflects the consumer demand for 'connectedness' to the making of the food that is consumed, its perceived quality and traceability which is, in their perspective, related to food production close-by involving a very limited number of factors.

Firms in supply chains may be able to exert market power, thereby raising their earning ('excess profits') at the cost of those in other stages of the supply chain as well as at the cost of consumers. This fact induces policy concerns as market power may put farmers and other with small market power at greater risk of exploitation in the prices they pay or receive, could hamper the price formation process, and make contract producers are vulnerable to arbitrary behaviour by 'integrators'.

As already from the outset it became clear that supply chains were only to a limited extent accounted for in the considered models, within the SUPREMA project a case study has been done, in which on the one hand it was checked to what extent and in what way supply chains, or their impacts, are already part of the current models, while on the other hand it was examined how important it is to include supply chains for a proper understanding of market and pricing (remuneration). The assessment of this section is based on the findings of this case study (for details see D2.6 from WP2).

7.2 Better modelling of supply chain issues

An assessment of the existing body of economic literature has revealed that despite the importance of understanding the functioning of supply chains, sector models do not offer an appropriate representation of them to analyse market shocks. In this context, a key subject for study is the modelling of revenue creation (and distribution) through the stages (and actors) that intervene in a certain supply chain. This issue is closely linked to the underlying assumptions of most sectoral models. More specifically, in most agricultural policy models perfect competition and arm's length pricing is assumed in all stages of the supply chain (McCorriston, 1997). That implies that parties to the transaction are independent and prices are determined by aggregate supply and demand. The models typically use a 'representative firm' approach for agricultural production, as well as the food processing stage of the supply chain. Wholesale and retail stages are often modelled as inputs to the production sectors. The downstream part of the supply chain, i.e. beyond processing, is then modelled as a service (marketing services or wholesale and retail services) or a fixed mark-up rather than a separate stage in the value chain (e.g. Magnet and other CGE models). Although some model versions allow increasing returns to scale or imperfect competition, these relationships are typically hard to implement in CGE settings due to a lack of data. Price transmission is either based on empirical estimations of elasticities of demand and supply or some exogenously determined price transmission equations (e.g. AGMEMOD). Drawing attention at other on-going developments, the H2020 VALUMIS project deserves to be mentioned.[12] The purpose of this project is to develop an agent-based model (ABM) to provide a comprehensive representation of the food system dynamics at EU level.

An extensive discussion on the relevance of imperfect price transmission is provided in Bakucs et al. (2014). As pointed out by these authors price changes have consequences for the welfare of consumers and producers; while different model outcomes due to incomplete (or more than proportionate) price transmission may have serious consequences for consumer and producer surplus. Moreover, prices convey information about scarcity. 'As a consequence, investigating price movements along the marketing chain could be relevant to understanding whether resources employed in agro-food production are allocated efficiently.' Another interesting argument is the fact that the analysis of price transmission from upstream to downstream stages in the chain can shed more light on the level of competition in the food sector and therefore of interest to competition authorities (McCorriston, 2002; Bakucs et al., 2014). Acosta et al. (2019) add to this debate that 'in the short-term, direct effects of this transmission on prices and the resulting incentives for supply and demand can affect food availability, access, price stability, and shift food use preferences. In the long term, domestic factors of production such as land, labour and capital can move towards new equilibria due to factor price adjustment, causing indirect dynamic effects on land use, production structures, dietary patterns, employment, and income. These issues have focused attention on price transmission (PT) analysis not only from researchers but also policy-makers.'

Box 12. Remuneration of the farmer in the supply chain

From a policy perspective increasing attention is given to the position of the farmer in the supply chain and his/her getting a fair return for their efforts. It has also been felt that farmers are bearing the brunt of the increased price volatility in agricultural markets. In 2016 the Agricultural Markets Task Force (AMTF) presented its report, concluding that there is a need to strengthen the role of the farmer in the food chain with the

[12] See: https://valumics.eu/.

objective of ensuring that he/she gets a fair return for their produce. More specifically it made a plea for increasing market transparency, enhancing cooperation among farmers, facilitating farmers' access to finance and improving the take-up of risk management tools. The EU has recently adopted new legislation the fight unfair trading practices in business-to-business relationships in the agricultural and food supply chain (Directive (EU) 2019/633) by enforcing EU wide standards. The aim of this legislation is to improve the protection of small food producers and retailers against the potentially unfair practices of their sometimes much stronger trading partners.

Another aspect related to remuneration of the farmer is the investigation into earning models for the green and blue services farmers deliver and for their efforts and actions at farm level to make their businesses more circular (Jongeneel et al., 2020). This could include the development of farm-level dashboards (e.g. advanced nutrient management schemes), which will then be linked to performance-based pricing.

Source: Authors.

As already introduced, deviations from perfect competition may significantly alter the modelling results with respect to price transmission between the various stages of the supply chain, and hence the responses of market actors (suppliers, processors, retailers, consumers) and the effects on producer and consumer surplus resulting from changes in agricultural policies (McCorriston, 1997). The existence of potential asymmetries in price transmission,[13] which have been identified in numerous agricultural supply chains needs to be properly captured within economic models (Peltzman, 2000; Meyer and von Cramon-Taubadel, 2004; von Cramon-Taubadel, 1998). Peltzman (2000) studies a selection of 77 consumer goods and 165 producer goods, identifying for many products that ‘immediate response to a positive cost shock is at least twice the response to a negative shock, and that difference is sustained for at least five to eight months.’ This contribution finds that prices do adjust and asymmetries are not sustained; identifying also contradicting effects of imperfect competition as measured by numbers of firms and concentration.[14] However, Peltzman concludes from this finding that there is no effect of imperfect competition without further investigating the two effects which are statistically significant in their own right. According to this study more price volatility leads to a lower degree of asymmetry in price transmission. Whether imperfect competition is a cause of asymmetric price transmission and under what condition, is still being debated. Commission of the European Communities (2009) reports that for most commodities price transmission is asymmetric in the sense that upward shock are transmitted faster than downward shocks, while in the long run price transmission is mostly symmetric.

Box 13. Econometric modelling approaches of price transmission along supply chains

Two main strands of the literature can be distinguished. On the one hand, there are studies that rely on structural equations and the assumption of equilibrium conditions. On the other hand, another branch of literature focuses on using time series modelling. In terms of the former, there are several ways to model the ‘intermediate food industry’, comprising the processing, handling and distribution stages between primary production and final consumption. The standard approach to model the retail/farm price linkage is based on the theory of derived demand, where consumer demand for the retail commodity generates a derived demand for the agricultural commodity (Gordon and Hazzledine, 1996; Jongeneel, 2000). The retail price of the commodity will reflect the farm price plus the cost of marketing the commodity from the farm to the retail level. McCorriston et al. (2001) state that ’the obvious framework to analyse this issue [of price transmission]

[13] Asymmetries in price transmission in general terms can be identified in those market situations in which cost increases are transmitted faster than cost decreases. This phenomenon could be explained by the existence of market power (McCorriston et al., 2001) and/or adjustment costs (Meyer and von Cramon-Taubadel, 2004) among others.

[14] Fewer competitors tends to increase asymmetry, while higher concentration ratios tend to decrease asymmetry.

is in the context of the equilibrium displacement model developed by Gardner (1975). However, the assumption of perfect competition in the food sector that is typically employed in these equilibrium displacement models does not appear to fit the facts'. Most of the policy analysis models start from the assumption of perfect competition, and price transmission is typically assumed to be complete (not necessarily equal to 1), with the price transmission parameters generally being below one. In a world without transport or transaction costs, without market power, or (government) policies restricting price transmission, cost increases would be fully transmitted.

Drawing attention to the time series literature, we refer to the studies that apply different specifications of the vector error-correction approach (VECM/ECM), with von Cramon-Taubadel (1998) being a seminal contribution. Key topics of these studies are the estimation of price transmission speed, completeness and asymmetry. For example, Cutts and Kirsten (2006) look at maize meal, bread, sunflower cooking oil, and milk in South Africa. They confirm that differences in price transmission can be explained by market concentration. Moreover, Falkowski (2010) finds that retail market power in the Polish dairy supply chain leads to positive price transmission. Lass (2005) compares price transmission in the periods before and after the formation of the Northeast Dairy Compact in the US in 1997 and finds that the formation of this compact has increased price transmission. Nevertheless, more restrictive regulations on entry barriers in the retail sector and the relative importance of the sector tend to promote symmetric farm–retail price transmission. The latter is also more likely in the presence of a strong processing industry. Moreover, with the increased market orientation of the CAP, the role of farm price support policies has weakened over time in the EU and seems no longer to be an explanatory factor, maybe except for cases of extremely low prices, when the safety net provisions could become operational.

Source: Authors.

Therefore, the assessment of the characteristics of the supply chain, as well as the behaviour of different players involved is important for understanding the evolution of the farmer-retail price spread. The literature on mark-ups and price transmission has shown a rich variety of relationships. A general suggestion from the supply chain and price transmission literature is that competition is often characterised by some form of oligopoly/oligopsony rather than by full competition. As market and sector models, do not explicitly model firms, nor take into account industry structure indicators as explanatory variables in empirically estimated (vertical) price transmission relationships, they are in general not suited to properly represent the actual industry dynamics. The 'approximation error' associated to market or sector models as a result of the poor representation of supply chains is difficult to define or to measure.

In short, sector models have revealed insufficiencies when analysing specific policy measures intending to influence industry behaviour or the position of farmers within the supply chain, e.g. CAP measures with respect to producer groups, 'leakage' of support in the case of direct payments from farmers to other stages of the supply chain, the impact of certain ways of contracting or integration along supply chains on farmer earnings, etc. When they are used in such occasions, they should be complemented by suitable supply chain models such targeted equilibrium displacement models that could be used to 'zoom' in the results of sector models (Zhao et al., 2000; USDA, 2016). In this sense, equilibrium displacement models offer broad possibilities such as distinguishing effects/representing interactions between different types of firms that operate within a sector, differentiating sub-sectors, or representing the exchange of very specific commodities that are not usually represented in large scale models. Another potential solution to overcome the mentioned weaknesses of sector models could come from further econometric analysis of price transmission, extending the approaches described earlier in this section.

7.3 Concluding remarks

Supply chains are important parts of the food chain and play a leading role in delivering inputs to and precuring products from farmers with the aim to serve consumers and other end-users with high quality products. Their impact is far-reaching and covers issues as standards (e.g. food safety, animal welfare), contractual arrangements (including sustainability requirements), price formation and price transmission-issues. From the assessment made it turned out that their role needs a better understanding. Models considered in this piece of research have a very poor representation of supply chains. This holds for CGE models as well as for PE models. There shared key limitation is that they do not model firms, nor make use of indicators characterizing industry structure.

From the literature assessment it followed that taking into account supply chain characteristics and the behaviour of different players in the supply chain is important for understanding the evolution of the farmer-retail price spread. A general suggestion from the supply chain and price transmission literature is that competition is often characterized by some form of oligopoly/oligopsony rather than by full competition, which could give rise to market power issues, and its abuse.

The 'approximation error' market or sector models make as a result of the poor representation of supply chains is difficult to define or to measure, as the results from the case studies done in the literature show a wide range of results depending on product, place, time, product-(des)aggregation level (e.g. distinguishing brands and private labels).

Given the previous observations, our overall conclusion is that it is important to put more efforts in modelling supply chains. Rather than integrating supply chain representations into the models that were used in this research, a more fruitful approach maybe to develop special supply chain models for key agricultural supply chains. Integrating the 'lessons' or results of such model into sector models is a separate issue, which needs still further development.

Supply chain analysis requires the availability of proper data. This is a big limitation for research since such data are not generally available. Moreover, competitive interests of supply chain players hinder the gathering of reliable data.

8 Modelling of trade flows

8.1 Introduction

The increased market orientation of the CAP has also lead to an increased role of trade (e.g. EU exports to China), and trade-related issues such as competitiveness, international standards, price volatility issues as a result of trade-related shocks. The models considered in the context of SUPREMA all have a representation of trade and trade policy measures, but in different ways, with the main distinction being whether bilateral trade flows (an good heterogeneity) are modelled (e.g. MAGNET), or whether a net-trade approach is followed (e.g. AGMEMOD). Border measures as well as market access trade measures (e.g. tariff rate quota) are usually accounted for, although regular checks are needed to check whether these data are up to date.

Moreover, an important development at EU level is the upcoming Better Agri-food Trade Modelling for Policy Analysis (BATmodel) project which has a focus on global value chains. The aim of BATModel is to further improve the assessments of agri-food trade policies along the following lines: (1) by improving the theoretical underpinning and methodologies of partial and general equilibrium models in ex-ante trade assessments; (2) based on micro-level evidence, by improving our understanding and modelling of value chain to enable more precise impact assessments (gains and losses, between and within member states, between and within groups of agents); and (3) by integrating econometric estimations into existing simulation models at micro- and macro-level, which will allow the analysis of extended welfare effects, like inclusiveness and sustainable development goals. [15]

Although multilateral trade liberalisation has go a lower ranking on the trade agenda priority list of many countries, trade issues are still playing an important role in policy agendas:

- Due to past trade liberalisation rounds there have been significant reductions in border protection through tariffs and also certain market access requirements have been established. As a result the role and impact of non-tariff measures has become of increased relative importance;
- Bilateral/regional trade agreements continue to play an important role (e.g. EU bilateral FTAs and EU-Africa relation);
- Missions of EU MS representatives to non-EU countries are organised on regular basis in order to facilitate and promote bilateral trade;
- Geo-political trade tensions or there threads have increased and require ex-post and ex-ante assessments (e.g. in the context of market outlook studies);
- The world's sensitivity to shocks seem to increase, be it only already for the impacts of climate change, which are differently impacting regions, where trade can act as a buffer contributing to food security, and/or trade policy measures (e.g. export bans) can aggravate trade distortion-impacts; and
- The increasing emphasis on sustainability and the environment, with the enhancement of circularity as a specific case, has several potential links with trade and trade policy measures, among which the wish to get more insight into how trade, or specific trade flows, are linked to value added, and environmental impacts (e.g. EU Green Deal).

From the policy needs assessment (see Chapter 2) it turned out that the increased policy priority with respect to sustainability will also affect trade and the questions that will be raised with respect trade. In particular when the EU would develop a more ambitious sustainability policy relative to other world

[15] See: https://cordis.europa.eu/project/id/861932.

market players (e.g. EU Green Deal), level playing issues in a context of different standards is likely to become an issue. Also enhancing the circular economy could create its own issues with respect to trade (e.g. scale levels at which to strive for closing the circles and under what conditions).

Looking at the Farm to Fork Strategy, an important element is the resilience and robustness of the EU (and global) food chain to shocks. From this angle, a key element is to allow the sector to be well-prepared to respond and 'survive' to crises, e.g. by means of risk prevention measures, crisis management mechanisms, contingency plans, etc.

From the SUPREMA stakeholder sessions (see WP1 from SUPREMA project) policy issues and modelling needs with respect to international trade were mentioned, which indicated the importance to pay more attention to supply chains and their complexities. The need to get a better insight into 'the value of trade' of specific trade flows, only increases now the recent EU policy documents emphasize the importance of trade-offs between economics (include trade exchange) and sustainability (environment) and climate, as well as the circular economy.

Apart from modelling challenges, trade data and trade data updating is important in modelling because it is an essential part of creating complete balances, which are a key starting point for all market or sector models. Together with production data, import and export data contribute to the determination of consumption or use in supply and use balances.

In the next sections the modelling needs with respect to non-tariff measures and supply chains are selected to be further elaborated on, as these are the ones which pose specific challenges and are, in relative terms, weakly developed. With respect to the modelling of supply chains and in-depth case study has been done in the course of SUPREMA (WP2, Deliverable D2.2), which underscored both the urgency and complexity including firm behaviour into economic models, although this research did not elaborate the case of international or even global supply chains.

8.2 Improvement of the modelling the international dimension

Although multilateral trade liberalisation has go a lower ranking on the trade agenda priority list of many countries, trade issues are still playing an important role in policy agendas:

- Due to past trade liberalisation rounds there have been significant reductions in border protection through tariffs and also certain market access requirements have been established. As a result the role and impact of non-tariff measures has become of increased relative importance;
- Bilateral/regional trade agreements continue to play an important role (e.g. EU bilateral FTAs and EU-Africa relation);
- Geo-political trade tensions or there threads have increased and require ex-post and ex-ante assessments (e.g. in the context of market outlook studies);
- The world's sensitivity to shocks seem to increase, be it only already for the impacts of climate change, which are differently impacting regions, where trade can act as a buffer contributing to food security, and/or trade policy measures (e.g. export bans) can aggravate trade distortion-impacts; and
- The increasing emphasis on sustainability and the environment, with the enhancement of circularity as a specific case, has several potential links with trade and trade policy measures, among which the wish to get more insight into how trade, or specific trade flows, are linked to value added, and environmental impacts (e.g. EU Green Deal).

The selected issues mentioned above imply a continuing need to work on the modelling of trade, with a special emphasis on aspects of non-tariff measures, the links between trade and value added or global value chains and environmental impacts of trade (foot print, standards).

Apart from modelling challenges, trade data and trade data updating is important in modelling because it is an essential part of creating complete balances, which are a key starting point for all market or sector models. Together with production data, import and export data contribute to the determination of consumption or use in supply and use balances.

8.3 Non-tariff modelling

The incidence of technical regulations in the world of non-tariff measures (NTMs) has increased substantially over the last two decades and the trend is not expected to revert (Fugazza, 2013). Most of the NTM regulations are grouped in two major categories, namely sanitary or phytosanitary (SPS) measures and technical barriers to trade (TBTs). The SPS measures include regulations and restrictions to protect human, animal or plant life or health, whereas the TBT measures address all other technical regulations, standards and procedures. Unlike tariffs, NTMs are not straightforwardly quantifiable, often difficult to model, and information about them is hard to collect. NTMs can provide valuable information to consumers or signal product quality, which can be welfare enhancing, while they can also be trade distortionary (Beghin et al., 2015).

Technical regulations can impact directly both exporters' and importing consumers' behaviour. Theoretical analysis, even in a partial–partial equilibrium context (one good one market) reveals that technical measures can affect trade volumes and/or the propensity to trade in either direction. Indeed, a tighter public regulation or standards promote trade if its demand-enhancing effect dominates its trade-cost effect, while it impedes trade if its demand-enhancing effect falls short of the trade-cost effect. The analytical ambiguity of the impact of technical measures on international trade calls for careful empirical assessment of the trade effects of these measures (Beghin and Bureau, 2001).

The large scale simulation models (e.g. GTAP hybrids such as MAGNET) include bilateral trade flows using an Armington approach, with most parameters being calibrated rather than being based on empirical estimation. Moreover, there goods aggregation level is often quite high, which makes them less suitable for trade agreement assessment that go beyond a general level into a more detailed commodity level.

The most recent empirical works based on a refined theory underlying gravity equations and econometric estimation techniques have addressed new issues, such as for example the treatment of zero trade flows. However, empirical approaches are usually limited to country- sector- or measure-specific analysis (Fugazza, 2013). The focus of gravity models is on the trade-effects, but can be used as a basis to determine the over-all welfare effects (Disdier and Marette, 2010).

Aside of modelling approaches also cost-benefit assessments (CBA) of NTMs have been made (e.g. Van Tongeren et al. 2009). The main advantage of a CBA approach is that it allows for the quantification of costs and benefits for all the different economic actors (domestic consumers, domestic and foreign producers, domestic government, and the like) involved allows for a more tailored evidence-based treatment of specific NTMs (Fugazza, 2013). CBA studies on NTMs apply only to specific case studies of NTMs and require detailed information. Relative to the modelling approaches dealt with above (trade models, gravity modelling) which focus on trade effects, CBA allows for a more comprehensive welfare analysis of NTMs.

8.4 Trade and global value chains

Trade is linked to countries exchanging goods and services between each other. Its importance has substantially increased with the globalization of economies. About one third of trade linked to exports or imports of final products for consumers. The dominant part of trade, about 70%, involves global value chains or global supply chains (will be abbreviated as GVCs), as services, raw materials, parts, and components cross borders – often numerous times. Once incorporated into final products they are shipped to consumers all over the world.

Exports from one country to another often involve complex interactions among a variety of domestic and foreign suppliers. Even more than before, trade is determined by strategic decisions of firms to outsource, invest, and carry out activities wherever the necessary skills and materials are available at competitive cost and quality (OECD, 2020). The evolution of trade and trade relationships have been beneficial to welfare (gains from trade), but also create a complex network of interdependencies that creates vulnerability to trade shocks (e.g. Covid-19 crises). Moreover, changing trade patterns and associated value or supply chain evolution impact employment and job-type distribution within and over countries.

The increased attention to sustainability and the enhancement of circularity of economies and sectors, creates new policy maker needs with respect to understanding different aspects of trade, notably its contribution to value added and its impacts of the environment. The OECD launched an initiative to measure trade in value added (TiVA) terms to provide a more accurate view of the underlying economic importance of trade (OECD, 2020). With TiVA it is possible to better identify where value is added along the supply chain and to estimate where income and jobs are created. Also the EU has worked on a tool to help users understand how international trade flows affect employment, income and environmental variables such as CO_2 emissions (Román et al., 2020). Their Trade-SCAN v2 trade supply chain analysis tool combines information from three global multiregional input-output databases (OECD 20181, EXIOBASE3.42 and WIOD 2016 Release3), as well as other complementary sources of information (e.g. EU KLEM).

The GVC approach links quite well to the food systems approach. Just like in a food systems context, in a world of GVCs, (trade) policy cannot solely focus on impediments to trade with direct trade partners, but the whole value chain and bottlenecks upstream and downstream among third countries have to be considered in order to boost exports and improve economic performance.

With the increase of sustainability and climate concerns, and the policy approaches this involves at domestic market level, also trade becomes under review for its role to enhance or impede improvements in food system sustainability. As a result environmental impacts of trade (e.g. indirect land use or AFOLU) and the trade-offs between environmental and value added aspects become more prominent. This aspect is poorly addressed in current models and requires further future action. In order to better account for the internationalisation and fragmentation of production, the OECD developed new trade statistics that can identify the value added by each country in GVCs. For specific cases further refinement may be necessary, which could be advanced by issuing sufficient case studies.

Outside the OECD the GVA-approach and the associated statistics have not yet found applications in the main current policy simulation models. However, in order to address future policy maker needs it is important to better take into account value added and environmental aspects of trade.

Economists have provided detailed analytical descriptions of GSC trade (e.g. Koopman et al. 2014). The challenge however is to develop economic (CGE) models or modeling frameworks that help to understand how GSC trade affects the various SDGs, welfare and its distributions between and within nations. Key characteristics of GVCs are fragmentation within sectors (regions are characterized by specialization in activities within the sector) and economies of scale at different supply chain stages. The state-of-the-art developments introduce supply chain modelling into a CGE framework (Walmsley and Minor, 2017, OECD). These new supply chain linkages, which do not exist in most macroeconomic simulation models, enable the direct tracing of trade flows from exporting producers in one country to importing firms and consumers in another country. This permits the direct tracing of spillover effects within the model as well as the characterization of specific supply chains. These challenges require current models to be extended, with the most important topic in trade modelling being the integration of GVCs and CGE. The current work is still mostly theoretical with illustrative numbers. What is really needed is to work on these idea's with proper numbers and intense cooperation between global supply chain and CGE models (Dixon and Rimmer, 2019). Key value chains (e.g. meat, dairy) which imply evolving and complex valorisation-processes should be subject of a better representation in modelling assessments.

8.5 Concluding remarks

From the previous assessment some main concluding observations can be made:

- Although multilateral trade liberalization may face its difficulties, still a number of key issues with respect to trade play a role, including the role of standards and other non-tariff measures, and value added and trade, with a special focus on global value chains.
- Whereas agricultural sector models are traditionally taking trade flows into account (it is implicitly always playing a role, even from a data perspective; e.g. balance closure) two prominent items deserving more effort are the modelling of non-tariff measures and global value chains.
- With respect to the NTM case modelling work has been done, but more refinement and validation are needed. Moreover, it was found that there may be a need to better understand and measure the impact of NTMs by applying specific case studies, using complementary approaches such as cost benefit analyses.
- As regards the global value chains, this is largely absent from the models taken into account in this study. Even at a theoretical level there are still a number of issues that need further development. One aspect is how to incorporate global value chain representations in sectoral models. Rather that fully integrating them, the current state of the art seems to be to combine separate value chain models with the large scale sector models.
- There is a need for value chain or supply chain modelling, as with respect to applied modelling going beyond what is done in some academic circles this field is at its infancy.

9 The role of food from a broader perspective

9.1 Introduction

The introduction of a food system approach (Section 2.4) has highlighted the connection between food (as a necessary means for the survival of individuals) and other dimensions such as health outcomes and environmental impacts. Therefore, dietary choices have been proven as an important determinant of human health and environmental sustainability, with the expectation of both gaining increasing attention in the coming years.

Focusing on food and its related health outcomes, the list of concerns regarding genetically modified foods, the presence of pesticide residues, heavy metals, hormones, antibiotics and other additives is now extended with the issue of a high consumption of certain foodstuffs, i.e. sugar, fat and meat (see, International Assessment of Agricultural Science and Technology for Development, 2008). For example, Springmann et al. (2018) studies the negative consequences of high meat consumption in the UK case. After assessing the negative health impacts, this study suggests that a tax that increases red meat prices by 14% and processed meat prices by 79% would be effective in preventing around 22% of deaths associated to diseases like cancer, heart disease, stroke and type II diabetes. Further details on the impact of dietary choices on health are provided in Section 9.2.

In terms of environmental outcomes, it is well-known the controversy regarding the large environmental footprint that is attributed to the livestock sector. For example, according to Gerber et al. (2013), in 2005, the livestock sector was responsible for about 14.5% of total anthropogenic greenhouse gas emissions, i.e. 7.1 Gt of CO_2 equivalents). As indicated by Grossi et al. (2018), the livestock sector is also responsible for using a significant amount of natural resources for its production processes. From a different angle, food waste is also a very important item when thinking of closing loops within the agricultural sector. In this sense, reducing food waste at different stages of the supply chain could improve the efficiency in the process of bring affordable food for all. This topic will be further discussed in Section 9.3. Moreover, in the case of the livestock sector, animal welfare and ethical reasons are other important elements that could lead consumers to considerable reduce their meat intake.

Looking at both the food impacts on health and environmental outcomes, Clark et al. (2019) explores the consequences of consumption of 15 food groups including: chicken, dairy, eggs, fish, fruits, legumes, nuts, olive oil, potatoes, processed red meat, refined grain cereals, sugar-sweetened beverages, unprocessed red meat, vegetables and whole grain cereals. This study finds that the foods that are associated with positive health effects (grain cereals, fruits, vegetables, legumes, nuts, and olive oil) are also the ones that have the lowest environmental impacts. Fish is also reported as having positive health outcomes. The authors concludes that dietary transitions toward greater consumption of healthier foodstuff would also contribute to sustainability.[16] Against this background, another modelling need is the extension of the list of products that are represented within the models with new commodities such as meat substitutes, e.g. pea-protein based products, tofu, tempeh, seitan, micro-proteins, etc.

Another important issue that emanates from looking at food production from an ethical perspective is animal welfare. This topic has been on the EU policy agenda since 1998, with the implementation of the

[16] See, also Westhoek et al. (2014) who uses the MITERRA model to assess the environmental consequences of replacing 25-50% of animal-derived foods with plant-based foods.

Council Directive 98/58/EC 'on the protection of animals kept for farming purposes which gave general rules for the protection of animals of all species kept for the production of food, wool, skin or fur or for other farming purposes'.[17] As will be explained later, this is a challenging topic to represent within standard models.

Drawing attention to the EU policy framework, the focus of the CAP is on food labelling and standards (European Parliament, 2019). However, the topic of sustainable and healthy food has become central in the context of the European Green Deal. In particular, the Farm to Fork Strategy aims at accelerating the transition towards a new food system that: '(i) have a neutral or positive environmental impact; (ii) help to mitigate climate change and adapt to its impacts; (iii) reverse the loss of biodiversity; (iv) ensure food security, nutrition and public health, making sure that everyone has access to sufficient, safe, nutritious, sustainable food; and (v) preserve affordability of food while generating fairer economic returns, fostering competitiveness of the EU supply sector and promoting fair trade.' (European Commission, 2020).

Within the SUPREMA project, WP3, and particularly, Task 3.2 have devote its efforts to the modelling of an agricultural policy scenario that focuses on a preference shift towards a more sustainable diets that are characterised for a lower meat consumption. For further details, the reader is referred to the specific deliverable D3.2 that describes the modelling exercise and presents its key findings.

9.2 Food and health outcomes

Food consumption per capita has been continuously increasing over the past fifty years, being a rising increase in consumption of fat, meat and sugar the explanation behind the increase in the daily calorie intake that is observed in the developing countries. This trend is explained by a variety of factors including: (i) socio-economic elements; (ii) population growth; (iii) urbanization; (iv) changes in retail-rise in supermarkets; (v) trade policies and market liberalization; (vi) availability of food; (vii) rising incomes; (vi), availability of long-product shelf life; (vii) entrance of female population into the labour market; (viii) expansion of intensive food production methods; (ix) new consumer attitudes; and (x) development of food industry (see, MI Consultancy, 2015). Some of these elements are also explaining the observed developments of food consumption in the rest of the World. However, the 'picture' at global level still shows important disparities across regions. For example, looking at meat consumption, global meat demand grew from 209 million tons in 2000 to 270 million tons in 2011 (1.3 times), while population increased at a slower path (1.1 times). This growing demand has had important repercussions on the demand for feed grain, which has been increasing as well (Mitsui Global Strategic Studies, 2016). While meat consumption has reached an unsustainable position in the case of developed countries,[18] daily animal protein intake is still below the recommended level in many developing economies.

Focusing on developed countries, there is an increasing body of literature that links the existence of several diseases with the current unbalanced diet. As already mentioned, type II diabetes, obesity, heart disease, stroke and certain cancers are among the diseases whose number of cases could be reduced with a lower meat consumption. For example, van de Kamp et al. (2018) jointly explores the environmental and health impacts of a dietary change in average Dutch diet. The study concludes that reducing meat consumption and/or replacement of all alcoholic and soft drinks are successful in

[17] Further details are available at: https://ec.europa.eu/food/animals/welfare_en.

[18] On average, protein consumption is 37% higher than the recommended intake (0.8 grams/kg/day).

reducing dietary GHG emissions (ranging from − 15% to − 34%) and also reduced saturated fatty acid intake and/or sugar intake which are also associated with negative health outcomes.

Nevertheless, another important problem that a part of the European society is facing is undernutrition, which is no longer a specific problem of low-income problem. As reported by Ljungqvist and de Man (2009), at least 25% of all patients admitted to hospitals in the EU are malnourished or at risk for malnutrition, with 5% of the EU population being at risk for malnutrition. Malnutrition can increase the risks for complications/comorbidity, lead to poor quality of life and increased need for care specially when looking to the older cohorts.

Therefore, there is a pressing need to urge consumers to make a transition towards more health choices. With regard to the 'tools' available to support this preference shift, the following alternatives are at hand: (i) media campaigns to raise awareness on health concerns related to unhealthy diets; (ii) implementation of production quotas at farm/country level, leading to an increase in domestic prices; (iii) implementation of a 'meat tax' that could operate similarly as a 'sugar' or 'fat' tax; and (iv) implementation of subsidies to favour the consumption of healthy products such as fruits and vegetables. At the EU level, the Farm to Fork Strategy is committed to support the process of redesigning the food system in such a way that reduces the negative impacts of under- and over-nutrition.

Keeping in mind the discussion above, it is very important to emphasise the need of improve the modelling of consumer preferences within the existing tools. Having a proper representation of consumers' choices within large scale models is key for a proper assessment of the consequences of embracing the consumption of more plant-based products across the Globe.

9.3 Animal welfare

Animal welfare has been already within the EU policy agenda for several decades, including within the Common Agricultural Policy which is reflecting the 'Five Freedoms' for animals. More specifically, the CAP supports animal welfare standards be means of its cross compliance instrument which promotes compliance to specific animal welfare standards by means of creating financial leverage. Apart from that, the Rural Development Policy also includes relevant measures to supports quality and animal welfare standards, which are mainly linked to private sector actions. As discussed by Baltussen et al. (2011), the impact of the CAP is positive but limited since the leverage created by cross compliance is often limited as intensive livestock producers receive relatively low direct payments because their land base is small. Similarly, the contribution of rural development policies to promote private initiatives for animal welfare enhancement is limited since there are important limitations with regard to the budget that is devoted to this item. Evidence suggests that much more important drivers of the process of enhancing animal welfare are consumer concerns and commercial opportunities behind producing according to certain standards that could obtain a 'premium' in the form of a higher price per unit when they are brought to the market.

An interesting dimension to consider when looking at animal welfare is the conditions during long distance transportation of live animals. However, this type of trade is a very minor/marginal part of total trade flows and it only plays a more prominent role in the case of some specific countries and products, e.g. piglets trade, trade of breed and beef animals, cross-border trade for using slaughtering capacities in neighbouring countries, etc.

The existing link between animal welfare and animal health needs to be mentioned. A key issue here is the use of antibiotics, which could play a role in favouring antimicrobial resistances in humans.[19] Ensuring animal health is also one of the objectives pursued for organic farming, and also an explanation for the preference of consumers for organic livestock production.

Related to the above, the issue of animal welfare and animal productivity also needs to be discussed. Beyond the obvious ethical considerations, poor animal welfare could lead to a decline in animal performance and productivity. Therefore, it is also in the interest of farmers to implement measures to ensure sufficient animal welfare.

From a modelling perspective, trade of live animals is already modelled within AGMEMOD, although only net trade flows are represented within the model. Thinking on potential modelling improvements and extensions with regard to the modelling of animal farming standards, the EDM methodology could offer a potential way forward since it has been successfully used in the case of food standards. Apart from, the data requirement for populating this type of models are rather limited compared with other large scale models, which could permit modellers to deal with the lack of available data on animal welfare indicators. The reader is also referred to Collins and Part (2013) for an extensive discussion of different modelling approaches that have been used in related fields of research which could be applicable for assessing animal welfare.

9.4 Fairness and distributional aspects

An important item in the policy agenda for the agri-food business is buyer power and competition policy in food supply chains. Looking at the position of farmers within the supply chain, Baltussen et al. (2018) reports that in the Netherlands most primary producers define their position in the chain as relatively weak in comparison to other actors of the chain. This is particularly relevant in the case of dairy farmers and pig farmers and, to a lesser extent, in the case of vegetable and fruit farmers too. The position of the business within the supply chain is considered to be stronger if the business is more profitable. Looking at sector cooperatives, in the dairy farming sector, arable farming sector, field vegetable sector and greenhouse vegetable and fruit sector they account for more than 83%. However, in the pig and poultry farming sector around 60-70% of businesses work together with other primary producers. In terms of the drivers, sales security and improved access to the market are the most important elements that favour cooperation, being access to knowledge and information also relevant factors. Higher prices were also mentioned as a driver, although the study does not conclude that businesses that work together experience more or less pressure to lower their prices. Drawing attention to the obstacles that prevent cooperation between businesses, social relationships such as different interests and lack of transparency and trust between businesses were considered as the main problems. With regard to pricing, supply and demand at international level seem to determine the price of agricultural commodities. Competition at the different levels of the chain seems to be strong, favouring buyers and eventually the consumer of the end-product. In the Dutch case the expectation is that cooperation between farmers and horticulturists will lead to improvements in efficiency, but not directly to higher prices for primary producers as long as competition and supply remain high.

Lloyd et al. (2009) explores the possible existence of buyer power in the case of UK food retailing sector. Starting with a theoretical model of oligopsony which delivers quasi-reduced form retailer-producer pricing equations, the authors test the null hypothesis of perfect competition by means of available

[19] This issue is also taken into account in the Farm to Fork Strategy (EU Commission, 2020).

market data. Relying on a cointegrated vector autoregression, this empirical evidence indicates that the null of perfect competition can be rejected in seven of the nine food products under consideration. Although there is no strong conclusion in favour of the existence of buyer power, this piece of research corroborates the views of the anti-trust authorities regarding buyer power as a potential source of concern. Focusing on the case of Finland, Niemi and Lui (2016) investigate the potential existence of buyer power in the food supply chain. In doing so, they apply the methodology proposed by Lloyd et al. (2009) to measure oligopsony power among the food industry and retailers against farmers operating in Finland. The results indicate that the spread between producer and retailer prices in the Finnish case is not consistent with perfectly competition, pointing at the existence of oligopsony power in the Finnish food supply chain among one of the causes explaining this imperfect behaviour.

Focusing on the dairy food supply chain, Di Marcantonio et al. (2018) explores the existence of unfair trading practices by looking at several regions in France, Germany, Poland and Spain. By conducting a survey that includes 1248 observations, the study identifies 29 types of unfair trading practices across all different phases of contract development. More specifically, 93% of surveyed farmers have reported at least one unfair practise, while 46% of surveyed farmers have reported at least three of them. The most controversial part of the process are contract negotiation and contract execution which have the highest shares of unfair trading practices reported.

In terms of modelling needs, once again the issue of the lack of realism of assuming perfect competition within the models emerges. Therefore, it is important to improve the representation of supply chains within models and as well as developing new approaches that permit modellers to 'abandon' the assumption of perfect competition when needed. The reader is referred back to Chapter 7 that has already discussed these methodological issues.

9.5 Food as a means for closing loops

One of the pillars for the achievement of a circular economy is the reduction of waste, being food production/consumption also a dimension for acting. For example, waste streams should be reduced by reusing waste as a resource elsewhere in the food system and the economy. In other words, the ultimate objective should be to achieve a circular food chain. In doing so, the current food chain should redesigned in such a way that raw materials can create the higher share of value added, while having the lowest negative environmental impact.

Before moving onto the analysis of the consequences of food waste within the current food system, some quantification of the actual food waste that is generated is needed. More specifically, one third of the food that is currently produced, on a global level, is wasted at various stages along the supply chain. This amounts to approximately 1.3. billion tonnes of food (FAO, 2011). Translating the food waste EU figures (100 million tonnes in 2014) into per capita levels, 200 kg per capita are waste annually.

Drawing attention to the environmental impacts of food waste, FAO (2013) reports that in 2007 the amount of food produced that was lost or wasted include was responsible for 3.3 Gtonnes of CO_2 eq., 250 km^3 of surface and groundwater consumption and 1.4 billion hectares per year of land occupation.

At the policy sphere, some actions that are looking at reducing food waste are already in place. At EU level, the Waste Framework Directive is including a definition for food waste after its last revision. Moreover, the establishment of the EU Platform on Food Losses and Food Waste is also another initiative to reduce food waste and contribute to the UN Sustainable Development Goal 12.3, with the EU goal of halving food waste and at consumer and retail level by 2030. Another element that shows the EU commitment with this objective is the EU Action Plan for the Circular Economy in which the potential contribution of food waste mitigation is acknowledged. Looking at this topic, Manfredi et al.

(2015) presents a life-cycle based framework methodology to quantify the environmental and economic sustainability performance of food waste management at EU.

In parallel to the development of elements at EU level, several actions at national level has been implemented. For example, the wide programme for a circular economy designed by Dutch Government is recognising the importance of avoiding food waste while encouraging a more 'food conscious' behaviour.[20] In the case of Italy, the RePoPP project is another good example of urban circular food policies against food Waste (Fassio and Minotti, 2019).

In terms of modelling needs and priorities, the first challenge that modellers will encounter when trying to carry out any type of analysis related to food waste, is the lack of proper (and sufficient) statistical data. Without satisfying the data requirements that are needed to 'feed' and extend large scale model, it is not possible to carry out a proper assessment.

9.6 Concluding remarks

Public health outcomes and environment effects are important issues that could benefit from a reduction in consumption (and associated production) of certain products, e.g. meat. Therefore, a dietary change should be a priority within the EU since livestock consumption and production are not within appropriate boundaries (see, RISE(2018) for further details). Transitioning towards a plant-based diet is a multi-dimensional phenomenon that requires the engagement of the public sector, all actors involved in the supply chain and consumers. In the same vein, the benefits associated with transitioning towards more healthy diets will not be limited to a reduction in the cost of medical services. Reductions in CO_2 emissions and acidification of soil and air, improvements in the sustainability of food systems, as well as potential creation of value added for arable farmers can be expected.

From an ethical point of view, animal welfare is also another concern that could favour the so-called 'protein transition'. This preference shift towards more plant-based diets will also contribute to bring the livestock sector within the EU into a more sustainable path.

Another important issue that was discussed within this chapter is the potential of reducing food waste for mitigating the negative environmental consequences of food production. In this regard it is important to highlight the huge challenge that modellers will face when looking for sufficient and robust data to use as an input for the assessment.

[20] See, also: https://www.pbl.nl/en/news/2017/food-for-the-circular-economy.

10 Integrated model use, model maintenance and model network

10.1 Introduction

This chapter examines a number of issues which are not directly related to specific modelling issues or domains, but rather to the development, use, application and maintenance of models used for policy assessments in general. Having a good model infrastructure has the characteristics of a public good, and a such is not a spontaneous result from 'market forces' or 'regular projects'. Moreover, since stakeholder interests are strong, it is important to keep a set of 'independent' tools, which avoids biases.

As it turned out from the assessment of recent policy documents, priorities and policies evolve over time. This implies that over the course of time objectives and needs for information are changing. In addition to the time dimension, which already request models to stay 'up to date', these changing needs requires models to be adjusted. As such changing needs create similar challenges for different models and could benefit from 'shared solutions' collaboration between modellers and modelling groups is beneficial for creating quick progress and also for their quality enhancement.

The EU Green Deal states that a food systems approach is needed in order to assess the current and future societal and policy challenges. Food systems are comprising a set of interrelated elements or subsystems, such as input supply, primary production, food processing, retail, distribution, handling and consumption of food by consumers, each with their impacts on societal welfare and their side effects with respect to the environment. Due to its complexity and comprehensiveness studying and analysing the functioning of food systems usually requires several models, which also may be of a different nature. As such this raises the questions what would be a proper ensemble of modelling tools needed, as well as the issue of integrated model use.

Integrated model use and letting models 'working together' is not only relevant in a food systems context, but also when analysing the agriculture subsystem, as different models may model different aspects of such a system, e.g. economic, agronomic, environmental. Moreover modelling approaches could be different (e.g. different granularity), underlying assumptions made by the models could vary, and data used could come from different sources. Within iMAP, operational since 2006, such a network is available, which comprises the JRC and cooperating closely with DG Agriculture and Rural Development (DG AGRI) as well as many academic and international research institutions, and creates a network of researchers and well-established economic models with a long record of applications in research and policy support. Within SUPREMA for different models a baseline and comparative scenario assessment has been made (see Deliverables D3.1, D3.2 and D3.3. from WP3), which confirmed the usefulness of such an exercise for a better understanding and interpretation of model results and insight into the factors explaining model outcome differences.

In the remainder of this chapter a number of aspects will be dealt with. The next section discusses integrated model use, which will be followed by a section on baseline harmonization, modelling consistency and cross validation. Subsequently, model maintenance and network development, data management and governance, and reconciling expectations with modelling capacity will be discussed. The chapter closes with some concluding remarks.

10.2 Integrated model use

Regardless the field of research, it is well-known by model builders that 'An economic model is a simplified description of reality, designed to yield hypotheses about economic behaviour that can be tested.' (IMF, 2011). This definition can be extrapolated to any other area of knowledge, e.g. environmental sciences, land use, biophysical sciences, etc. In other words, models are intermediary tools that help researchers to analyse specific (and targeted) problems. The complex reality surrounding us reveals that quite often analysing a particular problem involves considering elements that go beyond the representation that is offered by a single model. However, in those particular situations might be the case that the use of two different models which have a different purpose and focus could help us to capture all the aspects (and interactions) of the problem at hand. In this context, 'model collaboration' or 'model integration', i.e. the use of individual models in combination or an ensemble of model, allows us to target and represent very specific issues that can only be covered in a more 'vague' manner when using a large-scale model that has been expanded to 'cover everything'. A good example to illustrate the benefits of model collaboration resulting from SUPREMA is the 'system' AGMEMOD-MITERRA (see Box 9) which involves biophysical and economic models. Another promising area in which model collaboration could make an important contribution is when linking micro and meso models. This is especially relevant in those case in which researcher are facing a 'fallacy of composition' as explained by Keynes (1936).[21]

Box 14. Linking the AGMEMOD and MITERRA models

In the context of SUPREMA (and extending the experience of Lesschen et al. (2020)), a hard direct linkage has been established between the AGMEMOD and MITERRA models. The aim of this linkage was to deliver (by MITERRA) detailed information on GHG emissions, changes in soil organic carbon stocks and nutrient losses to water associated to a particular development of the primary agriculture sector as projected by AGMEMOD.

This exercise is a clear example of the fact that there is higher value in linking two models that individually provide a detailed modelling of aspects which are related compared to the development of a larger model with a lower level of detail. In other words, it was more valuable to link AGMEMOD (which provides a very good modelling of agriculture production) to INITIATOR (which can calculate the emissions associated in an accurate way) than adding a 'stylised' representation of emissions within the AGMEMOD model. Detailed explanations on the linkage between these two models, as well as an application in the context of exploring future pathways for the Dutch agriculture is presented in Jongeneel et al. (forthcoming).

Source: Authors.

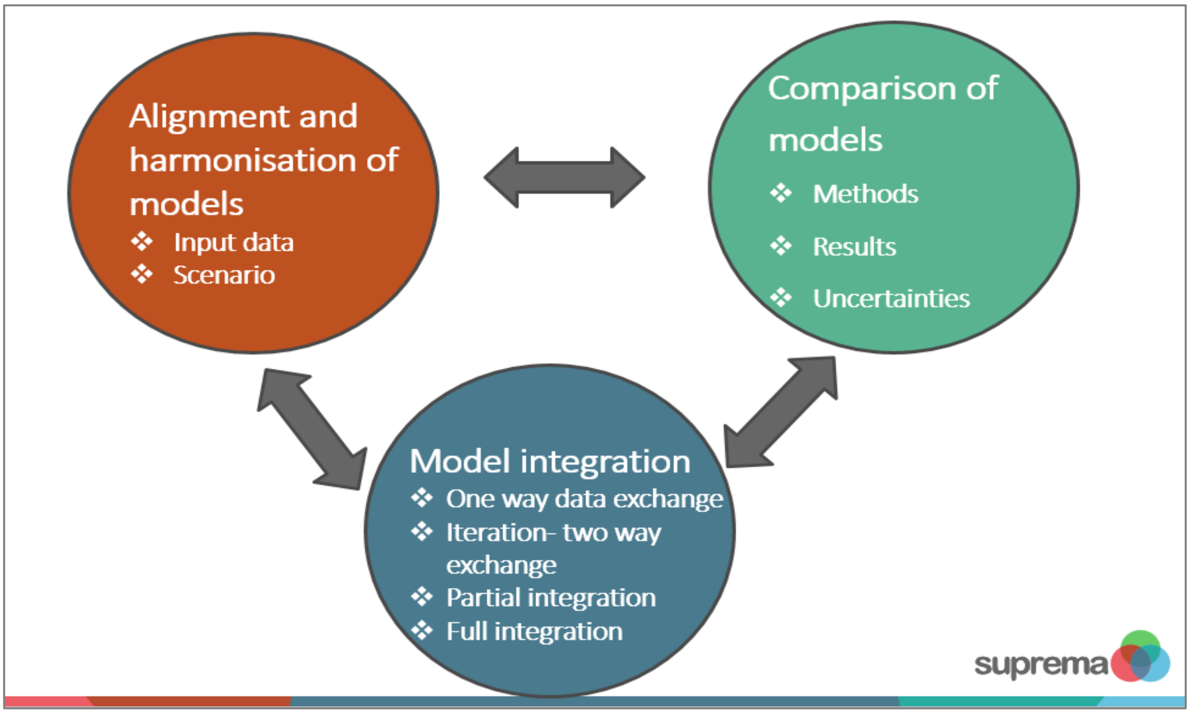
The need for model collaboration need to be carefully specified. It is important to be explicit on what the additionality of the linkage is. For example, a PE model does not model input markets, so one linkage can be to take input market shocks from a CGE model, which does represent these. As another example, an economic model may be linked to a biophysical model (e.g. AGMEMOD-MITERRA) in order to assess the environmental impacts associated with certain economic behaviour of farmers. As such it is useful to distinguish between linkages that are made to 'bridge', connect, or detail:

- different economic levels (e.g. farm level, industry level, regional and global market levels, including trade);
- different spatial scales (parcel, farm, region, province, state, EU, world); and
- different disciplines (economic, agronomic, environmental, ecology).

The type of linkage will have implications for its specification and the direction of causality that needs to be considered.

[21] It could be the case that the reality that is observed when looking at the sector level does not correspond to the what can be observed at farmer level.

Once the need for model collaboration and integration has been decided, the next step is to have a good understanding of how the different models will interact among them. Therefore, any attempt of 'connecting' two or more modelling tools will start with researchers defining in a concrete manner what the 'real' meaning of the 'model linkage' that they would like to stablish is. The response to this question should deliver a clear definition of the flow of information that will be exchanged and the feedback loops among the different models under consideration. The existence of the mentioned exchange of information ensures that running a sequence of models becomes a 'true' system of analysis.



Source: Adjusted from Wicke et al. (2015).

Figure 6. Typology of model collaboration

Note(s): Model collaboration can come in a number of forms, here three categories are distinguished: alignment and harmonization of models, comparison of models, and integration of models. Bullets present examples of how models can be aligned, harmonized, compared or linked. Each type of model collaboration can benefit from the others. For example, a basic alignment and harmonization of scenarios is needed to allow comparison of models, while a comparison or integration of models can identify the factors that require alignment.

Wicke et al. (2015) identify three forms of model collaboration, as shown in Figure 6).

- Alignment and harmonization of models focus mainly on input data, level of aggregation, and scenario definitions. In SUPREMA we aligned baseline and case study assumptions between models.
- Comparison of Models focuses on the methods, representation and parameterization of bio-economy, assumptions and uncertainties in input data, and/or on results and sensitivities to uncertainties in underlying data and approaches. In SUPREMA model results are compared for the baseline and the CAP and climate policy cases, and some of the differences are explained by differences in modelling approaches.
- Integrations of Models takes collaboration a step further and It can thereby provide a more comprehensive picture of the impacts of a certain policy or development. Model linkages can be of a number of forms, including using the results from one model as input to another model, iterating inputs from different models, partially integrating models by using a simplified form of one model in another model or fully integrating models and solving them simultaneously. In SUPREMA, several kinds of model linkages were initiated (see Deliverable 2.6). For example, within the baseline case CAPRI results are used to calibrate the IFM-CAP model. AGMEMOD output is used within MITERRA

within the CAP case. Various linkages are developed between CAPRI-GLOBIOM and MAGNET. For example, GDP and world energy prices developments from MAGNET are used in GLOBIOM and CAPRI. Afforestation developments of GLOBIOM are used within MAGNET and CAPRI.

The three forms of model collaboration are interrelated in such a way that for example model comparison can guide and improve alignment and harmonization of models. Conversely, under the condition of harmonized input data and scenarios, model comparison allows a better understanding of the results, its drivers and the differences across models (Lotze-Campen et al., 2014). Model cooperation can also reveal information about the robustness of the results when tested under different paradigms, about model biases and artefacts, and about strengths and weaknesses of different approaches (Wicke et al. 2015). Thereby, model comparison can be used to further improve and calibrate the individual models. Model comparison can also help expose the causes of differences and similarities in model output, which is important for interpreting the results for policy-making.

Once the interactions among modelling tools are defined, an important item becomes the assessment/measurement of the 'thinness' of those linkages. Although there is no consensus in terms of a clear definition/typology of model linkages, modellers could distinguish two broad categories: 'hard' versus 'soft' linkages. In particular, the most explicit form of models linkage is to define a 'hard' one, being unidirectional or multi-directional (iterative) depending on the complexity of the causality that is considered. 'Soft' linkages are defined in the case in which the relation between the models is unidirectional or/and the information exchange is not done in a structured and systemic manner. 'Soft' linkages also include the cases in which expert judgement of the output of a model is done in order to derive input for another model. Another dimension that modellers should evaluate when categorising the linkages is whether the relationship between the model components that are linked is 'direct' or 'indirect', being 'direct' in those cases in which the outcome of a model is used in another without going through any transformation process, e.g. an 'output' variable is used to compute a different indicator which eventually goes into a model as 'input'. This discussion can be encapsulated in the typology presented in Table 4.

Table 4. Typology of model 'linkages'

Linkage	Hard	Soft
Direct	Standard 'hard' model linkage, i.e. the components of the different models are related in a structured manner	It is a 'soft' linkage, but other model information is used more or less as it comes from the model
Indirect	Model linkage does not exist/not relevant	It is a 'soft' linkage. It is indirect because an expert uses a model to make a model-informed guess about information to input into (another model)

Source: Reproduced from Jongeneel et al. (*forthcoming*).

An alternative typology of model linkages is the one proposed by Perez-Dominguez et al. (2008). More specifically, these authors propose a first type of linking approach that relies on calibration techniques amongst several partial equilibrium models in the following way: (i) by means of econometrically estimated response functions; and/or (ii) by modifying the output of a partial equilibrium model in such a way that it fits that the combined output of other models. Secondly, calibration techniques can be also used in a more aggregated manner in order to connect general and partial equilibrium models. In this sense, Perez-Dominguez et al. (2008) proposed that: (i) a general equilibrium model could be recalibrated at sectoral level in order to mimic the output of a partial equilibrium model in a particular scenario; and (ii) the database of the partial equilibrium model can be re-organised in such a way that it fits the data structure of the general equilibrium model under consideration.

> Box 15. Equilibrium displacement modelling
>
> Equilibrium displacement models have a long tradition in agricultural economic modelling, which is traced back to Muth (1964), who was the first to develop reduced forms for proportional displacements from equilibrium for a system of equations of supply and demand (USDA). Sumner and Wohlgenant (1985) first applied the term 'equilibrium displacement modelling' to Muth's formulation. Wohlgenant (1993) also extended Muth's formulation to multistage industries. Piggott et al. (1995) employed the term 'equilibrium displacement modelling' and formulated their model in matrix algebra. Davis and Espinoza (1998) extended the Gardner analysis to develop the full distribution of parameter values rather than only selected values. Their strength is that they represent simple models, which can be easily created and targeted to specific problems. They have the advantage that they are quite flexible and can be extended to a detail that large scale models have more difficulty to cover. Their flexibility and simplicity comes at a price, however, which is their partial nature, and strict assumptions with respect to the EDM model closure. However, this limitation can be remedied by using them in an integrated way with large scale models. Examples of equilibrium displacement model applications, either as stand- alone or used in combination with other models are Sumner (2005), Jongeneel and Silvis (2018), Jongeneel et al. (forthcoming). As such EDM models are an interesting device to provide specific detail and work in combination with large scale models, while also for their construction they can borrow elements, e.g. elasticities, of large scale models.
>
> Source: Authors.

The discussion above reinforces the statement 'No model can serve all purposes' by Van Tongeren et al. (2001). Therefore alignment of model assumptions and harmonisation, comparison of models and model integration have been revealed as a potential solution to cover the gaps that can be identified when the existing modelling tools are individually used. Nevertheless, the integration of models is not the 'ultimate' solution for all cases since the analysis of certain questions also requires to improve or extend (parts) of existing models. This could happen when modellers need to:

- have a better policy representation in order to reflect in a more suitable way a new policy framework, e.g. the upcoming CAP reform;
- improve the parameter of the models responses that fit the current market reality, e.g. some re-estimation of the dairy module of the AGMEMOD model was needed after the abolition of the 'milk quota' and the openness of the market to international demand; and
- provide a representation of elements that will play a role in the current and future development of the economy that were not present when the model was initially developed, e.g. the on-going extension of the AGMEMOD model to incorporate bio-based products that were not available at the time of developing the model.[22]

10.3 Baseline harmonisation and cross validation

When using multiple modelling tools for policy assessment, an important issue is the reference or baseline scenario that is used. In the context of SUPREMA for generating comparable baseline scenarios of the EU agriculture in 2030, AGMEMOD, CAPRI and IFM-CAP models have been harmonized by aligning the sources of their major external factors (alignment and harmonisation of models). In particular, AGMEMOD and CAPRI models are calibrated to MTO 2019. MTO 2019 is as well the source for the projections of national GDP, GDP deflator, currency exchange rates including USD/EUR, population and

[22] The feasibility of this type of extension is mainly determined by the availability of new data as reported by official statistics.

crude oil prices that are used by AGMEMOD and CAPRI as exogenous variables. As IFM-CAP is not a market model, for producing the baseline it uses only growth rates of yields and producer prices of the current 2030 baseline of CAPRI. Also for the generation of the 2050 baselines by GLOBOIM, MAGNET and CAPRI a similar approach of harmonizing the sources of the external factors has been followed. A finding from that exercise was that homogenisation of the external drivers does not result in similar modelling outcomes among the models considered (model comparison). A number of model specific characteristics cause the differences. These causes could be aggregated into the following groups: (i) data requirements and data sources, (ii) model specification and methodology, and (iii) policy representation. The approach in calibration to the external baseline also matters for the models which generated the 2030 baselines.

Model comparison and analysis of the differences among the baselines and the models within the SUPREMA project revealed three important aspects which should be considered when linking the models:

- Differences among the simulation results of the models, unless stemming from different commodity/activity definitions or exogenous variables, add value to these results rather than devaluate them. As the models work with different levels of details of the agricultural and other sectors, consider different synergies between them, as well as they are based on varying data and evidence, e.g., processing coefficients, industry characteristics, their modelling results demonstrate a possible span of the effects of the simulated policy or shock. This allows for examination of the researched phenomenon from more perspectives and, thus, in a more complete and comprehensive way.
- As a follow-up from the previous point, model linking should elaborate on the strengths of each of the models involved. The models should complement the relevant modelling blocks of each other, rather than substitute them. Each model is built in a unique way and upon a set of evidence and theory based assumptions that altogether constitute an organism-like system. A particular advantage of such systems is that they simulate the impacts on the entire sector rather than on one or two specific areas. Therefore, it is important to avoid turning complex systems into a simplistic simulation tools with predictable outcome, when merging them.
- Finally, having the correct concordance tables between activities and commodities of the models may seem trivial, but is an important requirement. It is a common knowledge that commodity as well as activity definitions may differ among the models. Common examples are commodity aggregates such as Other cereals, definitions of specific commodities such as milk and definition of prices. Other cereals usually include all of the cereal crops not particularly specified in the model, thus, might be different among the models. Milk may be defined as raw milk including or excluding on-farm use or milk delivered to dairies. Prices may be defined as farm gate prices, wholesale prices, include or exclude transportation and processing costs. Therefore, careful mappings is essential for assuring proper functioning of the linked models.

Linking and harmonizing large scale economic models such as those reviewed in this project may be rather challenging. The quantity of model specific details that will need to be examined for relevance and compatibility, as well as the number of informed decisions which will need to be taken in this respect and which will nevertheless always be called into question by the reviewers and modellers themselves may be overwhelming. However, interdependencies in the world economy are likely to become tighter, growing world population, depleting natural resources, changing consumer demands and changing climate are likely to put more pressure on the agricultural sector in terms of producing food more efficiently, following stricter standards, e.g. food quality standards, animal welfare and environmental standards etc., and delivering social and environmental services. Thus, the research questions are likely to become more interdisciplinary and demand greater precision of the results. Linked large scale models with highly detailed components may appear a very useful tool for this kind of research.

Cross-validation of modelling results is important and can take place in various ways:

- Validation of baseline outcomes via discussing them with market experts. This is what usually take place in market outlook modelling. Experts could either being consulted individually but also react as invited experts for outlook workshops. Both forms are used in the EU Aglink and the AGMEMOD Member State outlook results cross-validation processes.
- Via comparative assessment of results from different model, which try to explain a same scenario or phenomenon (as this has been applied for midterm CAP and long term climate scenarios as part of the SUPREMA project), but can approach this from different angles (e.g. a sector model versus more micro economic or agent-based model).
- Via projects done for different clients, which includes feedback from the client on (preliminary) modelling results that is then integrated into the model in order to improve its outcomes.
- Via a cross-check how the results generated from larger scale models match with those of refined (smaller scale) models, which model a specific (often limited) domain.
- As part of the review process on publications based on model outcomes or reports on modelling results. These include the referee process that is part of quality academic publication outlets.

Naturally, the usefulness of a model is determined by the accuracy of its predictions. However, for the large scale models, which are considered here, reliance on well-known statistical criteria for model selection is of limited use. Most models use parameters that are based on calibration procedures, rather than econometric estimation. But even when econometric estimation is used, model reliability is not guaranteed as there are a host of problems (e.g. multicollinearity) which may compromise getting parameter estimates that are in 'plausible' ranges (Jongeneel and Gonzalez-Martinez, 2020). AGMEMOD and (to a lesser extent AGLINK) use econometric estimation of parameters, while other models (e.g. CAPRI) employ different inference methods (e.g. maximum/cross-entropy estimation) or calibration to a base year. In the 'distance' between the base year used for calibration and the time span that is analysed becomes 'too long' this may create trouble for model cross-validation. This even more holds so when the underlying economic dynamics are very strong (e.g. modelling trade of emerging economies).

10.4 Model maintenance and network development

Models need to be maintained to keep them up to date (e.g. adding each year newly available annual data). The best medicine for keeping models in good shape is to have them being used in projects and for policy support, since this automatically implies that efforts have to be put to keep them well-functioning and to stay 'aligned' to evolving client demands.

Data updates can be in some cases seen as part of typical research projects (e.g. for market outlook modelling work), but less so in other cases (e.g. counterfactual policy analysis, policy simulation analysis). But model maintenance is not limited to data-updating, but also includes parameter-updating, especially when the underlying economic/policy regime is changing. As an example, after the abolition of the milk quota in the EU in 2015, Member State level supply curves are in need to be reconsidered and re-estimated (Jongeneel and Gonzalez-Martinez, forthcoming). Similarly, the increased market orientation of the CAP that took place since the 1992 MacSharry reform, requires price transmission equations between the EU and non-EU and also between EU Member States to be re-examined. Often this parameter estimation work is time consuming, and for that reason costly to finance it from 'regular' projects, which are usually more problem or policy driven then aiming for data-precision-improvements. A third reason for model 'maintenance' is the need to keep them updated with respect to the policy development. Changing policies affect the policy representations as they are included in the models. As an example, the CAP is reformed about each 7 years, while sometimes 'midterm' evaluations may lead to policy implementation changes.

Despite model maintenance being a non-attractive and costly side of modelling, it is important for ensuring model performance. Because the adequate funding of model maintenance activities is often a problem this creates a situation where models may have domains for which a 'normal maintenance standard' is not achieved. Cost-sharing and effort-sharing may be helpful as then multiple institutions and a lager modelling network can contribute to its maintenance, together with its use. Also the EU's integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (iMAP) is of crucial importance here as it contributes to support the preservation of a high quality modelling infra-structure, including model maintenance, comparison and improvement activities (M'Bareck et al., 2015).

An important other effect if the iMAP platform is that it supports modelling network development. Creating networks of modellers is important for modelling knowledge and practices information, as well as for enhancing the quality of modelling work, since networks are likely to contribute to the setting and evolution of standards in modelling.

10.5 Governance and data management

Data management and governance differ for different model-linked networks, which partly reflect the origin and history of the model development. As the relatively large scale models considered in this project are too capital and human resource intensive to be carried by a single institute, a modelling network usually relies on contributions of multiple institutes (and their specialists).:

- The network around the CAPRI model is not governed by any specific legal document or contract, but is rather an informal collaboration of researchers sharing common interests. The explanation to this lack of formalized governance is found in the background of the model. During the first decade, there was not even a software versioning system in place, but access was managed via a network drive at Bonn University. The only way for 'satellite' developments to find their way into the code base or database was via Wolfgang Britz. When the software was moved to the software versioning system 'SVN' in 20YY, decentralized development by other network members became much simplified, but the need for coordination rose. Nevertheless, developments very frequently involved Wolfgang Britz for as long as he was involved in the network.
    - The SVN system has become the main way for the network to coordinate their efforts, because it requires the cooperative resolution of conflicting developments in a shared repository called the 'trunk'. All developers in the network can contribute code to the trunk. Many developments for specific projects or relating to specific model features take place in 'branches'. A branch is a copy of the trunk (or another branch) for which the SVN-software is able to keep track of differences. All members of the network can create model branches at their own discretion as a way of isolating 'their' particular model version from changes in the trunk. Coordination in the network takes place in targeted e-mail traffic and weekly virtual 'modellers' meetings'. Strategic issues, such as the organization of the annual training session, are discussed in an annual 'consortium meeting', generally taking place in connection with the annual training session. However, lacking a formal contract or governance structure, the decisions taken at the consortium meeting have the character of recommendations. No document defines which types of decisions can be taken at the consortium meeting or how voting rights should be allocated.

Box 16. CAPRI versioning system

The CAPRI versioning system incorporates the software that builds the various CAPRI databases from raw data, as well as the raw data itself. In many cases the raw data are associated with meta data that follows the data through the system. However, the CAPRI databases themselves are not versioned except for the (public) Stable Release versions. The reason is practical: binary data files cannot be versioned in the same way as the source code text files, but each change, however small, implies that a new copy of the data has to be stored. The programs that process raw data into CAPRI databases are also subject to the Stable Release process, and therefore tested for functionality and stability issues before being versioned and published.

Source: Authors.

- GTAP (Global Trade Analyses project). The Global Trade Analyses Project (GTAP) is a global leading consortium in quantitative economic analysis of pressing global concern in the areas of Trade and Development and Global Environmental Issues. It consist of 33 members including OECD, FAO, EC (JRC), World bank, IFPRI, Wageningen Economic Research, TI, USDA, but also consultancy companies like McKinsey and KPMG. The core of its success is an institutional innovation in economic modelling through international collaboration to increase quality of data and analysis. The idea is to cover together the fixed costs and create a public good to lower entry barriers in this complex field and to better serve policy analysts and decision makers. GTAP is truly a global network with users in almost all countries of the world. The corner stone of the Global Trade Analysis Project is a global data base describing bilateral trade patterns, production, consumption and intermediate use of commodities and services. The current GTAP Data Base may be purchased by anyone interested in using it. Proceeds help to offset the cost of producing the next release. This permits users to share in development costs and it prevents needless duplication of effort in creating this public good. Older versions are available free of charge (except for the preceding version). The GTAP Data Base is fully documented and produced by the GTAP Centre and the quality is enhanced by all consortium members and data contributors.

- MAGNET was developed at WEcR as a successor to LEITAP. With agricultural issues increasingly connected to other fields in matters concerning, for instance, bio-energy, sustainability and climate change, LEITAP became increasingly complex. The increasing complexity of LEITAP led to a corresponding increase in the costs associated with using the model. First, it increased the costs of changing model aggregations due to the use of external data, which needed to be manually adjusted when the aggregation was changed. The LEITAP aggregation also had a high level of detail (mainly at the EU level) which increased runtime even when the detail was not needed to answer a specific research question. A final issue was the high cost of training new staff members, who were discouraged by the increasing complexity of the model. To reduce the costs of using the model, LEI made a considerable investment in recoding the model, an effort that has resulted in MAGNET. Development has been driven by the following key principles:
    - A modular setup around a GTAP core: the modular setup has been designed such that model extensions can be switched on through choices in a single parameter file, sometimes in combination with changes to the closure file. This allows new users to start with GTAP and then add extensions as needed. For experienced users, it facilitates the tailoring of the model to the research question at hand and eases debugging when developing a model. The GTAP model was chosen as a basis for MAGNET not only because it is the premier CGE model, but also because the GTAP network provides a common background, which enables comparison across a wide variety of other CGE models developed from GTAP.
    - Data are kept and processed at the lowest level of detail; all databases are kept in their original format and processed at the lowest level of detail to increase aggregation flexibility.

   - All data changes and adjustments are coded in GEMPACK to enhance tractability and quality control. This approach also facilitates the updating of datasets, since the same code can be applied to the updates.

- MAGNET is several respects a modular extension to the standard GTAP model. As such, it benefits from the GTAP database, from the GTAP courses for users, and from part of the theoretical structure. This is in contrast with other models in the SUPREMA family, which have their own specific databases and theoretical structures. The MAGNET database embeds next to the GTAP data many supplementary datasets that enable to disaggregated sectors beyond the GTAP level and include modules on land land use and nutrition for example. Currently the MAGNET database is transformed to a database system called Datawarehouse that enables better version control, lower costs for updating the database, and is connected with Power-BI to has much more visualisation opportunities. MAGNET is run by a consortium of three institutions: Wageningen Economic Research, the Joint Research Centre and Thuenen Institute. WEcR hosts the MAGNET model and database and bilateral consortium agreements between WEcR and partners conceal the consortium. The consortium agreement specifies obligations of partners and the consortium is open for new partners. The strategy is discussed among partners in consortium meetings where partners indicate their priorities and where synergy effects are identified. Model developments remain however, largely project based as core funding is very limited. Dedicated MAGNET training courses are organised within the consortium. The consortium has a website, with information on model documentation and a list of all magnet related publications by all consortium members (https://www.magnet-model.org/). Funding for the model comes from both projects and own resources of the partner institutes involved. There is a user fee, which is required for the GTAP database and the GEMPACK software.

- AGMEMOD is formally organized as a Partnership, governed by a Memorandum Of Understanding (MOU) under German law. The Partnership has three main bodies: the Executive Committee, the Core Modelling Group, and the National Experts. All parties to the partnership (all the groups listed) meet at least bi-annually in a general assembly, where certain decisions can be taken. There are also more frequent (annual at least) ordinary meetings of the Executive Committee and the Core Modelling Group. The Executive Committee is responsible for the overall coordination and strategic planning. It is the legal entity acting on behalf of the AGMEMOD Partnership. Most importantly, it provides the combined model versions on a central server, and coordinates baseline work and results review. It consists of researchers from Thuenen and WEcR. The national experts is the broadest group of model users. They provide data and validation of baseline results for their respective countries, and may improve their respective country model. The Core Modelling group is responsible for work relating to scientific contents and output, including the final consolidation of the baseline. National experts contributing significantly to the AGMEMOD project can become members of the Core Modelling Group. All parties (signatories of the MOU) have access rights to the combined model and the baseline. If a party does not comply with the MOU, it 'defaults', and will lose their access rights. All parties fund their own work, i.e. there are no joint financial resources.
   - A unique feature of the network around AGMEMOD is that it has a network of market experts, including experts on different sectors, and from different EU Member States and institutes. This network of market experts plays an important role in the validation of outlook projections.
   - The model versioning is managed by an AGMEMOD cloud (hosted by Thuenen) which is used to store model versions, as well as a device allowing different partners to work on different issues. Model improvements have to be documented in a logbook, updated files have to be uploaded or shared. The Core Team takes care that regular new central versions are made, which include all the improvements made during a certain time span.

- GLOBIOM has been developed at IIASA, and has not previously been accessible to external collaborators. Since 2018 the team behind the model is working on an open source version of the model available via GITHUB (an SVN system). For the GLOBIOM team, GITHUB already serves as a platform for exchanging code developments, and regionally specific model versions have been distributed to partners of the FABLE consortium (a global research network). So far, the external users can modify their versions of GLOBIOM, but do not have the possibility to change the GLOBIOM code at IIASA, and thus cannot directly contribute to the model development. Thus, GLOBIOM is functionally an institutionally owned model of IIASA. IIASA can therefore handle overhead costs such as data updates, documentation and software architecture, and no formal governance structure is presently required. This may change when the move towards open source publication of the model and data is completed.

As regards the data management, in 2016, the 'FAIR Guiding Principles for scientific data management and stewardship' were published in Scientific Data. These FAIR principles emphasize the need to secure the findability, accessibility, interoperability, and reuse of data and metadata. Whereas the different modelling networks have their own solutions for data management, the DataM provision at the European Commission contributes to better follow the FAIR-guiding principles (see, Box 17). It also could enables the integration of data from one model with that of another (interoperability) and re-use of data. Principles need to be integrated into the practices followed by modellers, modelling groups, and research institutions. There are several developments going on, also as a response to publication policies (e.g. open science and open access publication policies), which create both progress, but also confusion is this field, as different institutions may follow different approaches and/or are at a different stage of development.

Box 17. DataM

DataM – a tool for flexible management, extension and integration of (model) databases

DataM has been developed at JRC Seville to ease the daily work of analysts and modellers in agriculture. It gathers data from the main databases on agriculture and trade, and allows easy access to, and exploration, visualisation and reporting of, the data.
Using one interface, users can rapidly access the main agricultural, trade and macroeconomic databases (as provided by Eurostat, FAOSTAT, USDA, OECD, GTAP), as well as the in-house model databases. The tool addresses different needs, ranging from data collection and data checks to advanced reporting, with the possibility of exporting data. The DataM facility contains thematic datasets created by putting together data from different sources on a specific topic. It is sued for the dissemination of information and data from different domains (e.g. economics) and domains (e.g. bio-economy, food security). Alongside empirical data, DataM also includes model simulation results. The main advantage of DataM is the data comparability among datasets on different topics.
Since 2014, the overall accessibility of DataM has been extended through a web-based version, which is currently available to the public (see https://datam.jrc.ec.europa.eu/datam/public/pages/index.xhtml for further details).

Source: Helaine et al., (2013) and M'Bareck et al. (2015).

Based on the discussion above, the following (policy) recommendations can be drawn:
- Designing data management plan is essential;
- Data should be kept and processed at the lowest level of detail;

- All data changes and adjustments should be coded to enhance tractability and quality control. This approach also facilitates the updating of datasets, since the same code can be applied to the updates;
- A modular setup of model code is highly recommended;
- Data sharing and model development by (international) cooperation to reduce development and maintenance costs; and
- Institutionalise the consortium, e.g. by means of a consortium agreement.

10.6 SUPREMA network

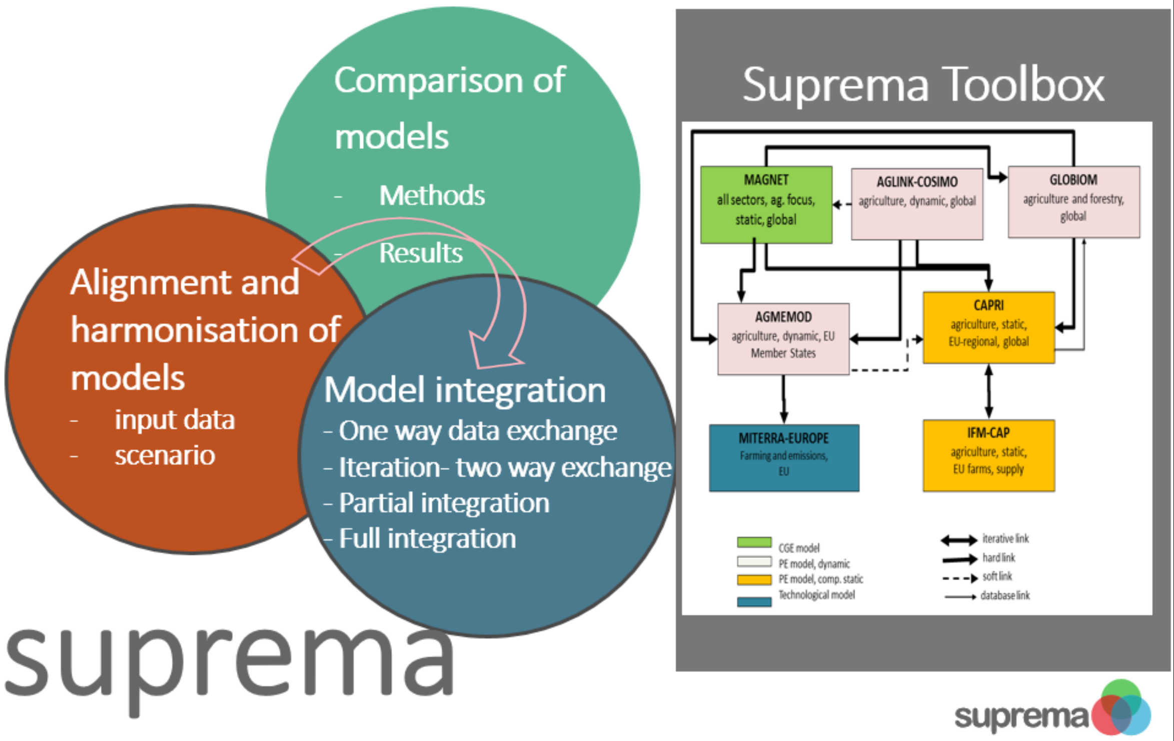
The sustainability questions related to agriculture and the emerging bio-economy and its contribution to the SDGs imply that no model can cover all dimensions and that cooperation between different approaches (model types) and the linking off models provides a possible way to address the questions from a broader perspective. Improved cooperation between the different approaches offers possibilities to reduce some of the shortcomings of the different modelling types, narrow the knowledge gaps highlighted above and strengthen our ability to assess (both direct and indirect) the impacts of for example, the green deal and\or farm to fork strategy. Thereby, model collaboration can contribute in improving the quality of information for policy-makers and contribute to better-informed decision-making (Wicke et al., 2015).

In SUPREMA, harmonisation and model comparison identified synergy effects between models and possible valuable links between models. In SUPREMA many interesting model linkages between the core models are explored and a method to assess the value added of model linkages have been developed. However, model comparison should guide and improve alignment and harmonization of models and identify options for model linkages. The linkages can be developed and possibly automatized. The increasing complexity of the questions and the requested coverage of all sustainability dimensions and SDGs requires integrated impact assessment, which in turn requires a deeper and deeper level of integration. Modular approaches facilitate the linking and design a certain model configuration at hand given the particular question to be answered. Therefore, a SUPREMA meta-platform is needed that embeds good data management protocols, preserves and enhances linkages between SUPREMA models and potential other models.

We conclude this sort of networking is essential for model comparison, model linking and model improvement. SUPREMA needs to meet the challenge to secure long-term impact beyond the limited duration of a project. SUPREMA currently explores the options for follow-up activities through the meta-platform, including financial resources. To achieve this objective it continues interacting with other platforms, to stakeholders and other experts to a nucleus for a long-term European meta-platform which supports modelling in agriculture with respect to a broad range of topics. Among those topics are the functioning of the EU agri-food sectors and its integration with up- and downstream sectors at different spatial scales. This meta-platform will cover the huge variety of existing policy and future policy options affecting agriculture, the agri-food value chain, global integration, sustainable development goals, adoption of technologies, land use, low carbon economy and climate change. It is foreseen that the future integration of models and experts in the network will be handled in a flexible manner. Together with stakeholders a plan for the coming 5 years will be developed further, including open access release of model runs, some model improvement and networking.

Vision

In the suprema network, the three forms of model cooperation (harmonisation, model comparison, model integration) get more and more interrelated and get eventually transformed into a harmonious 'dance' between these three modes of model cooperation in which each model plays its own role and in which new models are invited 'to join the dance'.



Source: Authors'.

Figure 7. The SUPREMA network

10.7 Concluding remarks

Based on this chapter a number of conclusions can be drawn with respect to the general issues of agricultural economic modelling:

- The need for integrated model use is increasing, with the proposed food systems approach even more underlining this. However, this requires a clear strategy with respect to integrated model use and the recognition of different ways to link models.
- Baseline harmonization between key models that are used for policy assessments is important for policy makers and also for modellers. On the one hand harmonization contributes to the comparability of modelling results, while on the other hand they provide insight into modelling result differences, model-limitations, and the different approaches to understanding economic phenomena
- Model maintenance is an important aspect of ensuring a good model performance, but a time demanding and costly activity, which are often difficult to get funded. Aside from having the models being used to answer client demands, care should be taken that investments are made to address 'larger maintenance' issues (e.g. re-estimating parameters, adding/extending specific modules).
- Model cross-validation is important to assess the credibility of modelling results and can take place in different ways (e.g. market expert assessments, statistical tests, client feedback, academic and professional review processes). It is also an important input for 'learning' and a

stimulus for model improvement. For calibrated models it is important that the base year, to which the model is calibrated, becomes not too 'distant' from the current reality.

- With respect to their governance the different models considered in this research have each their own approach, which reflect their origin, history and current institutional embeddedness. In particular when many researchers at different institutions from different countries are working with the same model a clear direction is needed, which usually is provided by a 'leading' institute, e.g. MAGNET, a concise core team, e.g. AGMEMOD, or the 'owning' institute, e.g. GLOBIOM, IFM-CAP.
- Data are the core of models and their proper management is a crucial but maybe a sometimes a bit neglected element in modelling activities. The modelling platform initiative of the EU (iMAP) has been important as a stimulus to improve the data management, including issues like data storage (together with metadata), and also to the interoperability and re-use of data. The FAIR-data principles provide a good guideline for data management and could be used as a basis for making or developing model-specific data management plans.
- A SUPREMA network of models is needed to assess the increasing complexity of the questions and the requested coverage of all sustainability dimensions and SDGs requires a deeper and deeper level of cooperation and integration. SUPREMA needs to meet the challenge to secure long-term impact beyond the limited duration of a project. It is foreseen that the future integration of models and experts in the network will be handled in a flexible manner. Together with stakeholders, a plan for the coming 5 years will be developed further, including open access release of model runs, some model improvement and networking.

11 Conclusions and recommendations

11.1 Conclusions

As regards the policy needs and the following priorities for future modelling of different aspects related to the agri-food sector an assessment has been made of recent policy documents, inputs from stakeholder workshops and expert opinions. Specific attention has been paid to the current (and upcoming) agricultural policy framework, and the notion of 'food system approach' as an overarching framework that covers the food market from a broad perspective. From this it appears that priorities shift from following a traditional and successfully pursued productivity-paradigm in the direction of a sustainability-paradigm. As such environmental impacts and climate issues are becoming increasing important and also subject to expected further future policy interventions. At the same time social and farm income objectives stay important, while also the Covid-19 pandemic underscored the vital role of agriculture in ensuring a safe and adequate food provision, even when circumstances become extreme.

With respect to primary production modelling a number of challenges have been identified that need 'solutions' in order for the models to serve the policy makers in their future policy development, implementation and design. Selected aspects that need attention are:

- The representation of production activities and sectors, in particular with respect to fruits and vegetables and Mediterranean products.
- A refined representation of specific input use (artificial fertilizer, antibiotics) and the costs of production, where such costs are attributed to the proper production activities and disaggregated to the level needed to better address current and upcoming policy priorities with respect to farm input use (e.g. pesticides, fertilizers, antibiotics).
- The modelling of adoption of voluntary policy measures (e.g. eco-schemes, AEC-measures), farm management practices and technological innovations. This also requires that more attention should be given in modelling to farmer individual decision making.

Specific elements within the CAP that affect the sustainability of farming practices, e.g. eco-schemes, also have implications for land use modelling. Models with a proper representation of land use and forestry are increasingly important for any assessment about the evolution and contribution of the bio-economy.

As followed from the needs assessment environmental aspects are becoming increasingly important in agricultural policies. Besides climate change mitigation, more focus has also to be set on the preservation and enhancing of biodiversity. However, modelling of biodiversity impacts, is only to a rather limited extend included in the current agricultural and economic models. Often only indirect aspects of biodiversity have been modelled, such as changes in land use, and modelling of emissions, which can be seen as an indicator for the risk of loss of biodiversity. Direct impacts on the impacts of species, e.g. number of red list species in a region or effects on population sizes of certain key species, etc., cannot be modelled yet.

Within the EU Green Deal, achieving climate neutrality by 2050 is a key objective which is encouraging agricultural models to provide a better representation of both adaptation and mitigation measures, leading to improved quantification of GHG emissions. The representation of measures as such should be also accompanied with an appropriate modelling of their adoption and diffusion through the agricultural sector. The CAPRI experienced gained through the EcAMPA projects could provide a set of good practices and lessons learnt which could be used when thinking of potential model improvements and further developments for the rest of the SUPREMA models.

Supply chains are important parts of the food system and play a leading role in delivering inputs to and precuring products from farmers with the aim to serve consumers and other end-users with high quality products. Their impact is far-reaching and covers issues as standards (e.g. food safety, animal welfare), contractual arrangements (including sustainability requirements), price formation and price transmission-issues. From the assessment made it turned out that their role needs a better understanding. Models considered in this piece of research have in general a very poor representation of supply chains. This holds for CGE models as well as for PE models. Their shared key limitation is that they do not model firms, nor make use of indicators characterising industry structure. From the literature assessment it followed that taking into account supply chain characteristics and the behaviour of different players in the supply chain is important for understanding the evolution of the farmer-retail price spread. A general suggestion from the supply chain and price transmission literature is that competition is often characterised by some form of oligopoly/oligopsony rather than by full competition, which could give rise to market power issues, and its abuse. Given the previous observations, our overall conclusion is that it is important to put more efforts in modelling supply chains. Rather than integrating supply chain representations into the models that were used in this research, a more fruitful approach maybe to develop special supply chain models for key agricultural supply chains (e.g. using EDM-modelling). A drawback is that supply chain analysis requires the availability of proper data. This is a big limitation for research since such data are not generally available. Moreover, competitive interests of supply chain players hinder the gathering of reliable data.

Although trade liberalization and multilateralism have declined in there are still a number of key issues with respect to trade modelling, including the role of standards and other non-tariff measures, and value added and trade, with a special focus on global value chains. With respect to the NTMs modelling more refinement and validation are needed. Moreover, it was found that there may be a need to better understand and measure the impact of NTMs by applying specific case studies, using complementary approaches such as cost benefit analyses. As regards the global value chains, this is largely absent from the models taken into account in this study. Even at a theoretical level there are still a number of issues that need further development. One aspect is how to incorporate global value chain representations in sectoral models. Rather that fully integrating them, the current state of the art seems to be to combine separate value chain models with the large scale sector models.

The Farm to Fork strategy pursues a farm and food policy, taking into account linkages to the consumer side of food provisioning. Public health outcomes and environment effects are important issues that could benefit from a reduction in consumption (and associated production) of certain products, e.g. meat. Therefore, a dietary change becomes a priority within the EU since livestock consumption and production are not within appropriate boundaries (see, RISE (2018) for further details). Transitioning towards a plant-based diet is a multi-dimensional phenomenon that requires the engagement of the public sector, all actors involved in the supply chain and consumers. In the same vein, the benefits associated with transitioning towards more healthy diets will not be limited to a reduction in the cost of medical services. Reductions in CO_2 emissions and acidification of soil and air, improvements in the sustainability of food systems, as well as potential creation of value added for arable farmers can be expected also, but needs more investigation. As regards agricultural modelling, it requires that the consumer side gets a more refined treatment than is has now. As an example, although information on the age structure of the population at Member State level is available, such information is not used in the considered models as a variable for explaining demand and changes in its patterns, let alone other information (e.g. % of population of flexitarians or vegans).

Another important issue, which also links to the policy priority put on making agriculture more circular, is the potential of reducing food waste for mitigating the negative environmental consequences of food production. In this regard it is important to highlight the huge challenge that modellers will face when looking for sufficient and robust data to use as an input for such an assessment.

With respect to general issues of agricultural economic modelling it is concluded that the need for integrated model use is increasing, with the proposed food systems approach even more underlining this. However, this requires a clear strategy with respect to integrated model use and a better recognition of different ways to link models. It has also been argued that baseline harmonization between key models that are used for policy assessments is important for policy makers and also for modellers. On the one hand harmonization contributes to the comparability of modelling results, while on the other hand they provide insight into modelling result differences, model-limitations, and the different approaches to understanding economic phenomena. As regards model maintenance this is considered crucial to ensure a good model performance, but it is at the same time a time demanding and costly activity, which are often difficult to get funded. Aside from the regular improvements made by having the models being used to answer client demands, care should be taken that investments are made to address 'larger maintenance' issues (e.g. re-estimating parameters, adding/extending specific modules).

Model cross-validation is important to assess the credibility of modelling results and can take place in different ways (e.g. market expert assessments, statistical tests, client feedback, academic and professional review processes). It is also an important input for 'learning' and a stimulus for model improvement. For calibrated models it is important that the base year, to which the model is calibrated, becomes not too 'distant' from the current reality. With respect to their governance the different models considered in this research have each their own approach, which reflect their origin, history and current institutional embeddedness. In particular when many researchers at different institutions from different countries are working with the same model a clear direction is needed, which usually is provided by a 'leading' institute, e.g. MAGNET, a concise core team, e.g. AGMEMOD, or the 'owning' institute, e.g. GLOBIOM, IFM-CAP. Data are the core of models and their proper management is a crucial but maybe a sometimes a bit neglected element in modelling activities. The modelling platform initiative of the EU (iMAP) has been important as a stimulus to improve the data management, including issues like data storage (together with metadata), and also to the interoperability and re-use of data. The FAIR-data principles provide a good guideline for data management and could be used as a basis for making or developing model-specific data management plans.

Moreover, a SUPREMA governance structure is needed beyond the level of individual models to enable enhanced and broader assessments of the increasing complexity of the questions and the requested coverage of all sustainability dimensions and SDGs. The analyses of these issues require a deeper and deeper level of cooperation and integration. SUPREMA needs to meet the challenge to secure long-term impact beyond the limited duration of a project in a flexible manner. Together with stakeholders a plan for the coming 5 years will be developed further, including open access release of model runs, some model improvement and networking.

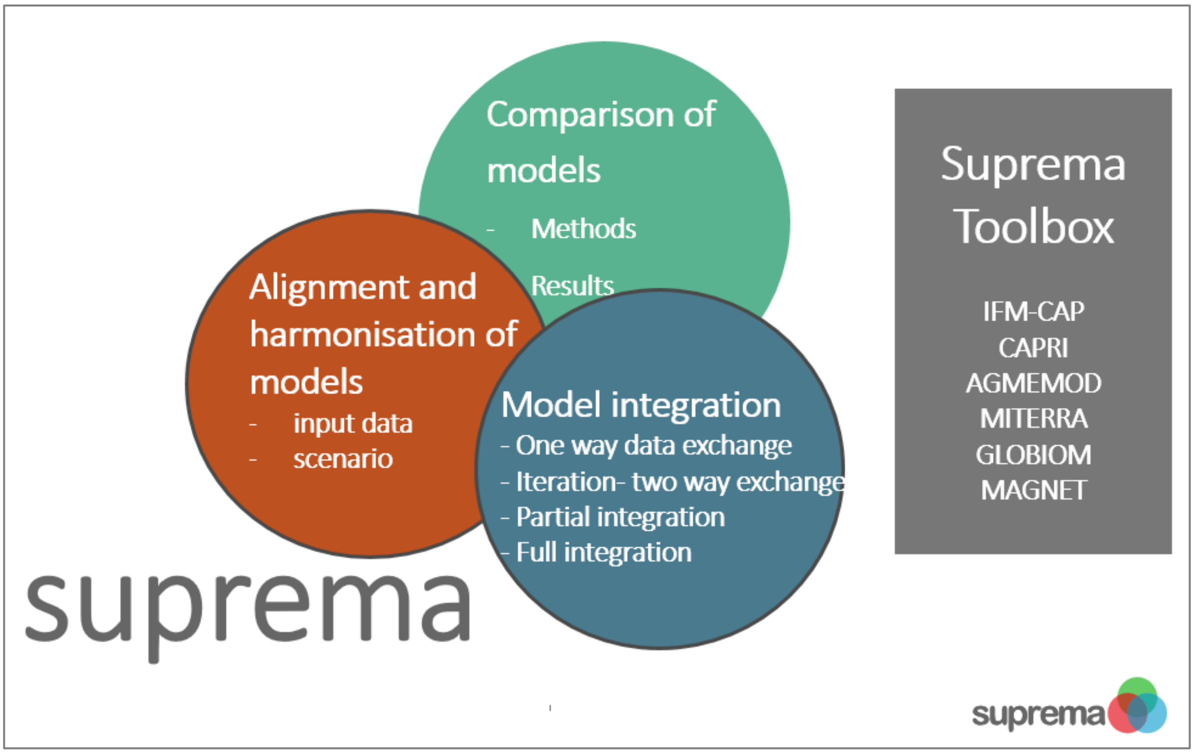
In short, SUPREMA has allowed the different modelling teams involved to conclude that there is an urgent need for an integrated model use in view of the complexity of the assessments that are required for the current (and upcoming) CAP discussions. Another important lesson from this project is the necessity for additional efforts to harmonise and improve the realism of the baselines that are used as starting point of the policy assessments conducted by the different models. Linked to the previous items, SUPREMA has also highlighted the importance of having solid basis underlying the modelling tools. This goes beyond data/estimation issues and includes the need of having a good understanding of the theoretical bases of models that work together, e.g. CAPRI and AGMEMOD-MITERRA as shown in T3.2. This is then when different modelling teams can delivered robust analyses and proper justification of the differences in model outcomes.

11.2 Recommendations

Based on the previous assessment of both the future policy needs and the strengths and weaknesses of agricultural models that were considered in this research, the following recommendations are made:

- The current and upcoming agricultural policy framework, and the notion of 'food system approach' as an overarching framework that covers the food market from a broad perspective require a reconsideration of the EU's modelling strategy in which integrated model use gets a more prominent place.
- The increased emphasis on sustainability, while maintaining the income perspective of farmers, makes that an increased attention has to be paid to the integrated use of environmental and economic modelling approaches to ensure coherence and consistency in the approach to a complex reality. It becomes increasingly unlikely that all these aspects can be in a satisfactory way integrated into one or a few models.
- A drawback might be that the (from a 'control'-perspective) attractive option of having a few 'recognized' models that have an EU wide spatial coverage and a comprehensive coverage of issues and themes is no longer the only best option. There are two 'answers' to this:
    - Firstly, the EU is already supporting several key models in different domains (economic-policy, environment, climate) and a challenge is to let these better work together. Additional investments will be necessary into model ensembling and the type of linkages that can be used. In the process of linkages-development, special attention need to be paid to circularity issues, which are so far under addressed.
    - Secondly, large scale models can never reach the degree of refinement regarding policy representation, spatial granularity and behavioural responses (e.g. innovation adoption) that is needed for delivering support to EU and national policy makers reflecting the indicated future priorities and the subsidiarity with respect to policy implementation and modality options that are planned to be given to Member States. More effort and support on refined and more 'localized' models (e.g. EDM-models) are welcomed and also more pluralistic approaches (e.g. agent-based modelling).
- In order to get further insights into the impact of policy measures at farm level, more emphasis should be put on understanding and modelling individual farm decision making.
- In the context of both actual economic developments as well as from the perspective of a food systems policy approach, food supply chain modelling needs more attention. Without this a number of insights that are crucial for effective policy making may be missed. It is still an issue how to best approach this, although starting from case studies that concentrates on key sectors seems a good idea.
- With respect to trade modelling a focus on the role of standards and non-tariff measures continues to be important, while the increased attention for 'functional trade' and 'fair trade' (level playing field corrections that account for maybe diverging EU and non-EU standards and requirements with respect to agricultural production and food processing) requires more insight into global value chains and trade linked sustainability indicators.
- Quality control, model (cross)validation, transparency, data management, research networks are crucial and become of increasing importance when more models and a plurality in modelling approaches are allowed for. The EU's role for providing services and platform-function has been recognized in the past and needs to be strengthened for the future.
- More generally, it is welcomed to have more academic publications on models, model applications and modelling results and maybe this also justifies a specialized journal on this as the standard disciplinary journals sometimes lack sufficient openness to such publications.

Finally, there is a need for a SUPREMA governance structure to guide long-term model developments, identify new potential interesting models, preserve and build stable bridges between models, integrate models and enable better policy research related to the Green deal and farm to Fork strategy with a broad coverage of objectives and SDGs. The SUPREMA Network will be launched in 2020 (see, figure below).



Source: Authors'.

Figure 8. Upcoming SUPREMA network

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