Available online at www.centmapress.org

Int. J. Food System Dynamics 12 (3), 2021, 287-300

DOI: http://dx.doi.org/10.18461/ijfsd.v12i3.91

INTERNATIONAL JOURNAL ON FOOD SYSTEM DYNAMICS

Lighting on the Road to Explore Future Directions for Agricultural Modelling in the EU – some Considerations on what Needs to be Done

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Received February 2021, accepted July 2021, available online August 2021

ABSTRACT

In the field of agri-food, impact assessments to support policy decision-making are often based on simulations delivered by models. The increasing complexity of policies affecting the agri-food sector requires improving the capacities of current models, connecting or redesigning them to deliver forward-looking insights on policy objectives. The EU-Project 'Support for Policy Relevant Modelling of Agriculture' (SUPREMA) has identified upcoming needs in the research and policy agenda, while exploring the feasibility of those potential modelling exercises by testing the existing tools. The assessment has pointed out necessities for model extensions and development of new tools. Besides, it has revealed the potential of model integration and collaboration to supplement the outcomes of individual models. This is supported in view of the food system approach that is becoming the fundamental framework for analysing the dynamics of the agri-food sector when considering it from a broad perspective. This paper describes shortly how the assessment was conducted and presents the outcomes and lessons learnt from the project. It pays special attention to the challenges and the policy priorities that are expected to become important issues in the policy agenda in the coming years.

Keywords: *Common Agricultural Policy, Agriculture, Modelling, Model interaction, Policy Assessment.*

1 Introduction

Policies related to agriculture are supposed to address an increasing number of objectives as demanded by society (Brooks et al., 2019; Hanotis, 2020). Central challenges for the future Common Agricultural Policy (hereinafter 'CAP') are: (i) promoting research and innovation in agricultural and food production; (ii) fostering a smart and resilient agricultural sector; (iii) enhancing the environmental care and climate action; (iv) strengthening the socio-economic conditions of rural areas; and (v) addressing citizens' concerns in the areas of health, nutrition, food waste and animal welfare.[1]

[1] Relevant policy documents by the European Commission are available at: https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en.

In the context of policy analysis, models can contribute to support evidence-based policy-making. Broadly speaking, models can help us to project the current trends into the future and give us an indication of the areas in which policy interventions will be needed. Models could also help us to anticipate the consequences of certain policy measures, and therefore, provide useful insights to support the design (and fine-tunning) of the policies under consideration. Another interesting application of models is their use for quantitifying the potential impacts of shocks of diverse nature such as economic crisis or diseases outbreaks. In other occasions, models could also be used to 'draw' the situation which could have been in place otherwise, e.g. if a policy that was implemented during a certain period would have never been adopted.

The increasing need for impact assessments in the field of agriculture that are (partly) based on forward-looking outcomes delivered by models has required the frequent maintenance and further development of modelling tools. Nowadays, modellers should keep their tools well prepared for assessing (sometimes at very short notice) a broad range of issues. To give some examples we can refer to: (i) the impact of upcoming policies, e.g. the new CAP reform, the Sustainable Development Goals (SDGs), the Paris climate agreement, the Green Deal Roadmap and the associated EU Farm to Fork and Biodiversity Strategies; (ii) the effects of disease outbreaks, e.g. the African Swine Fever (ASF) disease, the Covid-19 pandemic; and (iii) the consequences of changes in the existing body of legislation, e.g. the so-called 'N' problem in the Netherlands, among others. These maintenance activities, e.g. updating of databases, re-estimation/re-calibration of equations, etc., and development tasks, e.g. extension of models to incorporate new commodities, regions and/or policy instruments, etc., are not a trivial issue and might require a considerable amount of resources in terms of labour, time, sector knowledge, computing capacity, etc.

Keeping in mind this background, the EU-Project 'Support for Policy Relevant Modelling of Agriculture' (SUPREMA) has identified upcoming needs and challenges in the research/policy agenda, while exploring the feasibility of carrying out those potential modelling exercises by using the existing tools. The SUPREMA model family includes 'core models' already used in support of key European impact assessments in the fields of agriculture, trade, climate and bioenergy policies. More specifically, this suite of models includes: MAGNET (Modular Applied GeNeral Equilibrium Tool), GLOBIOM (Global Biosphere Management Model), CAPRI (Common Agricultural Policy Regionalised Impact), AGMEMOD (AGricultural MEmber State MODelling), MITERRA-Europe, IFM-CAP (Individual farm Model for the Common Agricultural Policy).[2]

The findings of several applications of the SUPREMA core models, including the development of several linkages between them[3], as well as the outcomes of extensive discussions with stakeholders in three workshops have provided input into a Roadmap for future directions for agricultural modelling in Europe.[4] The overall goal of this exchange between scientists and other stakeholders (EU representatives, ministry officials, farmers organisations, etc.) is to 'bridge the gap between the expectations of policy makers and the capacity of models in a more complex environment by improving the mutual understanding and clarifying research needs and feasible strategies'.[5]

Additional assessments of recent policy documents and expert consultations have been made in SUPREMA, while special attention has been paid to the upcoming agricultural policy framework by using the 'food system approach' as the cornerstone. All these have revealed that priorities shifted from a pursued 'productivity' paradigm to a 'sustainability' paradigm where environmental and climate issues are becoming increasingly important subjects of policy interventions. Social issues and farm income also remain as important topics, while the Covid-19 pandemic underscored the relevance of food provision. In short, SUPREMA has allowed the different modelling teams involved to reach an agreement on the urgent need for cooperation and integrated model use in view of the complexity of the assessments for upcoming CAP discussions (Hanotis, 2020).

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[2] The model documentation is available at:
MAGNET (https://www.magnet-model.org/); GLOBIOM (https://iiasa.ac.at/web/home/research/GLOBIOM/GLOBIOM.html); CAPRI (https://www.capri-model.org/dokuwiki/doku.php); AGMEMOD (https://agmemod.eu/); MITERRA-Europe (http://content.alterra.wur.nl/Webdocs/PDFFiles/Alterrarapporten/AlterraRapport1663.1.pdf); IFM-CAP (https://op.europa.eu/en/publication-detail/-/publication/13480ce0-803e-4ec4-9f88-24d44d565eab/language-en). In terms of the typology of models, MAGNET is a General Equilibrium Computable (GCE) model; while all the other tools belong to the Partial-Equilibrium (PE) modelling category.

[3] We refer to the modelling system AGMEMOD-MITERRA as an example of a model linkage that has been developed in the context of SUPREMA.

[4] The Roadmap document (deliverable D1.10) is available at: https://www.suprema-project.eu/output/deliverables/work-package-1.

[5] See: https://www.suprema-project.eu/project/objective.

The objective of this paper is to present in a condensed and synthetic manner the key outcomes of the research and assessments carried out within SUPREMA. From the methodological point of view, SUPREMA has demonstrated that cross-cutting topics can be better analysed by using a set of models working together rather than a single modelling tool. In practical terms, SUPREMA has also revealed that some of the upcoming items in the policy agenda will require the update (and/or extension) of the existing models. The dissemination of these findings will benefit a broader modelling community and all researchers in field of agriculture, by raising awareness on the topics that will shape the research (and policy) agenda in the coming years and how they can be addressed.

After this introduction, the remainder of this paper is structured as follows. Section 2 focuses on the modelling needs that have been identified, linking them with a food system framework. Section 3 concentrates on the challenges that the agricultural modelling community will encounter in the near future when supporting the policy-making process. Section 4 discusses the potential use of models in an integrated manner as the way forward to address the mentioned challenges. Finally, Section 5 provides some concluding remarks.

2 Understanding the modelling needs from a food system approach perspective

2.1 The notion of 'food system'

'Food system' is a relatively new concept that 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 (EAT-Lancet Commission, 2019). Within the policy domain, there is an 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 sustainable manner (Food Chain Evaluation Consortium, 2014; FAO, 2014). At this stage, it is important to provide the reader with a clear and comprehensive definition of food systems. More specifically, 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 1).[6]

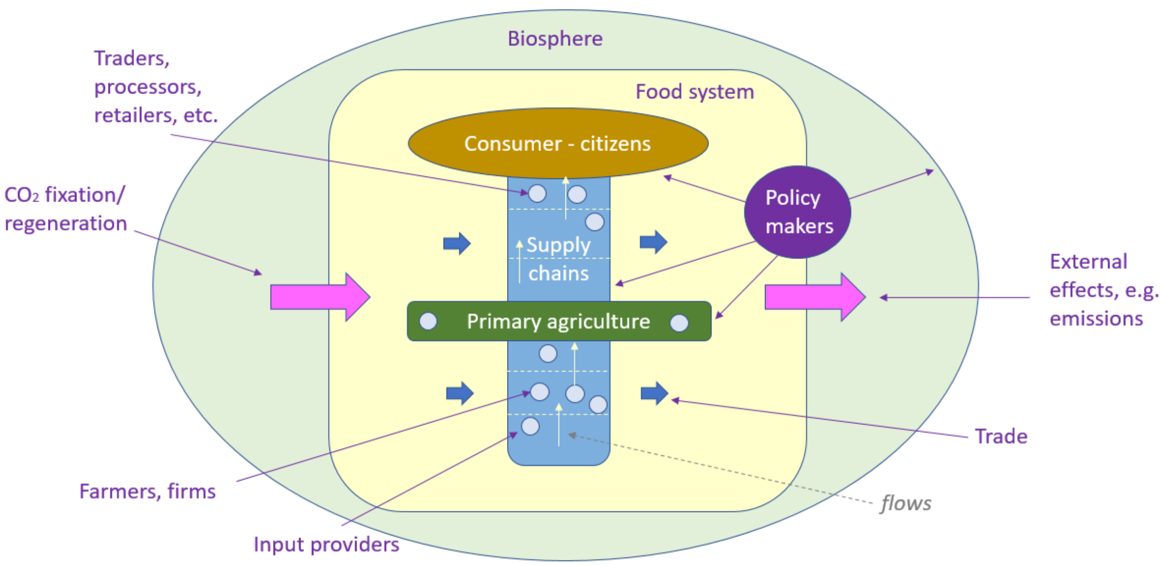

Figure 1. Food system framework
Source: Authors' elaboration based on various sources.

[6] See, also, Hebinck et al. (2021) for further discussion on policy options for a sustainable food system.

Moreover, Hoes et al. (2019) highlight that a food system framework considers the interactions and feedback loops among food systems activities (supply and demand) and the ecological and socioeconomic context in which these activities take place. A better knowledge of the interactions and feedback loops provides relevant insights to carry out a possible mapping of opportunities for a more efficient use of natural resources (beyond one product and/or value chain). It also reveals the importance of the food system's socio-economic context. Another relevant outcome of having a better understanding of the interactions and feedback loops within the food system is that it shows the implications of food consumption and production for health, nutrition, livelihoods and the environment. At the same time, it helps to shed light on the trade-offs between different intervention strategies. Having a proper understanding of the dynamics also contributes to clearly represent the non-linear processes and feedback loops in the food system that might go beyond more 'obvious' relationships that only emerge when all elements are taking into consideration.

Linked to the notion of food systems, a new field of applied research was born. In general terms, the so-called 'food system analysis' (Veronez de Sousa, 2015) 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 dietary aspects (see, for further discussion, FAO (2013b) and Nordhagen (2020) among others), as well as on environmental and animal welfare issues (Place, 2018). Bearing in mind the discussion above, it is essential to identify the challenges that agricultural modelling will face in the coming years.

2.2 Identifying future needs

Looking at Figure 1, one could think of the necessity of interacting with the variety of stakeholders that are included within the food system in order to understand their priorities and concerns. That was the reason why a series of workshops were organised in the context of SUPREMA in order to facilitate the exchange between economic modellers, EU policy makers, researchers, ministry officials from several member states and industry associations among others. The key findings of these stakeholder consultations are presented in this section and linked to the existing literature.[7]

Consensus has been reached around the fact that the current and upcoming topics of interest and relevant research questions are having a stronger cross-cutting focus. By definition a model is a simplification of reality, and therefore, it cannot cover everything (van Tongeren et al., 2001; Ouliaris, 2011). Hence, there is a need for further developing the existing models by linking or extending them in order to capture all the dimensions that should be considered to answer the complex research questions that will be on the upcoming policy agenda.[8]

Model linkages have the potential to deliver the capacity for assessing impacts across different spatial-scales and stages of the value change, for example, by having a proper representation of the behaviour of decision-units like farmers, consumers, processors or traders, as well as policy instruments that policy-makers have at hand. Moreover, the establishment of model linkages has been identified as a potential solution to obtain deeper and better insights into the interactions among different actors in the supply chain. The process of linking models is not exempt from challenges since it will involve important efforts for further harmonisation among models and model outcomes (Perez-Dominguez et al., 2008; Creutzig et al., 2012; Lotze-Campen et al., 2014; van Meijl et al., 2018). Moreover, additional actions in order to solve problems in data requirements, availability and access would be also needed. In other words, data is the core of models, being its proper management crucial. The availability of data is often steered by activities outside the realm of models which limit their representation and their possible field of application.

In terms of the CAP, a number of topics appeared as relevant during the discussion held with the different stakeholders. An important aspect is to study the impacts of policy and market shocks on income generation covering all relevant groups. Other examples are soil and water acification, as well as the loss of biodiversity. Moreover, the potential consequences of implementing measures for adaptation, introducing mitigation strategies or adopting new technologies was also mentioned as a key topic during the workshops and highlighted in the existing literature. It seems to be very relevant when it is associated to the cost and their transmission along the supply chain to consumers (see, Garnett (2011) for further details). Having a proper representation and modelling of water (Kersebaum et al., 2007) is another

[7] The outcomes of this series of workshops are detailed in deliverables D1.1, D1.4, D.1.9. Available at: https://www.suprema-project.eu/output/deliverables/work-package-1.

[8] Further discussion on model linkages within SUPREMA is presented in deliverable D2.2. Available at: https://www.suprema-project.eu/output/deliverables/work-package-2.

relevant area in which models are expected to be improved in order to cover aspects such as quantity (scarcities and sudden surplus) and quality (see, Querner and Zanen (2013) for an example in the case of the Limpopo River). The modelling of the impacts of farm management on greenhouse gas (GHG) emissions, including mitigation and adaptation options towards climate change is another direction for model improvement, by paying special attention to the long-term perspective and the assessment of impacts on this time horizon (see, Eory, et al., 2018). This context reinforces the necessity of linking and somehow coupling modelling tools in order to capture the complexities associated with these topics. [9]

Going deeper on the topic of climate change, innovation processes, new technologies and its diffusion play an important role in GHG mitigation and climate adaptation, and therefore, in how agriculture can deal with it (Dessart et al., 2019; Finger et al., 2019). However, technology and innovation processes are considered as an exogenous element in case of the vast majority of large-scale models. Therefore, the uptake is potentially restricted over time by some assumed technology adoption rates. In this regard, there is a need for models to consider adjustments due to innovation in inputs, input use and in production systems with respect to climate change in a more detailled manner (Gonzalez-Martinez et al., 2021). This is key in order to ensure realistic outcomes and enable technology adjustment to differ between countries. Other elements that should be considered when modelling the development of agriculture in the near future are the adoption of new technologies concerning digitalization; micro robots and automated processes at farm level as well as further along the supply chain (see also Pesce et al., 2019).

A good biophysical representation of agricultural production, including its interaction with the biosphere in the core is also a pressing issue to be accounted for in the existing modelling tools.[10] 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.[11] A circularity approach should be used when modelling the closing of nutrient cycles and the reduction of mineral fertilizer use (Bremmer et al., 2020). The combination with life cycle assessment (LCA) becomes relevant in this regard. Another important element that needs to be well represented by modelling tools is sustainability, capturing its economic, environmental and social dimension.[12]

Other challenges identified refer to the representation of changes in consumer preferences and the behaviour of economic agents, i.e. the final stage of the 'supply chain'. Dietary changes towards more sustainable choices with a lower content of animal protein might be driven by changes in consumer preferences which eventually could have an important impact on GHG emissions (Clark et al., 2019). Therefore, changes in consumer decisions increasingly reflect their perceptions regarding production processes with respect to ethical issues, sustainability issues and aspects of fairness among others. To what extent changes might materialise at the point of sale will depend on the individual circumstances like e.g. availability, labelling, income situation, health concerns, ethical upbringing and environmental reasons, etc.[13] Although demand shifts in society are evolving quite smoothly, disruptive changes may occur quite suddenly, often in combination with quality, hygienic, diseases or animal welfare problems.[14] Keeping in mind this background, there is a need for improving the representation of consumer preferences within the existing models. Some previous experiences of how consumer preferences can be modelled in the case of different products are provided by Pazarlioğlu et al. (2007) and Dubé (2018). Related to the representation of the supply chain, the diffusion of innovation was highlighted as another direction for improving the current models, mainly with a focus on the impact on jobs and other global issues such as climate change, health impacts or lifestyle changes. Models should also be prepared to reflect the start of new manufacturing sectors and new productions.

[9] See, Gonzalez-Martinez et al. (2021) for an illustration of how integrated modelling use was applied in order to assess the impact of implementing alternative mitigation packages in the context of the Dutch agriculture. This study relies on the modelling system AGMEMOD-MITERRA, which is linked to an optimisation model that represents the current environmental policy framework of the Netherlands.

[10] See, Castro et al. (2018) for additional discussion on the use of bio-economic models to inform the decision-making process regarding land use planning.

[11] See, Carbon Trust (2006) for an example of the environmental value of reducing CO_2 emissions across the supply chain using a case study from the UK snack food sector. Life cycle assessment (LCA) is the basis for the methodological approach.

[12] An illustration of how these three dimensions interact together is provided by Raworth (2017).

[13] See, Tsakiridou et al. (2010) for an analysis of the impacts of animal welfare standards on consumer choices. See, European Parliament (2020) for some discussion on sustainable consumer choices from an environmental point of view.

[14] Jongeneel et al. (2020) provide an assessment of potential consequences of the 2019 African Swine Fever outbreak by simulating several recovery scenarios for a mid-term horizon. This assessment relies on an equilibrium displacement model (EDM).

Apart from that, strategies towards a more bio-based economy are an important element to consider.[15] In this respect, the stakeholder consultation revealed that the focus should be on the strong relation that exists to a low carbon and circular economy, particularly in a global context. From the modelling perspective, both challenges will call for a more integrated approach that includes the utilisation of different models in a harmonised way. Since the 'pathway' to the bioeconomy is an uncertain one, additional research is needed for modelling this transition. Within models, bioeconomy and in particular bio-materials and bio-chemicals are only represented to a limited degree. In order to fill this gap, the on-going H2020 BioMonitor project focuses on the development of a model tool-box that represents the bioeconomy and allows for the quantitative assessment of forward-looking scenarios.[16] This initiative also confirms the need for using models in an integrated manner. Nevertheless, for a proper representation of the bioeconomy an important data challenge needs to be overcome.[17] More specifically, data and parameters on flows of food, feed, bio-material, bioenergy, waste, residues and other uses for substitution of fossil-based resources are scarcely registered, with mostly 'isolated' values that refer to a single year scattered in reports. In order to better reflect circularity, models are required to provide a more detailed representation of product-flows including by-products, intermediate products, re-used products, product waste.

Therefore, it is evident that models should 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 EU policy context and the increased reliance on policy measures addressing individual farms, e.g. 'voluntary-adoption' type of measures such as certain management practices. All these changes create a need to align policy directions and tools for an appropriate model assessment.

The complexity of the questions that researchers in the field of agricultural economics would need to explore is illustrated in Table 1.

3 Challenges for the modelling community

All the challenges that have been identified require 'solutions' to better serve policy makers. This set of challenges covers a broad range of topics and activities: (i) improved representation of products (fruits and vegetables, Mediterranean products) and inputs (use and cost); (ii) adoption of voluntary policy measures; (iii) implementation of CAP elements affecting sustainability; (iv) land use modelling; (v) better representation of biodiversity, adaptation and mitigation measures; (vi) supply chain issues (standards, contractual arrangements, price formation and price transmission); (vii) the role of standards and other non-tariff measures (NTMs) in trade; (viii) better representation of the demand side of the agri-food market with changing consumption patterns (environment and health) and population's age structure; (ix) modelling of food waste; and (xi) the representation of the bioeconomy. All these elements are further discussed in this section, be it in a brief way.

To begin with the modelling of primary production, an aspect that needs further attention is the representation of production activities and sectors, for example in the case of fruits and vegetables and other Mediterranean products, as well as products under EU quality schemes. An important contribution in terms of modelling agricultural production is Carpentier et al. (2018). Another challenge is a better representation of specific input use (fertilizers, pesticides, antibiotics) and production costs, where the latter is 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. Farm to Fork objectives with respect to pesticides, fertilizers, antibiotics, etc. Moreover, a pending task is the representation of farmers' behaviour, which needs to reflect the key trade-offs that they face as these are playing a crucial role in reality. It should also account for objectives (e.g. profit maximization), decision-making rules (e.g. farming practices, agent-based modelling, etc.), and relevant farmer interaction effects, as well as the adoption of voluntary policy measures, farm management practices and technological innovations.

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[15] See, Oudendag et al. (2020) for an application in the case of the MAGNET model.

[16] This modelling tool box includes some of the SUPREMA models such MAGNET and AGMEMOD, as well as the recently developed BioMAT (Bio-based MATerials) model among others. BioMAT can work as a stand-alone model or as a module of AGMEMOD. In this project, additional efforts have been done in order to develop new linkages between the models included in the toolbox. Further details are available at: https://biomonitor.eu/.

[17] This is another challenge that the BioMonitor project addresses.

Table 1.
Overview modelling needs by broad research topic

Topic/Subject	Strength	Weaknesses	Examples
Primary agriculture economy	**Response to market signals and trade policies**	**Explain risk management behaviour and scheme/technology adoption, efficiency gaps**	**Technology adoption and eco-schemes**
Supply chains	**-**	**Poor representation of supply chains (stages, firms, flows)**	**C4 concentration ratios 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), animal welfare, traceability**	**Consumer red meat preference shift**
Bioeconomy	**Bioenergy 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' elaboration based on the outcomes of the workshops that were organised in the context of the SUPREMA project (WP1).

Technological and social innovations (as well as their adoption) are complex and still more efforts are needed to better understand them. Before integrating the results into the larger scale sector models, first the assessment of a number of detailed case studies is still welcomed.[18] Results from detailed econometric studies enable the modelling of endogenous technological change, by introducing research and development (R&D) investments in macroeconomic models. Empirical studies assess the rate of return and factor biasedness of technological change and *ex-ante* models quantify the sustainability impacts of these developments.

[18] The reader is referred to the SUPREMA deliverable D2.2. in which a case study of the modelling of the dairy supply chain is presented. Available at: https://www.suprema-project.eu/output/deliverables/work-package-2.

Turning to the modelling of land use, the present exercise permits us to point at some specific elements within the CAP that affect the sustainability of farming practices, e.g. eco-schemes, as well the importance 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. Since land use is closely related to the role of technological innovation, agricultural modellers will need to devote resources to endogenously model technology and its progress for a better assessment of the implications of climate change as well as the potential of mitigation and adaptation options.

Apart from that, models with a proper representation of land use and forestry are increasingly important for any assessment about the role of the bioeconomy. Specifically, a key challenge is to introduce all potential new bioeconomy applications within the available modelling frameworks.[19] Much progress has been achieved for biofuels 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 by the fact that bio-based materials\chemicals are very heterogenous and technological change quickly transform them.

With respect to biodiversity, it has been argued that the current status of the agricultural and economic models which have been considered is rather weak.[20, 21] However, this weak modelling status does not reflect the importance attached to biodiversity objectives in the CAP (Poláková et al., 2011). 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 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 and might constitute another point for development/model linkage in the future. Moreover, another aspect that constitutes a challenge for improving this type of modelling is the important locality issue that surrounds biodiversity, requiring for its proper representation a high level of geographical disaggregation within the model. This level of granularity is not always compatible with large-scale modelling tools which provide a representation of the system at EU, global level, etc. Therefore, additional efforts are needed to improve policy impact assessment models and update them by using insights from the latest results obtained from the ecological literature. Related to this, it has been identified that environmental issues are becoming increasingly important in agricultural policies. Besides climate change mitigation, more focus will be set on the preservation and enhancing of biodiversity.

Focusing on the EU policy framework, i.e. the EU Green Deal,[22] 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. Once again, the representation of measures as such should be also accompanied with an appropriate modelling of their adoption and diffusion through the agricultural sector. Insights into marginal abatement cost curves, associated with the mitigation measures, could help to provide cost-effective solutions to climate policy objectives with respect to agriculture. In particular, the previous experience with CAPRI gained through the Economic Assessment of GHG mitigation policy options for EU agriculture (EcAMPA) projects (Pérez-Domínguez et al., 2016) 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. Moreover, another important topic to be considering when modelling/assessing the impact of climate change on agriculture is the role that can be played by extreme weather events which could severely affect yield evolution. Important studies in this regard are Pérez-Domínguez and Fellmann (2017) and Hristov et al. (2020).

Another element whose representation will bring several challenges is the modelling of supply chains (Dixon and Rimmer, 2019). Supply chains are important and complex parts of the food system, with a far-reaching impact that covers issues such as standards (e.g. food safety, animal welfare), contractual arrangements (including sustainability requirements), price formation and price transmission-issues (McCorriston et al., 2001; Commission of the European Communities, 2009). 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 whose key limitation is that they do not model firms, nor make use of indicators characterising industry structure. From the literature assessment, it follows that considering supply chain characteristics and the behaviour of different players along 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

[19] See, BioMonitor Policy Brief No. 2, for further discussion: http://biomonitor.eu/wp-content/uploads/2021/03/2021-03-11_BIO_PolicyBrief-2_digital.pdf.
[20] See, Tscharntke et al. (2005) and Chopin et al. (2019) for further discussion on biodiversity and its modelling.
[21] MITERRA-Europe is one of the few models that can provide some biodiversity indicators.
[22] See: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

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, the overall conclusion is that it is important to put more efforts into modelling supply chains. Rather than integrating supply chain representations into the models that were used in SUPREMA, a more fruitful approach may be to develop special supply chain models for key agricultural supply chains.[23] Nevertheless, a big limitation for pursuing this type of modelling is that the type of data that might be needed at this level is not generally available.

Drawing attention to the modelling of trade flows, this assessment permits us to make several observations. First of all, although multilateral trade liberalisation may face its difficulties, still a number of key issues with respect to trade play a role, including standards and other non-tariff measures, as well as the relationship between value added and trade, with a special focus on global value chains (Beghin et al., 2015). Whereas agricultural sector models traditionally take trade flows into account (it is implicitly always playing a role, even from a data perspective; e.g. balance closure), two prominent items that deserve more effort are the modelling of non-tariff measures (NTMs) and global value chains. With respect to the NTMs modelling, some work has been done, but more refinement and validation are needed. Moreover, it was found that there might 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. 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. Instead of fully integrating them, the current state of the art seems to be to combine separate value chain models with large-scale sector models.

Finally, some other modelling challenges have been identified when considering the role of food from a broader perspective. In this respect, public health outcomes and environmental effects are important issues that could benefit from a reduction in consumption (and associated production) of certain products, e.g. meat.[24] Therefore, dietary changes should be a priority within the EU since livestock consumption and production are not within appropriate ‘planetary’ 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, as well as improvements in the sustainability of food systems can be expected. The 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 needs to be somehow captured by modelling tools is the potential of reducing food waste for mitigating the negative environmental consequences of food production. [25] 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.

4 Lessons for the future

Quite often the study of the complex aspects mentioned above, e.g. sustainability related to agriculture, the development of the bioeconomy and its contribution to the SDGs, implies that no single model can cover all dimensions which need to be taken into account. This becomes more evident when analysing issues that involve several aspects of the food system, e.g. the impact of dietary choices on environmental degradation will required a detailed model of demand of agricultural products and a robust modelling of all the emissions associated to the production which is required to satisfy consumer needs. In order to tackle this issue, SUPREMA has explored the feasibity of ‘combining’ several models when analysing a policy/research question. An important finding of the project is that ‘cooperation’ between different modelling tools by developing appropiate linkages between them is the way forward to address these complex and multi-dimensional questions.[26] The ‘collaboration’ between different approaches offers possibilities to ‘fill’ the gaps that a single model/approach has and strengthens the capacity to assess the

[23] Equilibrium displacement modelling (EDM) could be a helpful approach to follow when working on this direction. See, for further details on the EDM approach, Muth (1964), Sumner and Wohlgenant (1985) and Wohlgenant (1993). See, also, for empirical applications, Jongeneel et al. (2018; 2020).

[24] Deliverable D3.2 presents the outcomes of simulating a reduction in red meat consumption in the EU by using CAPRI and the modelling system AGMEMOD-MITERRA. Available at: https://www.suprema-project.eu/output/deliverables/work-package-3.

[25] See, FAO (2011, 2013a) for further discussion on food waste.

[26] For theoretical discussion and some examples of modelling linkages, see also, Perez-Dominguez et al. (2008), Von Lampe et al. (2014), Wicke et al. (2015) and Gonzalez-Martinez et al. (2021).

direct and indirect impacts of a particular shock. Therefore, the use of models in an integrated manner, i.e. using models together to calculate a final output while exchanging information among them, can improve the quality of information for policy-makers and contribute to better-informed decision-making (Wicke et al., 2015). An illustration of the concept of integrated use of models in the context of the green economy is provided by PAGE (2017). The mentioned 'integrated modelling use' is also referred in the existing literature as 'model collaboration'.

Harmonisation and model comparison have also led to the identification of synergies between models and possible valuable links between tools, e.g. the link AGMEMOD-MITERRA.[27] The experience in SUPREMA has revealed that in an initial stage model comparison could: (i) guide and contribute to the alignment and harmonisation of models; and (ii) identify additional options for model linkages, which can be further developed and possibly (partly) automatised.[28] Subsequently, when a set of similar scenarios has been simulated by the different models, model comparison can: (i) improve the insight into specific contributions that different models can make; and (ii) constitute a 'procedure' for validating the modelling outcomes. More specifically, the validation of modelling results can take place in different ways, e.g. market expert assessments, statistical tests, client feedback, academic and professional review processes, etc. This exercise also has a role to play in the learning process of modellers and can become the 'seed' for additional model improvements. For calibrated models, it is important that the base year, to which the model is calibrated, becomes not too 'distant' from the current reality.

Thinking about the development of model linkages, modular approaches facilitate the linking and the activation of a certain model configuration that permits to have a tool for analysis tailored to a particular policy question.[29] All these could benefit from the development of a meta-platform that embeds good data management protocols, contributes to the maintenance of the exisiting modelling linkages and favours the development of new ones. This 'meta-platform' could be take the form of a 'virtual space', for example hosted by an official body, which facilitates the exchange among all members of the agricultural 'modelling community'.

On a practical note, there are two additional elements that SUPREMA highlighted as important factors to facilitate model comparison, model linking and model improvement in general, i.e. model governance and networking. Firstly, with respect to their governance, the different models considered in this piece of 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 is the corner stone of models and their proper management is a crucial but maybe sometimes a bit neglected element in modelling activities. The modelling platform initiative of the EU, i.e., the so-called 'Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (iMAP),[30] 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.[31] The FAIR-data principles (Findability, Accessibility, Interoperability, and Reuse) provide a good guideline for data management and could be used as the basis for making or developing model-specific data management plans. [32] SUPREMA has emphasised the need for stablishing a governance structure for the different models that were considered. This structure should go beyond the level of individual tools and permit broader and cross-cutting assessments that can substantially contribute to the upcoming policy agenda.

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[27] A description of the findings of the comparison of the baseline of the models involved in SUPREMA is presented in deliverable D3.1: https://www.suprema-project.eu/output/deliverables/work-package-3 . The reader is also referred to D2.1 on data comparison: https://www.suprema-project.eu/output/deliverables/work-package-2.

[28] An example of how model linkages can be automatised is the Model Junction linkage Tool (MOJITO). This tool links GLOBIOM, AGMEMOD and MAGNET. Further details on the structure and functionalities of the tool are available at Wolf and Bouma (2016).

[29] 'Modular approach' refers to the internal structure of models, which can be set up a in such a way that the different components of the models can be 'activated' or 'switched' off depending on the interest of the researchers. For example, in the case of the AGMEMOD model there is a module that represents fishery activities which is not 'active' when running an scenario in which a shock on crop yields is analysed. The reader is also referred to the MAGNET model which is a good illustration of the notion of 'modular structure'.

[30] Further details on iMAP are available at: https://ec.europa.eu/jrc/en/scientific-tool/imap-%E2%80%93-integrated-modelling-platform-agro-economic-commodity-and-policy-analysis.

[31] See, also, Helaine et al. (2013) and M'Bareck et al., (2015). The DataM platform that is a tool for flexible management, extension and integration of (model) databases which was developed by JRC is available at: https://datam.jrc.ec.europa.eu/datam/public/pages/index.xhtml.

[32] See, also: https://www.go-fair.org/fair-principles/.

Secondly, focusing on networking, one element that could shape the strategy of networking is the organisation of activities through a meta-platform, including the access to financial resources. In this sense, it is important to interact with existing modelling platforms (e.g. iMAP), stakeholders and other experts which eventually could bring to fruition a long-term European platform which supports modelling in agriculture with respect to a broad range of topics. This list of topics includes the functioning of the EU agri-food sectors and their integration with up- and downstream sectors at different spatial scales. This platform will cover a 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 among others.

5 Conclusions

This article is an attempt to bring some light on the priorities for future modelling of different aspects related to the agri-food sector, relying on the assessment of recent policy documents, inputs from stakeholder workshops and expert opinions. In particular, special attention should be 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. Therefore, it seems that there is a transition with regard to the paradigm to be followed when understanding agriculture, i.e. from a traditional 'productivity' paradigm towards a 'sustainability' paradigm. As such, environmental impacts and climate issues are becoming increasingly important and also subject to expected further future policy interventions. 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. 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.

Another important issue, which also links to the policy priority of making agriculture more circular, is the potential of reducing food waste for mitigating the negative environmental consequences of food production. Hence, 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. Moreover, circularity emphasises the importance of improving resource efficiency, the reuse of by-products and the need to think in terms of integrated or system-sustainability rather than individual sector sustainability.

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 being the cornerstone for analysing the dynamics of the agri-food system. However, this requires a clear strategy with respect to integrated model use and a better recognition of different ways to link models. Baseline harmonisation efforts between key models are important for policy makers and modellers. Harmonisation contributes to the comparability of modelling results, while providing insights into modelling result differences, model limitations, and the different approaches to understand economic phenomena. Linked to the harmonisation item, it is also key to have solid basis underlying the modelling tools. This goes beyond data/estimation issues and includes the need of having a good understanding of the theoretical underpinnings of the different models that will work together. Moreover, model maintenance is also considered as a crucial task to ensure a good model performance. Nevertheless, this is a very resource-intensive task, many times problematic to get funded. Apart 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.

This contribution has permitted to draw some policy recommendations that are applicable to the SUPREMA modelling community and can be extrapolated to other models in the agricultural field and beyond. First of all, elements such as quality control, validation of the modelling outcomes, transparency, data management and research networks have been identified as paramount. In particular, they become of increasing importance when more models and a plurality in modelling approaches are allowed for. In this sense, the provision of services and platform-function by international organisations such the European Commission has been recognised in the past and needs to be strengthened for the future. Secondly, increasing the number of academic publications on models and their applications could largely contribute to the cooperation among modelling teams, as well as increasing the impact of the research and the visibility of its findings. Positive outcomes in terms of transparency and knowledge sharing can also be expected from an increasing body of specialised literature. Finally, there is a need for a SUPREMA governance structure. The aim of this structure is to guide long-term model developments, identify new potential interesting models, preserve and build stable bridges between models and enable better policy research related to the Green Deal, the Farm to Fork Strategy and the SDGs among others.

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