MIND STEP

MODELLING INDIVIDUAL DECISIONS TO SUPPORT THE EUROPEAN POLICIES RELATED TO AGRICULTURE

Deliverable D5.1:
Final report on the concept of the MIND STEP model toolbox

AUTHORS	Kozicka Marta (IIASA), Addo Felicity (IIASA), Boere Esther (IIASA), Femenia Fabienne (INRAE), Frank Stefan (IIASA), Gosseling Irene (WR), Havlík Petr (IIASA), Helming John (WR), Hinkel Niklas (IIASA), Koutchade Obafemi Philippe (INRAE), Krisztin Tamás (IIASA), Mittenzwei Klaus (RURALIS), Müller Marc (WR), Neuenfeldt Sebastian (THUENEN), Sckokai Paolo (UCSC), TILLIE Pascal (JRC), van Dijk Michiel (WR), van Meijl Hans (WR), Wögerer Michael (IIASA)
APPROVED BY WP MANAGER:	Petr Havlík (IIASA)
DATE OF APPROVAL:	07-07-2022
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ACRONYMS

ABM	Agent Based Models
Agrispace	A Multi-Commodity Market Model based on the Spatial Equilibrium approach
CAP	Common Agricultural Policy
CAPDIS	Spatial dis-aggregation module of CAPRI results
CoESM	Collective Ecosystem Services Management model
DownScale	Model for high-resolution land-use change projections based on the GLOBIOM output
EPIC	Environmental Policy Integrated Model
EU	European Union
FADN	Farm Accountancy Data Network
FarmAgriPoliS	An interactive game which simulates the development of an agricultural region made up of farms
FarmDyn	A dynamic mixed integer bio-economic farm level model
FARMDYN	A dynamic mixed integer bio-economic farm scale model
FFS	Farm Structure Survey
FSU	Farm Structure Units
GHG	Green House Gasses
GLOBIOM	Global Biosphere Management Model
GTAP	Global Trade Analysis Project
IAMs	Integrated Assessment Models
IDM	Individual Decision Making
IFM-CAP	A comparative static positive mathematical programming model
MAGNET	Modular Applied GeNeral Equilibrium Tool
MIND STEP	Modelling INdividual Decisions to Support The European Policies related to agriculture
SDG	Sustainable Development Goals
SPAM	Spatial Production Allocation Model
(s)T	(sub-)Task
WP	Work package

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EXECUTIVE SUMMARY

The MIND STEP project aims at delivering a modelling toolbox for impact assessment of the EU (regional) policies, taking into account global events, on various aspects of the farming sector across different geographical scales – from regional to global – and different thematic dimensions. This is achieved thanks to the development and integration of various tools that can be grouped in three broad categories identified by their scale of analysis: tools focussing on the individual farmer, developed in MIND STEP Work package (WP) 3; tools focussing on interactions among farmers and within the supply chain, developed in WP4; and market-level tools used at the European Commission, in particular those gathered in the SUPREMA modelling platform. These tools cover a wide range of methods, including econometric estimation, Individual Decision Making (IDM) models, Agent Based Models (ABMs), and global or regional equilibrium models. WP5 makes a decisive step in developing the toolbox by establishing linkages between the models from across these categories in order to achieve the cross-scale exchange of information, both bottom-up and top-down. This Deliverable (D) 5.1 describes the identified combinations of the models, conceptualizes their linkages, details data exchange protocols, and discusses their policy relevance.

In order to facilitate the interfacing of the large-scale models with IDM models, section 3.1.1 explores the representation of production systems in commonly used databases, such as the Farm Accountancy Data Network (FADN), and their usability in simulation models across geographical and organizational scales. Those data, and models built on them, will be further used to improve the capacity of the large-scale models to capture impacts of changes in agricultural input costs (section 3.1.1) and land-use change dynamics, incl. input use (section 3.1.2). Next, model linkages are conceptualized with the focus on specific policy-relevant impacts: farm structural change and related land market developments (section 3.1.3), farmers risk preferences and adoption of insurance against weather-related risks (section 3.1.4), adoption of climate change mitigation technologies (section 3.1.5), farmers' market power and resulting price transmission along the value chains (section 3.1.6), and indirect impact of the EU policies or global events on farms through markets (3.2).

Two types of model integration are used in the WP5, depending on the objectives of the framework and the types of models. The first one, the bottom-up approach, serves in the MINDSTEP toolbox to inform the large-scale models about farm-level responses to relevant policy measures through IDM models and ABMs developed in WP3 and WP4, respectively, (section 3.1). The bottom-up linkage can take multiple forms, from integration of the parameters directly estimated by the IDM/ABM models into the large-scale models, through manual refinement of the model parameters based on evidence from case study analysis, to alignment of the model behaviour through indirectly related parameters. The second type of model integration, top-down, enables farm-level models to simulate future projected farm level behaviour dependent on global shocks (section 3.2). This approach is used when linking the large-scale models, GLOBIOM, MAGNET, and CAPRI, to FarmDyn or IFM-CAP. The output data will be downscaled to match the resolution of the IDM/ABM models using downscaling modules – DownScale and CAPDIS. Furthermore, the detailed indicators provided by farm and regional level models with a limited geographic or farm type coverage are in this approach complemented by downscaled indicators from the macro-level models, which at a lower level of resolution cover the whole EU and the rest of the world. Detailed data exchange protocols to enable these model linkages are elaborated.

1. INTRODUCTION

Agricultural policies of the European Union (EU) increasingly target multiple objectives related to climate mitigation, environmental sustainability, social justice, nutrition and health, for example referring to objectives of the Paris Agreement on climate and the Sustainability Development Goals (SDGs). MIND STEP core stakeholder group interviews (Coderoni et al. 2020) revealed that the stakeholders have a clear focus on environmental policy objectives. The post-2020 CAP objectives of "preserving biodiversity, ecosystem services and landscapes", "fostering environmental care" and "climate change action", were rated by the stakeholders as the most important ones. The gravity of the environmental issues coherently emerged also from the proposed scenarios, where stakeholders indicated more frequently environmental and low carbon setups, as compared to the elements of social development, e.g. vibrant rural areas and support generational renewal (Coderoni et al. 2020). Simultaneously, food and agricultural systems are shaped by, sometimes global, environmental and socio-economic drivers, such as climate change, urbanization, population and income growth. These drivers and the EU policies can affect farmers directly, but also indirectly through market mediated impacts.

In order to comprehensively inform policymakers and other stakeholders on the multiple impacts of the CAP and other policies related to agriculture, modelling frameworks used for impact assessment also need to be adapted to capture all these various cross-scale, cross-temporal and functional linkages and feedback loops. They need to provide analysis of the trade-offs between economic and environmental objectives, and among environmental objectives. It is particularly important that these tools are flexible, allowing for diversity of policy measures targeted to specific regions of the EU, and considering heterogeneity of farm management systems and farm types.

Integrated modelling frameworks have gained popularity in the broader context of (agricultural) land use and commodity markets (Wolfgang Britz and Hertel 2011; Wolfgang Britz et al. 2021; Ewert et al. 2011; Kozicka et al. 2021; Müller et al. 2020; Schönhart, Schauppenlehner, and Schmid 2011). Integrated Assessment Models (IAMs) that integrate large-scale (partial or general) equilibrium models attempt to incorporate the complexity of the agricultural and food system, and have been applied to policy impact assessment (e.g. Philippidis et al. 2018; Havlík et al. 2011). However, these tools still fail to fully integrate the multi-scale connections, particularly in terms of the heterogeneity of actors. Among the recent attempts to bridge this gap is SUPREMA (Support for Policy Relevant Modelling of Agriculture) project (Gocht et al. 2020) that strengthened existing and established new linkages among some of the existing models that include CAPRI, MAGNET, GLOBIOM and IFM-CAP. However, to support public decision making in agricultural, rural, environmental and climate policies by taking into account the behaviour of individual decision-making units in agriculture and the rural society, these tools need to be further improved, extended with lower-scale (farm, field and landscape level) models and integrated into a flexible and versatile way.

In response to this need, the MIND STEP project develops a modelling toolbox for impact assessment of (regional) policies on various aspects of the farming sector. It takes into account heterogeneity and dynamics of the farming sector in the EU and its member states. MIND STEP modelling toolbox builds on the existing tools and their linkages, as well as develops and integrates new ones. The architecture of the suit of tools aims to invite continuous innovation in modelling as new modelling approaches (with new data sets or new ICT developments) can be tested and easily added to the suit of tools. As a prove of concept, MIND STEP tests different new types of tools - agent-based models (ABMs), econometric estimation, etc., and adds them to the toolbox. Work package (WP) 5 plays a crucial role in developing the toolbox by establishing the linkages between the models across scales: models focusing on the individual farmer, developed in WP 3, and the models focusing on interaction among farmers and within the supply chain, developed in WP4, with the existing market-level EU/Global economic models.

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This report details the MIND STEP modelling toolbox, in particular it describes the tools and their combinations, and conceptualizes their linkages. Focusing on the variable definition, including its spatial and temporal resolution, and farm typology, it describes protocols related to the data exchange across scales. Data exchange goes in both directions: from individual decision-making (IDM) farm level models to ABMs or regional and global models (bottom-up) and from the global and regional models to the IDM farm level models (top-down). Interfaces for exchange of parameters between the models necessary for a consistent assessment are provided. The combinations of the models are conceptualized with the focus on specific policy-relevant impacts.

The deliverable first provides an overview of the MIND STEP model toolbox (Section 2), then dives into the details of its components and linkages established in WP5 (Section 3) - organized along the sub-tasks of task 5.2 and 5.3. Each component description (sub-task modelling framework) is structured along four elements:

1. Description of the work in the sub-task, research questions, policy relevance or applications of the modelling framework
2. Models and data that were used in the sub-task – focusing on the details important for the interface
3. Interfacing models across scales – modelling framework and linkages between the models
4. Discussion, including risks and caveats

The deliverable ends with the discussion and policy applications of the toolbox (Section 4).
Additionally, data exchange protocols are provided in the Supplementary Material.

2. MIND STEP MODEL TOOLBOX

2.1. Model overview

The following models belonging to the **macro-level models** are used in the MINDSTEP modelling suite:

MAGNET (Modular Applied GeNeral Equilibrium Tool) is a general equilibrium model of the global economy that describes the development of prices, production and trade at an individual country level (Woltjer and Kuiper 2014). It covers 141 regions and countries, 113 sectors and 127 commodities. It is used to calculate the effects of changes in the world economy and policy changes, such as international trade barriers. The model allows for quantitative analyses related to the bio-economy and food security.

GLOBIOM (Global Biosphere Management Model) is a global recursive dynamic bottom-up partial equilibrium model integrating the agricultural, bioenergy and forestry sectors (Havlík et al. 2011; 2014). GLOBIOM explicitly covers production of each of the 18 world major crops and incorporates a particularly detailed representation of the global livestock sector. The model covers 53 world regions, including all EU member states. The model was initially developed for impact assessment of climate change mitigation policies in land-based sectors, including biofuels, and nowadays is also increasingly being implemented for agricultural and timber markets foresight, economic impact analyses of climate change and adaptation, and a wide range of sustainable development goals. GLOBIOM uses **EPIC (Environmental Policy Integrated Model)**, large-scale gridded crop modelling frameworks, to assess the main global agricultural systems in response to management interventions such as cropping practices, fertilization and irrigation options, and changing environment, including climate change and soil degradation (Balkovič et al. 2013). Besides, EPIC is used to compare cropland management systems and their effects on environmental indicators like water availability, nitrogen and phosphorous levels in soil, and greenhouse gas emissions.

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CAPRI (Common Agricultural Policy Regionalised Impact) is an economic partial comparative static equilibrium model of the agricultural sector with a focus on Europe (i.e., the disaggregation into 276 NUTS2 regions, detailed activity data and coverage of Common Agricultural policies) embedded in a global market model to represent bilateral trade between 45 trade regions (countries or country aggregates) (Kesting and Witzke 2021). It is used to assess the impacts of agricultural and international trade policies with a focus on the European Union.

Spatial disaggregation of the macro-level models output data is achieved thanks to two **modules**:

CAPDIS (Spatial dis-aggregation module of CAPRI results) (CAPRI Online Manual (update) 2022) provides a successive disaggregation of agricultural information from the NUTS2 regional level to high-resolution spatial units (so-called HSU, homogeneous spatial units), starting with crop shares, yield and irrigation shares, livestock density, nitrogen budgets, and finally environmental indicators. It allows monitoring and ex-ante assessment of environmental impacts of agriculture at a 1×1 km spatial scale.

DownScale (Krisztin 2022) module provides consistent high-resolution land-use change projections based on the GLOBIOM output. The priors of the DownScale module are estimated using an econometric model (when observations are available), which uses observed land-use change patterns and relates them to a set of exogenous and dynamically updated endogenous variables. The latter is updated with each scenario and model output of GLOBIOM, thus allowing for dynamic scenario output. This approach allows for the reproduction of observed land-use change patterns while still taking the dynamic nature of future land-use change into account.

FADN spatial (FARMtogrid) tool is a methodological approach for linking economic and bio-physical data (Bielza Diaz-Caneja 2021). It uses a Constraint Optimization approach based on variables such as altitude zone, less favored areas classification, land use shares, crop yields and others, to estimate probabilities of belonging to a spatial unit with homogenous conditions. It is used to overcome the shortcoming of not knowing the spatial location of individual observations. This allows individual farm models to address spatially relevant topics or carry out EU wide high-resolution modelling in the agricultural sector.

The **individual decision-making models (IDMs)** group includes:

FarmDyn (W Britz et al. 2016) is a dynamic mixed integer bio-economic farm level model. It provides a flexible, modular template to simulate different farming systems (dairy, mother cows, beef fattening, pig fattening, piglet production, arable farming, biogas plants) at a single farm scale. The model allows for simulating, in detail, the changes of farm management and investment decisions under different boundary conditions such as prices and policy instruments. Furthermore, the linkage of biophysical parameters to farm activities allows to assess the impact of environmental policies such as, e.g. the EU Nitrates Directive or emission taxes on a wide range of environmental indicators. In addition, FarmDyn enables the examination of a multitude of farm management and economic indicators such as dynamics in herd size, crop shares and intensity of crop production, as well as their economic and labour-related implications on farm.

IFM-CAP (Kremmydas et al. 2021) is a comparative static positive mathematical programming model applied to each of the 81,107 individual farm from the Farm Accountancy Data Network (FADN) in 2017**.** It can be characterised as a template model that consists of a number of individual farm models. IFM-CAP includes all FADN activities for crops (arable crops, vegetables and permanent crops, fodder and grassland, fallow) and livestock (cattle, pigs, small ruminants, poultry, and other animals). The model allows for assessing a wide range of farm-specific policies while capturing the heterogeneity of EU commercial farms. Its main simulation outputs are land allocation, herd size, livestock density, share of arable land in utilized agricultural area (UAA), share of grassland in UAA, land use change, agricultural production, intermediate input use, CAP first and second pillar subsidies, intermediate

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input costs, variable costs, total costs, gross farm income, and net farm income, as well as biodiversity index and soil erosion. IFM-CAP uses data from FADN, Farm Structure Survey (FSS), CAPRI database and Eurostat.

Agrispace (Wolfgang Britz and Mittenzwei 2017) a Multi-Commodity Market Model based on the Spatial Equilibrium approach, recursive-dynamic, with a yearly resolution regionalized at NUTS III level for Norway, with fixed international prices. It is used to analyse impacts of market and policy changes on the agricultural sector and farm structural change in Norway. Norwegian agricultural policies are characterized by a multitude of farm degressive payments which implies that payment rates differ by farm size. The correct modelling of such policies requires to keep track of farm size and farm structural change throughout the model simulations. This is exactly the virtue of Agrispace.

The **farm-level econometric models** are:

Cost estimation model - an EU-wide farm-level micro-econometric model. This model provides farm-specific estimates of costs per farm activity across different agricultural outputs. The model harmonizes farm-level data and estimates farm-level fertilizer and pesticide costs, labour costs, and other inputs per output category and activity level.

Risk management model - either a new stylized model based on FADN or FarmDyn will be expanded to include risk preference. This model will inform GLOBIOM to translate the revealed risk preference related to the experiment to a crop-specific risk aversion parameter that takes the form of a cost.

Farm exit model - farm exit estimations are carried out to find out the probability of a farm exiting or staying in business. Usually, logistic regression models are employed, and important drivers of the binary decision are the age of the farm holder, the farm type, profits, rental area payments and agricultural support payments, to name a few. The farm exit estimations are done for the German agricultural sector with farm structure survey data. A more thorough explanation will be made in Deliverable 4.2. With the results from D4.2 we want to incorporate farm exit probabilities in the land market module of IFM-CAP to incorporate structural change in terms of farms exiting business.

Structural change model - an econometric structural change model of European farm types. It is of a multinomial logit-type, featuring spatial dependencies. The explained variable are the land-use and production system composition of each NUTS-2 regions, while explanatory variables are GLOBIOM outputs on agricultural prices, previous land-use and cropping allocations, as well as exogeneous (scenario specific) observations on sectoral composition, educational attainment, economic impact, and other biophysical factors.

Crop production choice models - micro-econometric models considering crop yield and chemical input use levels and crop acreages at the farm level. These models mostly describe how farmers' choices respond to input and output prices (in the short-medium run) and, therefore, deliver price elasticities of yield, input use and acreage choices, including the decision to produce the considered crops or not. Importantly, the considered models featuring (random) farm specific parameters for accounting for farmers' and farms' unobserved heterogeneity (*i.e.*, that not controlled by observed variables), the obtained elasticities are (statistically) calibrated at the farm level. These models are designed to fit arable crop farms (crops: major grain crops, sugar beet, potatoes, *etc*) or mixed livestock–crop farms (crops: major grain crops, fodder corn, temporary pastures).

In the group of **Agent Based Models (ABMs)** in the toolbox are**:**

AgriPoliS (Sahrbacher, Sahrbacher, and Balmann 2014; Happe, Kellermann, and Balmann 2006) allows to perform experiments with artificial economic agents interacting in a dynamic and spatially explicit manner, especially focusing on structural change and land markets.

CoESM (Collective Ecosystem Services Management) (Reinhard et al. 2022) models farmers' decision-making towards implementing flower strips at the farm level. Individual farmers must decide whether to invest in the provision of pest regulation services on their farms by converting arable land into flower strips. Farmers display different decision strategies in selecting their land allocation. They rely on recurring habits, imitating peers or role models, making deliberate comparisons, and asking friends or colleagues for advice.

Land market model was developed to model structural change in IFM-CAP (Heckelei et al. 2022). The land market handles competition among farms, but also between agriculture and other uses for land and land-transformation between different land use classes. Regional land market agents allow interactions in-between farms or between farms and other sectors supplying or demanding land. The regional land market agent works within geographical regions within which competition for land takes place.

Finally, an **econometric market-level model** that can be interacted with IDM models to identify impacts at the farm level:

Supply chain mechanism model - a New Industrial Organization (NEIO) structural econometric model which enables to estimate the relationship between the extent of price transmission along agri-food chains and the degree of market power (i.e., conjectural variations) at different stages of the supply chain (i.e., farmers, manufacturers, and retailers). Following the framework originally developed by Sexton and Zhang (2001), this model describes price transmission dynamics along a three-stage supply chain, where farmers supply agricultural raw commodities to food manufacturers, which, in turns, sell food products to the retail sector, that delivers final products to consumers. However, contrary to previous works on price transmission mechanisms in agri-food markets, the current model formulation allows for the presence of bargaining power also at the farm level, which may derive from the use of contractual agreements and/or the participation in producers' organization. The estimated market power parameters can then be used in large market models in order to carry out counterfactual simulations to predict changes in price transmission dynamics under different market conduct scenarios.

2.2. Outline of the toolbox and model linkages

Models in the MINDSTEP model toolbox can be classified as operating on three organizational levels: considering a single-farm level, on the multitude of farms – taking account their interactions, or on a macro-scale level – considering impacts mediated through markets (Figure 1). Exogenous drivers considered encompass various global trends and shocks, for example related to climate change, as well as policy measures and technological innovations. The outcomes captured by the toolbox extend over different scales, from local to global, and include a wide range of sustainability indicators, from environmental to socio-economic. The macro-level models provide outputs on the county or NUTS2 level with European-wide or even global coverage. The lower-level models have much more detailed outcomes, with fine spatial resolution (grid level – 10x10 km), however they have usually limited geographic or farm type coverage, e.g., covering a selected sub-national region.

Downscaling models, DownScale and CAPDIS, bridge the two scales by mapping the output data from the macro-level models to the resolution of the IDM/ABM models. The downscaling is used in two types of top-down linkages. First, the results provide input parameters, "drivers", representing market mediated effects of the EU policies or global events, for the IDM models. This enables farm-level models to simulate future projected farm level behaviour dependent on global shocks. Second, the downscaled output complements the thematic and geographic coverage of the IDM models for a comprehensive cross-scale assessment across different sustainability dimensions. These linkages are developed in WP5, Task3.

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Another important component that completes the micro- to macro- level tracing of the impacts in the MIND STEP model toolbox, developed in WP5 Task2, is bottom-up linkages between ABMs, IDM, and econometric models, with the macro-level models. Results of the lower-scale models are used either directly in the large-scale models, or indirectly, to estimate the behavioural parameters, such as yield and acreage elasticities for the macro-level models, or for the alignment of the model behaviour through indirectly related parameters.

These linkages are conceptualized with the focus on specific policy-relevant outcomes. GLOBIOM model is linked to a battery of econometric models to improve inputs use, land-use change and risk aversion analysis. Specifically, cost estimation model, improves behavioural parameters for choice of agricultural output and input levels and their substitution. Structural change model and production functions significantly improve GLOBIOM's dynamics of land-use, land-use change and structural change representation in Europe. Finally, risk management model adds to GLOBIOM representation of risk aversion which enables assessment of impacts of the adoption of a crop-specific insurance on land allocation and markets. FarmDyn improves representation of mitigation technologies in GLOBIOM and MAGNET. Farm exit model and Land market model are linked to IFM CAP, and AGRISPACE to CAPRI, to capture structural change through land market and farm exit.

The details of these linkages are discussed in Section 3 of this report. Furthermore, linkages between IDM models to ABMs, developed in WP4, improve the representation of individual decision making in ABM models. They are not detailed in the current report, as they are reported elsewhere (Heckelei et al. 2022). However, they are part of the Toolbox and are represented in Figure 1. Specifically, FarmDyn is linked to the ABM AgriPolis. This linkage allows to capture the interactions between the farms and hence conclude about the economic and environmental outcomes of the policy interventions at landscape and regional scales. The ABM model CoESM has been developed to facilitate the implementation of behavior factors in decision-making. Based on the Consumat model, the model allows to “close the loop” by feed forwarding aggregated population behavior of farmers towards the decisional context of individual agents at the next moment in time. To gather all the necessary data to run the model, e.g. gross margins resulting from different assumptions regarding how the farm decides to allocate his inputs (optimization with or without additional restrictions) the inputs from FARMDYN are used. Task supply chain mechanism model (an econometric model developed in task 4.4) uses conjectural elasticities that capture market power along the supply chain and specifically (and for the first time) the power of farmers arising from contractual agreements or the formation of producer organizations. The conjectural elasticities are incorporated in the MAGNET model for a more realistic representation of price transmission along the supply chain.

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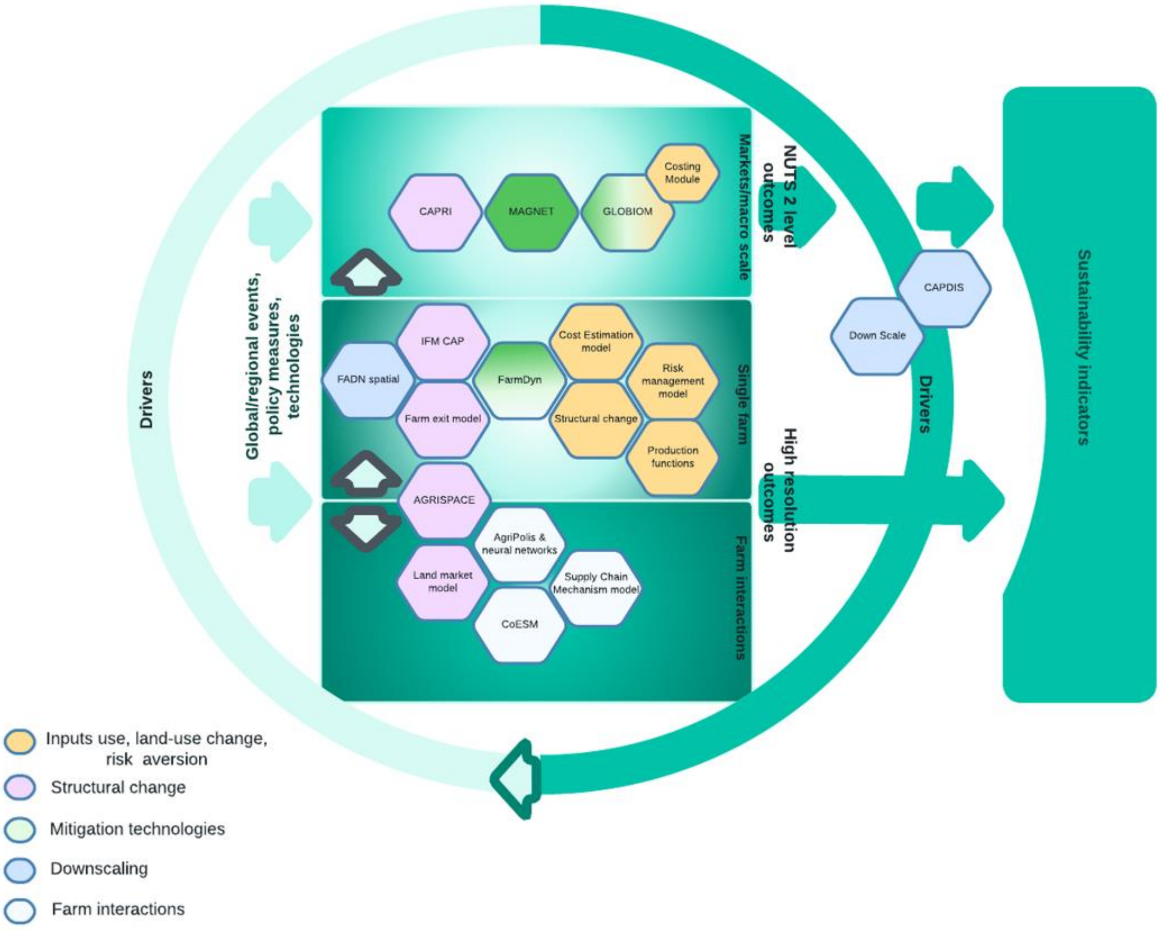

Figure 1 MIND STEP model toolbox: Integration of IDM models, ABMs and large-scale models

2.3. Data exchange protocols

Data exchange protocols for the sub-tasks of task 5.2 (bottom-up linkages) were developed following Table1. The exchanged data is described at its source (the original data with the spatial and temporal details), how it is transformed, and where it is used, together with the spatial and temporal details at its destination. The resulting detailed data exchange protocols are provided in Appendix 2.

Table 1 Data exchange protocol template for bottom-up linkages (subtasks of task 5.2)

	Source							Destination					
sub-task number	Description	Data	Spatial scale	Temporal scale	Spatial coverage	Temporal coverage	Transformation needed	Description	Data	Spatial scale	Temporal scale	Spatial coverage	Temporal coverage

Down-scaling work in task 5.3 was facilitated by building on the AgMIP/**SUPREMA model output protocol.** The SUPREMA tables detailing outputs from the large-scale models in the MINDSTEP toolbox were shared with the modelling teams working with IDMs. The details contained lists of variables, their description, units, regional coverage: country-level, NUTS-2, grid (10x10 km) (directly resulting

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from the model, and with the possibilities of further downscaling). Furthermore, the teams were asked to formulate data requests exceeding the indicated outputs, e.g., higher resolution or more disaggregated commodity groups, which resulted in an enhanced reporting protocol, particularly increasing the spatial resolution of selected parameters.

3. INTERFACING MODELS IN THE MIND STEP TOOLBOX

3.1. Upscaling IDMs and ABMs to EU/Global agricultural sector models

3.1.1. Harmonization of production system, sector and farm type typology used within the MIND STEP model toolbox (sT5.2.1)

Description and research questions, policy relevance or applications

Several policies and technologies analysed within the MIND STEP project require a differentiation of crop and livestock production systems. Prominent examples are measures that target nutrient and carbon fluxes and the reduction of emissions from agriculture. Conceivable measures are, for instance, investments in fertilizer application and management systems, spreading of animal manure, or changes of animal rations. Such measures are usually specific to certain production systems and model-based analysis depends on their adequate representation in the models. A paramount feature of the MIND STEP project is that the impact of policy and technology measures is analysed at farm- as well as regional and sectoral levels. In the example of emission reduction, it is important to understand how new technologies will be adopted at the farm level and which policy programmes farmers are willing to participate. In addition, the aggregate impacts of widespread adoption and participation are relevant to understand the efficiency of a policy at the sector level.

The large-scale models MAGNET and GLOBIOM already operate at varying degrees of spatial resolution and differentiate alternative production systems for crops and livestock. In order to facilitate the interfacing with IDM models developed in WP3, the representation of production systems in commonly used databases, like the farm accountancy data network (FADN), will be explored with regard to their usability in simulation models across geographical and organizational scales. This includes the identification of the potential to further disaggregate the **representation of production systems in MAGNET and GLOBIOM using the FADN database** and **the harmonization of definitions for the existing classifications**. In the case of the MAGNET model, this includes the split of standing animal herds from the overall capital stock to ensure an improved linkage to IDM models, explicitly including the substitution between variable inputs like feeds, labour, capital and land at the sector level. Furthermore, our work will provide a novel (an updated parameterization of the production systems) bottom-up agricultural costing module for GLOBIOM that accounts for a range of cost components, e.g., fertilizer, seed, and feed costs. It will substantially improve the management system representation in GLOBIOM. The costing module will allow the GLOBIOM model to represent better future developments in input prices and costs of specific components, such as fertilizers or labour markets. This will provide insights into the land-use effects of energy or labour market spill overs (**future input use scenarios**).

Models and data

The Farm Accounting Data Network (FADN) database is the primary source of farm-level data used in the subtask. The FADN is the only source of microeconomic data and monitors farms' income and business activities based on harmonized bookkeeping principles. It is based on national surveys and only covers the European Union (EU) agricultural holdings that can be considered commercial due to their size. The methodology applied with the FADN framework aims to provide representative data according to region, economic size, and type of farming.

Although the FSS is carried out by all (EU) Member States and conducted consistently throughout the EU with a common methodology and provides comparable and representative statistics across countries and time, at regional levels (down to NUTS 3[1] level), access to the data is restricted and limited. Therefore, Eurostat will enhance the FADN data to acquire socio-economic data on employment, income, and human capital attainment at a regional (NUTS-2 and NUTS-3) level.

Moreover, the FADN database does not report costs per activity and production process but by the farm. That is, costs are reported as totals across multiple products. Therefore, in order to build a costing database that can inform the macro-level agricultural models, particularly the GLOBIOM model, these aggregate costs need to i) be **harmonized** with GLOBIOM specific definitions and ii) be allocated to individual activities using an **econometric model**. The harmonization of crop production systems in GLOBIOM, MAGNET and IDM models requires an understanding of the classification used in the underlying databases, namely the linkages between FADN classifications and those used in the GTAP (Global Trade Analysis Project) database, which is the dominant data source for MAGNET. An advantage is that both FADN and GTAP follow certain conventions regarding the representation of production systems, which facilitates their harmonization. As an example, a correspondence between crop classifications in FADN, GTAP, and GLOBIOM is shown in ***Table 2***. In most cases, the crop classifications in FADN can be combined into one group within GTAP (many-to-one linkage) or directly mapped to the GLOBIOM classification (one-to-one). This greatly facilitates the aggregation of farm-level data to sector level the comparison of results of IDM models and GTAP/MAGNET.

Table 2 Crop production systems

GTAP Name	GTAP Code	CPC Code	CPC Name	GLOBIOM Name	FADN Common name	FADN Code	FADN Description
Paddy rice	pdr	113	Rice	rice	CRICE	10170	Rice
Wheat	wht	111	Wheat	soft wheat	CWHTC	10110	Common wheat and spelt
				durum wheat	CWHTD	10120	Durum wheat
Cereal grains nec	gro	112	Maize (corn)		CMZ	10160	Grain maize
		114	Sorghum		CCEROTH	10190	Other cereals for the production of grain
		115	Barley	barley	CBRL	10140	Barley
		116	Rye	rye	CRYE	10130	Rye
		117	Oats	oats	COAT	10150	Oats

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[1] Nomenclature of territorial units for statistics (NUTS) classification is a hierarchical system for dividing up the economic territory of the EU and the UK. It lists 92 regions at NUTS 1 (major socio-economic regions), 242 regions at NUTS 2 (basic regions for the application of regional policies) and 1166 regions at NUTS 3 (small regions for specific diagnoses) level.

		118	Millets		CCEROTH	10190	Other cereals for the production of grain
		119	Other cereals		CCEROTH	10190	Other cereals for the production of grain
Vegetables, fruit, nuts	v_f	12	Vegetables				
		13	Fruit and nuts				
		15	Edible roots and tubers with high starch or inulin content	potato	CPOT	10300	Potatoes (incl. early and seed)
		17	Pulses (dried leguminous vegetables)	peas	CPEA	10210	Peas, field beans and sweet lupines
Oil seeds	osd	14	Oil seeds and oleaginous fruit	soybeans	CSOYA	10606	Soya
				sunflower	CSNFL	10605	Sunflower
				rapeseed	CRAPE	10604	Rape and turnip rape
				cotton	CCOTN	10603	Cotton
Sugar cane, sugar beet	c_b	18	Sugar crops	sugar beet	CSUGBT		
Plant-based fibers	pfb	192	Fiber crops	flax	CFLAX	10609	Flax
Crops nec	ocr	16	Stimulant, spice and aromatic crops				
		191	Forage products	corn silage	CFODMZ	10921	Green maize
				other green fodder	CFODOTH	10923	Other plants harvested green not mentioned elsewhere
		193	Plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes				
		194	Beet seeds (excluding sugar beet seeds) and seeds of forage plants				
		195	Natural rubber in primary forms or in plates, sheets or strip				
		196	Living plants; cut flowers and flower buds; flower seeds				
		197	Unmanufactured tobacco		CTOBAC	10601	Tobacco
		199	Other raw vegetable materials nec				

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Splitting animal herds from capital stock in MAGNET is, in principle, possible using the FADN database. A crucial step is to derive the share of animal herds in total farm assets at national level, such that the types of considered animal herds are consistent with the definition of animal production activities in MAGNET. This is possible by following either the production systems (e.g., milk production) or the farming systems (farm specialized on milk production). The most important difference between these two approaches arises from the inclusion of non-specialized farms in the aggregation, which can create biased results regarding the importance of the standing herd in farm assets at aggregated levels. The current animal activities in MAGNET are shown in ***Table 3***. With the distinction of beef cattle and poultry, the MAGNET database is more detailed than GTAP. While this is still more aggregate than the corresponding FADN groupings, challenges may arise from the farm typology used in FADN, which groups pigs and poultry into a “granivores” group (***Table 4***). The most appropriate way to split animal herds in MAGNET is the topic of ongoing research.

Table 3 Animal production in GTAP and MAGNET

GTAP Name	GTAP Code	MAGNET code	CPC Code	CPC Name
Bovine cattle, sheep and goats, horses	CTL	BFCTL	211	Bovine animals, live
		CTL	212	Other ruminants
		CTL	213	Horses and other equines
		CTL	2411	Bovine semen
Animal products nec	OAP	OAP	214	Swine / pigs
		POULTRY	215	Poultry
		OAP	219	Other live animals
		POULTRY	23	Eggs of hens or other birds in shell, fresh
		OAP	2419	Semen, n.e.c
		OAP	291	Natural honey
		OAP	292	Snails, fresh, chilled, frozen, dried, salted or in brine, except
		OAP	293	Edible products of animal origin n.e.c.
		OAP	295	Hides, skins and furskins, raw
		OAP	296	Insect waxes and spermaceti, whether or not refined or colo
Raw milk	RMK	RMK	22	Raw milk

Table 4 GTAP animal sectors and FADN farming systems

GTAP Name	GTAP Code	MAGNET Code	FADN TF14 Code	FADN TF14 Name
Raw milk	RMK	RMK	45	Specialist milk
Bovine cattle, sheep and goats, horses	CTL	CTL	48	Specialist sheep and goats
		BFCTL	49	Specialist cattle
Animal products nec	OAP		50	Specialist granivores
			60	Mixed crops
			70	Mixed livestock
			80	Mixed crops and livestock

We **harmonize the production (management) systems** in GLOBIOM across different farm types (i.e., livestock, crop production and mixed farming systems). Crop production systems defined in GLOBIOM are based on the Spatial Production Allocation Model (SPAM) methodology. Here, the production system captures and delineates crop production by water supply conditions and input-use intensity and management. Therefore, crop production is classified into four systems: i) irrigated–high input, ii) rainfed–high input, iii) rainfed–low input, and iv) rainfed–subsistence production (You and Wood 2006; Wood-Sichra, Joglekar, and You 2016). Irrigated–high input systems capture crop production equipped for either full or partial irrigation and use improved inputs such as modern seed varieties, chemical fertilizer and advanced management such as soil/water conservation measures. The rainfed–high input systems reflect rainfed crop production that uses high-yield varieties, optimal fertiliser application, chemical pest, disease and weed controls, and full mechanization. The rainfed–low input systems use traditional seed varieties, mainly manual labour without (or with little) application of nutrients or chemicals for pest and disease control. Finally, the rainfed–subsistence captures production by small-scale farmers mainly for their own consumption under rainfed conditions with low inputs, regardless of the suitability conditions of the land. Given that FADN focuses on commercial farms, our classification excludes subsistent farms. We use **cluster analysis** to categorize sampled EU farms in the FADN according to input-use intensity, expenditures, and farm management practices.

Based on this, we allocate aggregate farm-level costs to different major crops produced using an **EU-wide farm-level micro-econometric model.** This model provides estimates of costing components per activity level and output types. In addition, this model harmonizes farm-level data and estimates farm-level fertilizer and pesticide costs, labour costs, and other inputs per output category and activity level.

The **bottom-up costing module** uses the estimated activity- and output-specific cost components and bio-physical data from the micro-econometric farm-level model. These estimated cost components jointly amount to bottom-up agricultural production costs for a range of major crops and farm production systems. In the costing module, the estimated costs can be extrapolated to cover regions with limited availability of cost data to provide GLOBIOM with a comprehensive source of detailed cost data. During the calibration phase of GLOBIOM, unobserved costs and subsidies are estimated and added to costs already observed by the model to adjust the cost structure of the model. This allows the replication of historical data from perfectly competitive equilibria in agricultural markets in the calibration period. The costing module will reduce unobserved costs via extending the share of observed costs. The bottom-up foundation of cost data will enable shocks to individual cost components (e.g., energy costs) in GLOBIOM simulations.

Interfacing models across scales

In general, activities in this sub-task focus on the harmonization of production systems across model scales and the efficient usage of farm-level data to improve the database of more aggregate models like GLOBIOM and GTAP. These linkages are presented in Figure 2.

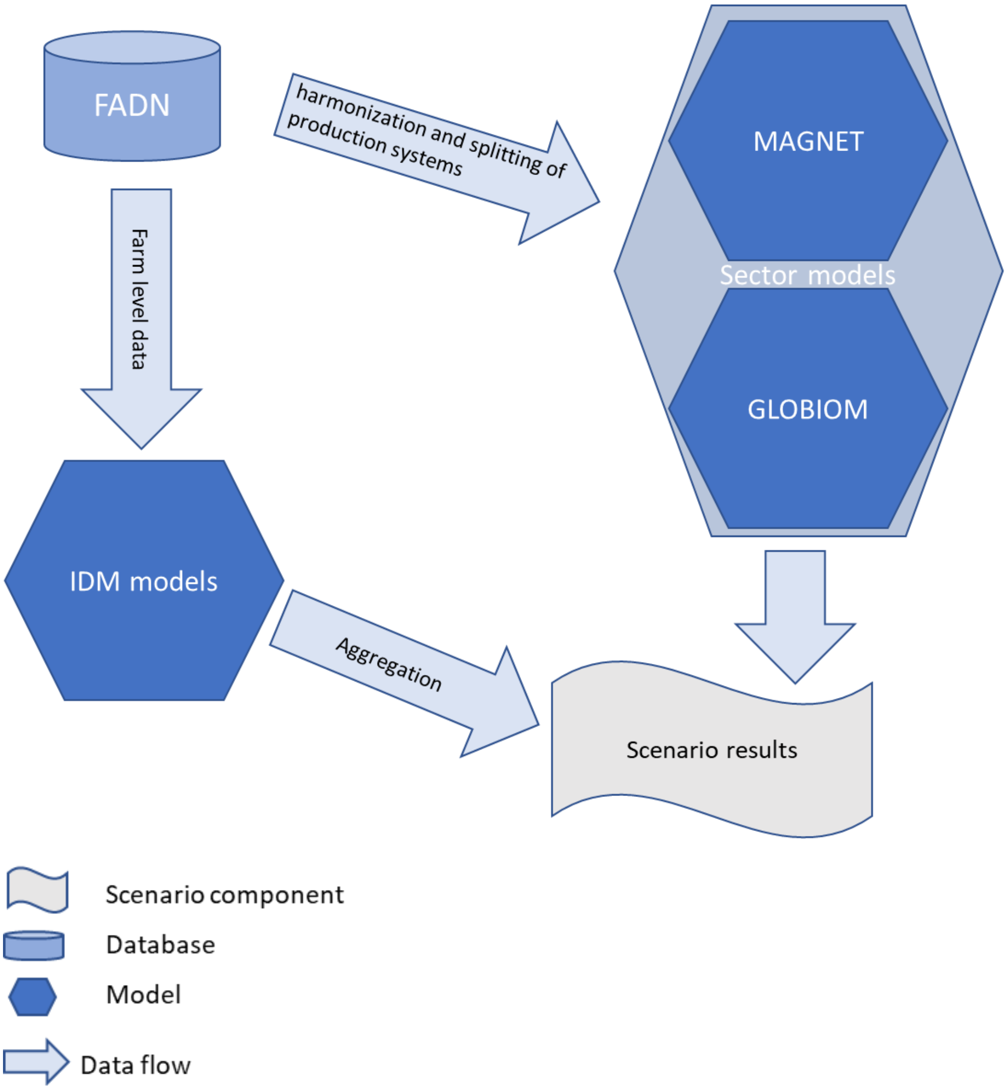

Figure 2 Schematic presentation of the modelling framework for harmonization of production systems

On the inputs side, FADN data sources are used, as well as other subnational NUTS2 level data collected from European publicly accessible data sources (e.g., EUROSTAT). For this purpose, we will rely on the interfaces developed earlier (WP2) to access those data sources and collate the data. The data will be analysed with the econometric farm-level model to quantify production costs and subsequently inform the data on the GLOBIOM base year production systems.

In GLOBIOM, different production systems are categorized according to the input-use intensity and management. Therefore, linking empirical work from other farm-based or simulation models will still require that the information obtained from the farm-level analysis can be interpreted in terms of GLOBIOM estimations and analysis. Hence, we harmonize the production and farm structure data from FADN to reflect production systems in GLOBIOM. The harmonization introduces a link to GLOBIOM through an improved representation of costs and the supply side of GLOBIOM. In addition,

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other agroecological production classifications (i.e., organic, conventional etc.) can be further introduced, thus improving the production assumptions of farmer's behaviour.

Furthermore, the results will serve to validate GLOBIOM's production system classification data at the NUTS-2 level, which is based initially on the Environmental Policy Integrated Model (EPIC)[2] and the Spatial Production Allocation Model (SPAM) database. Finally, the results will be used in subtask 5.2.2 to explore the structural dynamics of regional and national input costs. These linkages are presented in Figure 3.

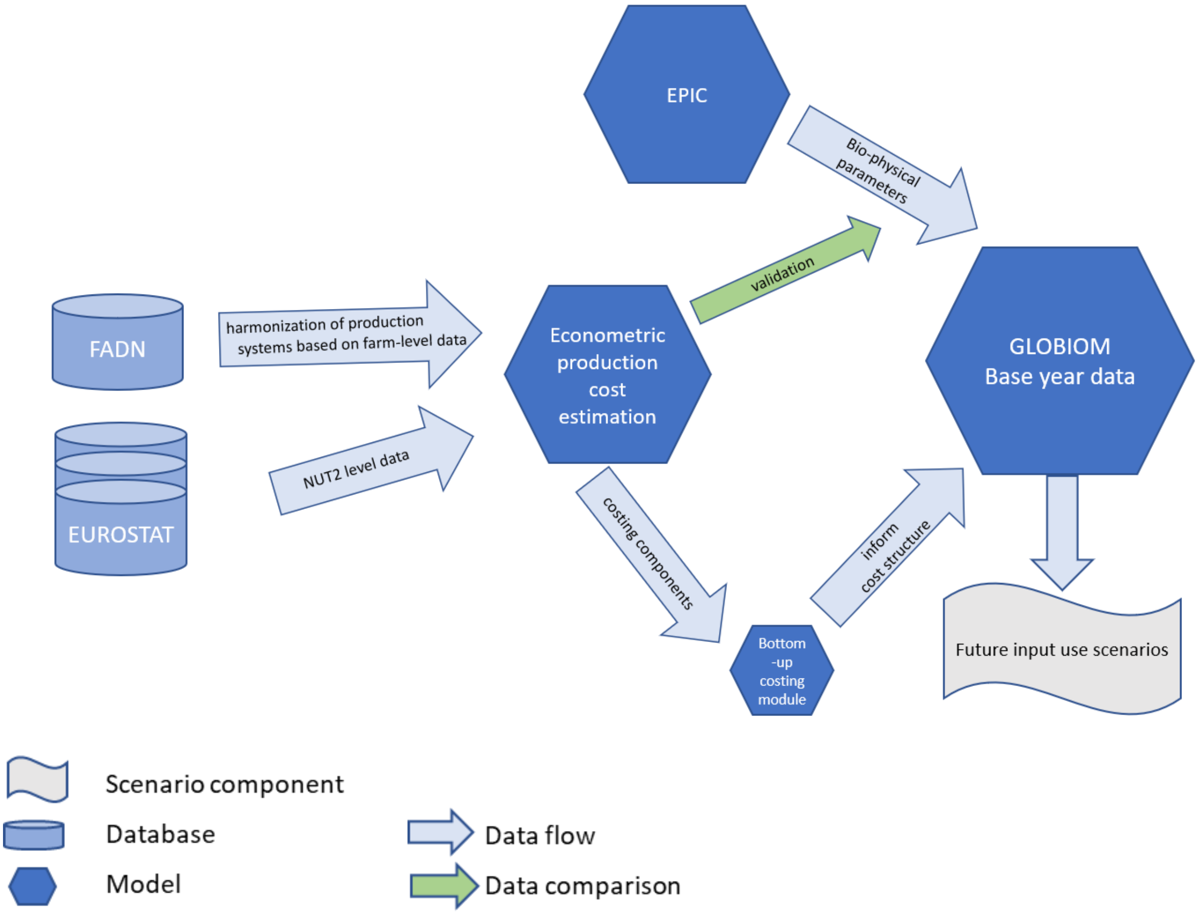

Figure 3 Schematic presentation of the modelling framework for harmonization and costing module in GLOBIOM

Discussion

While the harmonization of crop and animal production system between FADN, GLOBIOM, and MAGNET is in general feasible, it must be noted that the disaggregation of e.g., the representation of animal production and the relevance of standing herds as part of the total capital stock requires a further analysis of the most appropriate method, i.e., following either a production- or farming-systems approach. In any case, the discussion above has only addressed the harmonization of the representation of the agricultural sector in a base year or scenario. The simulations regarding the introduction of policies or the adoption of new technologies may result in a wide range of model

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[2] EPIC simulates agricultural activities and their interactions within ecosystems.

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results originating from the model coverage, like purely supply oriented in the case of IDM models or market-equilibrium-oriented in the cases of GLOBIOM and MAGNET. Combining the results of modes across these scales will remain a research topic for the MIND STEP project.

Furthermore, the analysis is heavily reliant on statistical estimates of historical data, both for the cost estimates (for extrapolation of trends and inference on drivers), as well as for the estimates of elasticities. For this purpose, a careful review of explanatory variables will be undertaken.

3.1.2. Improved behavioural parameters for choice of agricultural output and input levels and their substitution (sT5.2.2)

Description and research questions, policy relevance or applications

Our work will significantly improve GLOBIOM's dynamics of land-use, land-use change and structural change representation in Europe. Currently GLOBIOM captures land-use in cropland across 17 different crop types under four production systems (irrigated, high-input, low-input, and subsistence farming). The model does not endogenously track farm size or other characteristics of the farm landscape explicitly. The dynamics between these land-uses are regulated by the cost-efficiency of production systems, marginally raising costs of land-conversion and water availability. Moreover, the maximum area of land allowed to convert in each time step between uses is regulated by inertia coefficients. These parameters regulate, jointly with spatially explicit yield and cost data, the dynamics of GLOBIOM's production system. Note that elasticities can be calculated, but they are provided implicitly through the aggregate regional costs, inertia coefficients, as well as gridded production costs and yields.

The update of GLOBIOM's dynamics will be achieved through two distinct components: (1) an econometric modelling for estimating the expansion inertia coefficients (maximum land-use change parameters) per NUTS-2 region, based on socio-economic and farm-composition specific explanatory variables. Projections from this model will be used to dynamically update the maximum expansion boundaries of GLOBIOM, based on exogeneous assumptions of farm-level dynamics. (2) Farm-level estimates of production system input elasticities, as well as crop-specific and cross-crop area elasticities to price changes, will be used to validate GLOBIOM’s response and ensure that it produces realistic elasticity bounds. Together with a consistent linkage to various IDM and ABM models, and a bottom-up costing module, these elasticities will be used to verify GLOBIOM's land-use change dynamics.

The updated dynamics will substantially improve GLOBIOM's representation of land-use change dynamics in Europe. Particularly the explicit inclusion of (exogeneous) structural change and farm structure in the elasticities of the model can be used to explicitly represent European farm-oriented policies and analyse their wider consequences.

Models and data

The three main databases used in the subtasks are **FADN, FSS, and Eurostat**. Based on these databases a consistent NUTS2 level panel dataset will be developed, containing information about the structural composition of farms, their average income, education levels, production systems, agricultural subsidies, as well as age and farm size characteristics.

An econometric structural change model of European farm types will be estimated. It will be harmonized with **GLOBIOM** dataset and the harmonized GLOBIOM farm classifications and typologies developed during this project. The model will be of a multinomial logit-type, featuring spatial dependencies. The unit of observations will be NUTS-2 regions, as this is the lowest resolution available from the FADN data. The explained variable are the land-use and production system

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composition of each NUTS-2 regions, while explanatory variables will be GLOBIOM outputs on agricultural prices, previous land-use and cropping allocations, as well as exogeneous (scenario specific) observations on sectoral composition, educational attainment, economic impact, and other biophysical factors. The model will allow for a representation of structural change within the GLOBIOM projection framework, through informing the inertia coefficients through upper quantile bounds of projections.

A second strain of work focuses on estimating econometric production functions to obtain the elasticities of production systems to input factors, such as labour, fertilizers, pesticides, or agricultural prices.

Interfacing models across scales

FADN and regional-scale FSS data, as well as other subnational NUTS2 level data collected from European publicly accessible data sources (e.g., EUROSTAT) will be used to estimate econometric models of structural change and production. These two models will be estimated using GLOBIOM specific production systems and will provide parameter estimates for the GLOBIOM model. The estimates will be maximum land-use change parameters, which regulate per NUTS2 the rate of conversion between crops and cropping systems within a time step. Projection of the econometric models will provide highest posterior density bounds for these parameters. This will allow – based on endogenous agricultural prices and land-use projections, but also on exogeneous projections of socio-economic developments and farm sites, faster or slower rates of transformation in the GLOBIOM model.

The econometric estimates of elasticities will be used compared to GLOBIOM dynamics and this verify their behaviour and provide potential benchmarks. Specifically, the elasticities to production or exogeneous input price shocks will be simulated within the GLOBIOM framework, using either exogeneous prices or scenario projections. The resulting 1% shocks will be used to calculate (average) elasticities, which can be compared to the econometric estimates.

Furthermore, in GLOBIOM simulations, bottom-up cost components and improved yield parameters from 5.2.1 will offer adjusted spatial dynamics due to regionally heterogeneous developments in these components and ensuing cost effects.

In addition, extrapolations of these revised cost structures and yield parameters into regions without certain farm activities in the base period will allow the introduction of these novel activities beyond their initial occurrence.

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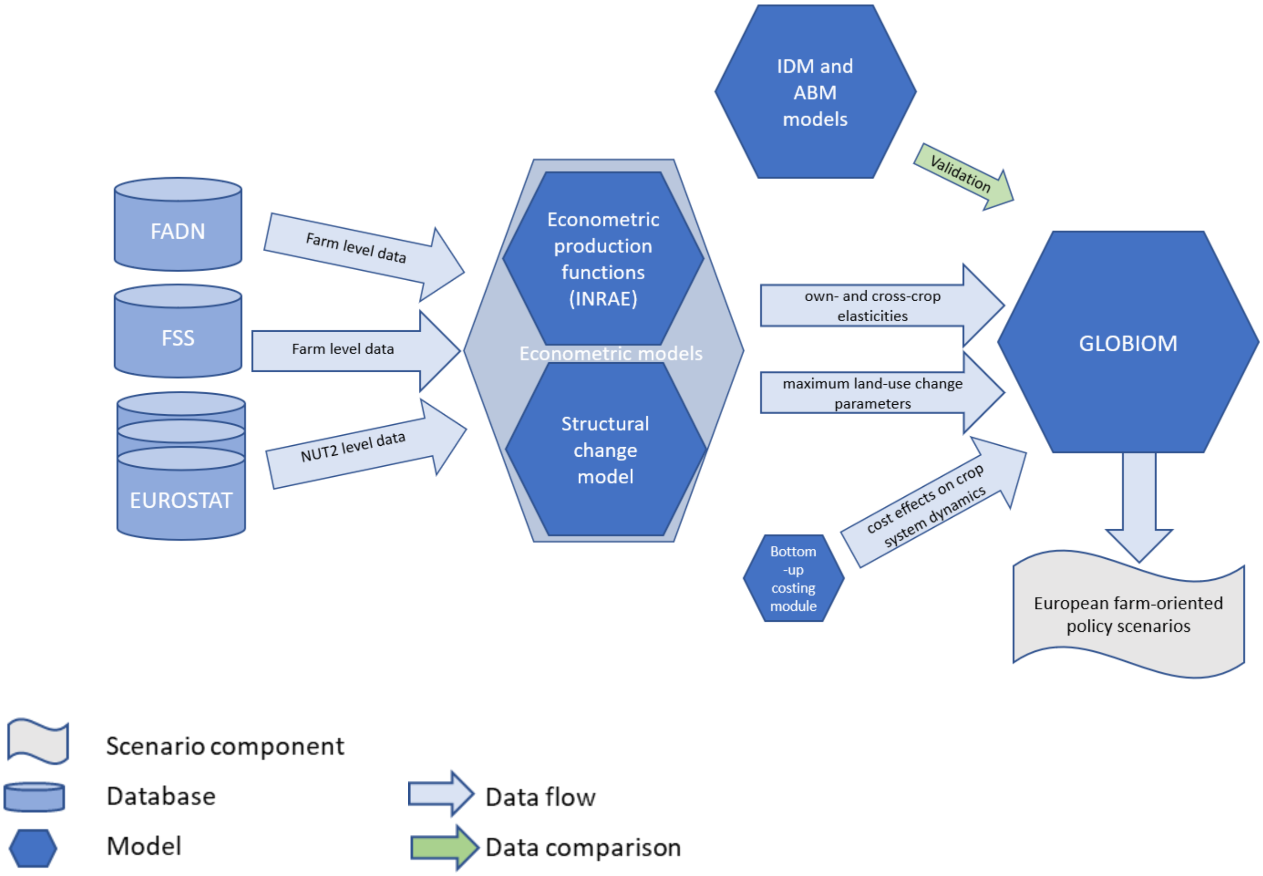

Figure 4 Schematic presentation of the modelling framework to improve behavioural parameters for choice of agricultural output and input levels and their substitution

Discussion

The analysis is heavily reliant on statistical estimates of historical data, both for the cost estimates (for extrapolation of trends and inference on drivers), as well as for the estimates of elasticities. Therefore, special care must be taken that the model dynamics will be also relevant in future projections. For this purpose, a careful review of explanatory variables will be undertaken.

Additionally, GLOBIOM's updated inter-temporal land-use change dynamics will have to carefully examined. This will be done in a consistent set of socio-economic and climate change scenarios. The results will be contrasted with stylized agricultural economic facts, and IDM/ABM model dynamics.

The analysis carried out in this sub-task will concern only a few selected supply chains in Germany and Italy. Results obtained in the selected supply chains cannot be automatically extended to other products and regions. This actually means that although conceptually feasible, the upscaling to CAPRI and/or MAGNET would not be very promising. A method could be developed which could serve as a proof of concept for future research. However, the order of magnitude of the impacts related to the presence of contracts/producer organizations coming from the estimated supply chain model are already relevant for policy makers, at least as a first approximation

3.1.3. Structural change representation in current models (sT5.2.3)

Description and research questions, policy relevance or applications

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Although structural change in agriculture is a subject discussed relatively often, we have not found an explicit definition of the term. In the agriculture context, Reimund et al. (1981) defines it as: *„a significant change in the ownership, control, and organizational characteristics of resources used in the production of a commodity or within a subsector".* We will follow the above definitions' approach. *Structural change* in agriculture is a notion that applies to the whole sector or subsectors and is about the changes in one or more of the following distributions (further elaborated in Chavas, 2001):

1. Farm size (and economies of scale)
2. Specialization (many outputs or one)
3. Technology and farm organization

Several authors highlight the relevance of incorporating structural change into policy evaluation models. Reidsma et al. (2015) says that structural change will influence impacts and adaptation of the sector and thus excluding it will possibly overestimate the effects of climate change. Espinosa et al. (2016) says that information about farm structural change is of great interest for policy makers and stakeholders and provides the basis for policy analysis. More specifically, she highlights that the new CAP design interacts with investment decisions and enter/leave decisions CAP. Zimmermann et al. (2009) also support that within the integrated impact assessment context, structural change is necessary to be included. It may significantly improve the validity of the social, economic and environmental indicators.

In a static comparative context, policy evaluation models estimate the impact of a policy change as follows: (i) The model is shocked with the policy change, ceteris paribus (i.e. all other model assumptions being equal) (ii) the results of the model are the projections of the policy shock into a medium to long term horizon (iii) the result of the policy is the difference between the projection of the policy change and the projection of a baseline situation. The implicit assumption is that the policy change does not interact with the other model assumptions. However, as explained above, this is not the case for structural change and the new CAP.

There are two different ways to incorporate structural change into current policy evaluation models. The first approach is an exogenous one, where structural change is exogenously inserted into the model. A potential application of this kind could be the following. The model is shocked with the policy change. However, it is also shocked with the projected structural change, that has been pre-calculated outside of the model. Thus, the differential between the shock and the baseline will now include the potential effects of structural change. The second approach is an endogenous one, where structural change elements are incorporated in the model's logic. An example application could be the following. The policy model is augmented with a land market and an exit module. The model now outputs not only the changes in income, but also changes to farm exit rates and land sizes. Running the model for the baseline and the policy shock will produce results that contain the structural change core elements of the number of farms and of the distribution of farm size. Thus, the differential between the baseline and the policy shock will have endogenously included the interaction between policy change and structural change.

Models and data

IFM-CAP: The model uses data derived either directly from the FADN database, or through estimation using FADN and other variables. The observed crop and animal activity levels, subsidies and activity costs refer to the model's *base year* (currently 2017), while time series data (2012–2016) are used to calculate expected yields and prices. Procedures were also carried out to identify and correct out-of-range values and outliers and handle missing values.

The structural change in IFM-CAP will be modeled using a ***land market* module**.

We make the following assumptions:

1) Agricultural land is not fixed, instead agriculture competes with other activities uses such as forestry for land. Those other activities are external to the farm models of IFM-CAP.
2) Competition for agricultural land primarily takes place among individual farms that are operating in the same geographical region.
3) Decisions on conversion of land between arable and grassland and farm's decision to trade land are simultaneously modelled by a representative land agent interacting with the farms in a geographical region.

From the assumptions above, we derive a system with two main components: one regional land market model and the already existing set of single farm models. The two components are iteratively linked.

Regional land market agents allow interactions in-between farms or between farms and other sectors supplying or demanding land. Technically, those markets do not require detailed information about farm-specific technology, and can therefore be modelled separately from the single farm optimization models. Modelling land markets separately is appealing from a code modularization point of view. If land markets are not activated, the system still functions in the same way as before with land endowments in the individual farm models fixed. Furthermore, modular land markets allow for future methodological extensions of those markets without interfering with the farm models.

The regional land market agent works within geographical regions that we call cells. A cell is an area within which competition for land takes place. For the present project, we assume that land within each cell is homogeneous, and that all farms in a cell compete with all other farms in the same cell, but not with any farms in neighbouring cells. The land market agent treats arable land and grassland as different goods with their own prices, but allows for (costly) transformation into each other and between agricultural and non-agricultural land. The actual spatial resolution of the cells may be currently aligned with available information on the farm's location in administrative regions (NUTS2 or NUTS3), but can be adjusted later to newly available, more detailed information on farm locations.

Each single farm model (i.e. FADN data record) represents several farms from the full farm population, as indicated by the farm weight. This implies that the single farms represented by one IFM-CAP farm model are spatially dispersed. For the present project, we assume for simplicity that they are all entirely contained within one cell.

The single farm models do not transform land between arable land and grassland, but rather technically interact with the land market agent transforming the land subject to a transformation cost. The transformation cost is based on the biophysical characteristics of the land as defined by the cells. Since the land market model within each cell is not spatial, it does not specify which particular hectares of a cell are used for grassland or arable land. However, there is spatial information available on potential yields of grass or (say) cereals. Furthermore, it is reasonable to assume that grass is growing on land that is relatively more suitable to grass considering the opportunity cost of arable crops. This assumption together with land qualities considered to be evenly distributed across the farms in the cell allows to approximate the land transformation costs of the farm models.

Farm exit module: Farm exit estimations are carried out to find out the probability of a farm exiting or staying in business. Usually, logistic regression models are employed and important drivers of the binary decision are the age of the farm holder, the farm type, profits, rental area payments and agricultural support payments, to name a few. The farm exit estimations are done for the German agricultural sector with farm structure survey data. A more thorough explanation will be made in Deliverable 4.2. With the results from D4.2 we want to incorporate farm exit probabilities in the land market module of IFM-CAP to incorporate structural change in terms of farms exiting business.

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Agrispace: A series of structured simulations will be conducted in Agrispace varying the degree of payment degressivity. The results will be used to inform **CAPRI**

Interfacing models across scales

The interfacing of the three models (IFM-CAP, land market and exit module) can be described in the following sequence (Figure 5):

1. (IFM-CAP) Individual farmers supply and demand of land at given output prices needs to be estimated (netput function).

2. (Land market module) Land transformation agent converting non-agricultural, arable and grass lands

3. (Farm exit module) With the land market alone, the number of single farms does not change. In order to advance here, the exits rate estimation will be used to simulate farm exits under certain scenario settings. The exit module uses the result of IFM-CAP to update the farm exit probabilities.

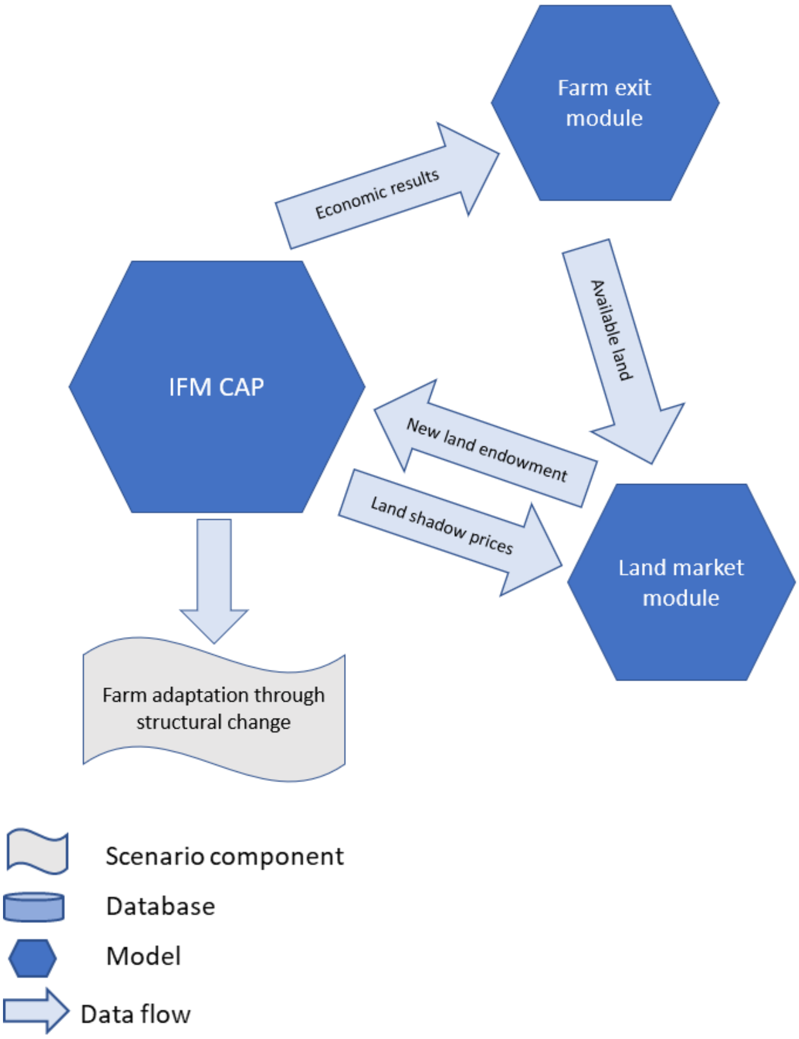

Figure 5 Schematic presentation of the modelling framework for structural change representation in current models

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Additionally, Agrispace will be used to inform the CAPRI model about how structural change may affect the supply response of various production activities in the presence of farm degressive payments. Based on the model outcomes, the supply response at the regional level will be estimated for major crop and animal activities. In a final step, these estimation coefficients will be implemented and calibrated in the CAPRI model for Norway. As a result, the CAPRI model will be able to reflect the impact of different structural change paths in its simulations and model runs.

Discussion

The following caveats/limitations are present in the proposed solution for modeling structural change in IFM-CAP. They can be the target of future research work:

Shadow prices of land: One obvious condition for the approach to work is that marginal values for the land constraints can be retrieved from solving the IFMCAP model. While that is guaranteed for (N)LP models, it is not necessary the case of models involving integer variables. Related to that is the question if the finite difference based estimation of the change in marginals in sensitivity analysis provides a good proxy for the behavior of the actual model in simulations. Here again, integer variables provide a challenge as they increase the likelihood of basis changes which sudden larger changes in marginals. Unfortunately, the latter point can hardly be tested in a generic way as the behavior depends how large the relevant stability ranges are in a specific counterfactual. That implies that even successfully testing the approach on a wider set of scenarios and single farms cannot exclude that convergence problems could evolve for specific farms in other scenarios. Potential approaches to minimize abrupt basis changes include preferring equality over inequality constraints, avoiding a PMP parameterization which leads to very high elasticities and keeping the number of integer variables as small as possible.

Behavioral functions for the supply of non-agricultural land: The LMM introduces behavioral functions for the supply of non-agricultural land and for the transitions between land use classes. Those functions need empirical specification. We relied on parameters collected from various sources within the CAPRI project: The first function to specify was the supply of non-agricultural land. We use two parameters from CAPRI, collected by Renwick et al (2010). We use the *supply elasticity of agricultural land* per member state (originally from the LEITAP model), and multiply it by the relative responsiveness of each nuts2-region relative to the national average (obtained from simulation experiments with the model Dyna-CLUE). This gives us an estimate of the nuts2-specific agricultural land supply elasticity η_r.

Comparison with alternative methods of modeling structural change: An alternative pathway to model farm exits which consists in updating the aggregation weights. Whereas for a single individual farm, an exit is a zero-one decision, one could model for a farm representative of many others, such as the ones in IFM-CAP, also exit probabilities. A probability of exit could in that case be mapped into a share of the represented farms leaving which implies technically a reduction in the aggregation weight. It would interesting to compare the results of the current approach with that of changing the farm weights.

The resolution of the “land exchange cell”: In LMM, farms are grouped into a land markets that represent the real world situation. It is likely that a more fine-grained “representative resolution” for the land markets beyond the “FADN region” is more appropriate. It is of research interest to see how the grouping of land markets (less vs more aggregated spatial units) affect the results.

3.1.4. Risk representation in current models (sT5.2.4)

Description and research questions, policy relevance or applications

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 817566.

European Union's policies to reduce intervention in agricultural markets have shifted support payments away from programs that incentivized production towards the support of farm incomes through direct payments and compensation for the provision of public goods (European Commission, 2014). At the same time, climate-induced adverse weather conditions occur in increased frequency and magnitude, leading to increased crop failures and therefore income variability. This requires greater focus on agricultural business risk management and adaptation options such as crop insurance.

In task 5.2.4 we analyse the impacts of crop specific insurance aimed at reducing risk in agricultural production on crop area allocation and agricultural markets (prices and trade). To be able to analyse the impacts of crop specific insurance on agricultural markets, one first has to analyse the effects that the option for insurance has on individual farmer's decision making. Results from a risk experiment on Italian tomato farmers reveal how farmers' risk preference influence their adoption of a weather index insurance. The farmer's decision to adopt insurance to mitigate risk of crop failure depends on the level of risk aversion that the farmer puts on a certain agricultural activity and whether this weighs against the premium the farmer would have to pay for adopting the insurance. To show the impacts of the potential adoption of such an insurance on land allocation and markets in a partial-equilibrium model like GLOBIOM, a quantification of the risk aversion in terms of costs or expected revenues is necessary.

GLOBIOM's objective function is defined as the sum of global consumer and producer surplus (details in Annex I). Prices and trade are endogenous to the model and adjust based on changes in demand (exogenously driven by population and GDP constraints) and supply. Because of the deterministic nature of the model, in combination with the equilibrium structure where the optimum between supply and demand is sought, without explicitly representing agents, the influence of risk in area allocation would naturally enter the model through a change in the cost or a change in the revenues. This added cost component that acts on the consumer surplus would have to be parameterized through a more farm-level decision making model that could quantify the risk in terms of costs. This cost component would enter GLOBIOM directly in the objective function and be specific to the agricultural activity employed.

Models and data

The models used in this subtask are:

- **Risk experiment** from UniCatt: Results from a risk experiment on Italian tomato farmers reveal how farmers' risk preference influence their adoption of a weather index insurance.

- **FarmDyn** or Farm household model to be developed as described in Annex I: To translate the revealed risk preference related to the experiment to a crop-specific risk aversion parameter that takes the form of a cost.

- **GLOBIOM**: GLOBIOM will be used to analyse the impacts of crop specific insurance on crop area allocation and agricultural markets (prices and trade) through the inclusion of crop-specific risk parameters and the possibility for the adoption of crop-specific insurance as developed in the method section.

- **EPIC-IIASA**: To simulate various possible yield outcomes based on CMIP6 climate projections.

The data used in this subtask are:

- **FADN**: In case of a farm-household model to be developed as described in Annex I: Crop-specific parameters on ha allocated, price, variable costs, direct payments and gross revenues belonging to an average farm and coming from the typology as developed in sub-task 5.2.1, sector and farm type typology used within the MIND STEP model.

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- **EPIC-IIASA** yield projections: Various possible yield outcomes based on climate events will be employed based on ISIMIP3b data from the 6th phase of the Coupled Model Intercomparison Project (CMIP).

Interfacing models across scales

In Task 3.5 the outcomes of a risk experiment on insurance adoption from Unicatt are brought into the IDM model FarmDyn using a Prospect theory framework (Britz et al., 2016). As the deliverable is currently being written and the outcomes of the linkage aren't fully clear yet, it's not yet possible to define whether a direct linkage between FarmDyn and GLOBIOM can be used based on the framework developed in Task 3.5. In case this linkage is not possible to be established, a farm-household model with be developed using the FADN data and the results of the experiment. Therefore, risk attributed to cropping activities will be assessed using one of the two alternative ways: (1) an inclusion of a crop-specific risk parameter, estimated in terms of a cost component based on the earlier linkage employed with FarmDyn; (2) an inclusion of a crop-specific risk parameter based on a to-be developed farm level household model.

The derived crop-specific risk parameter takes the form of a cost parameter and will be included in GLOBIOM's objective function (for further details see Annex I). The objective of the linkage with GLOBIOM is to analyse how the effects that insurance has on a farmer's land-use (crop allocation) decisions perturb over space and, therefore, what impacts are on land use and markets.

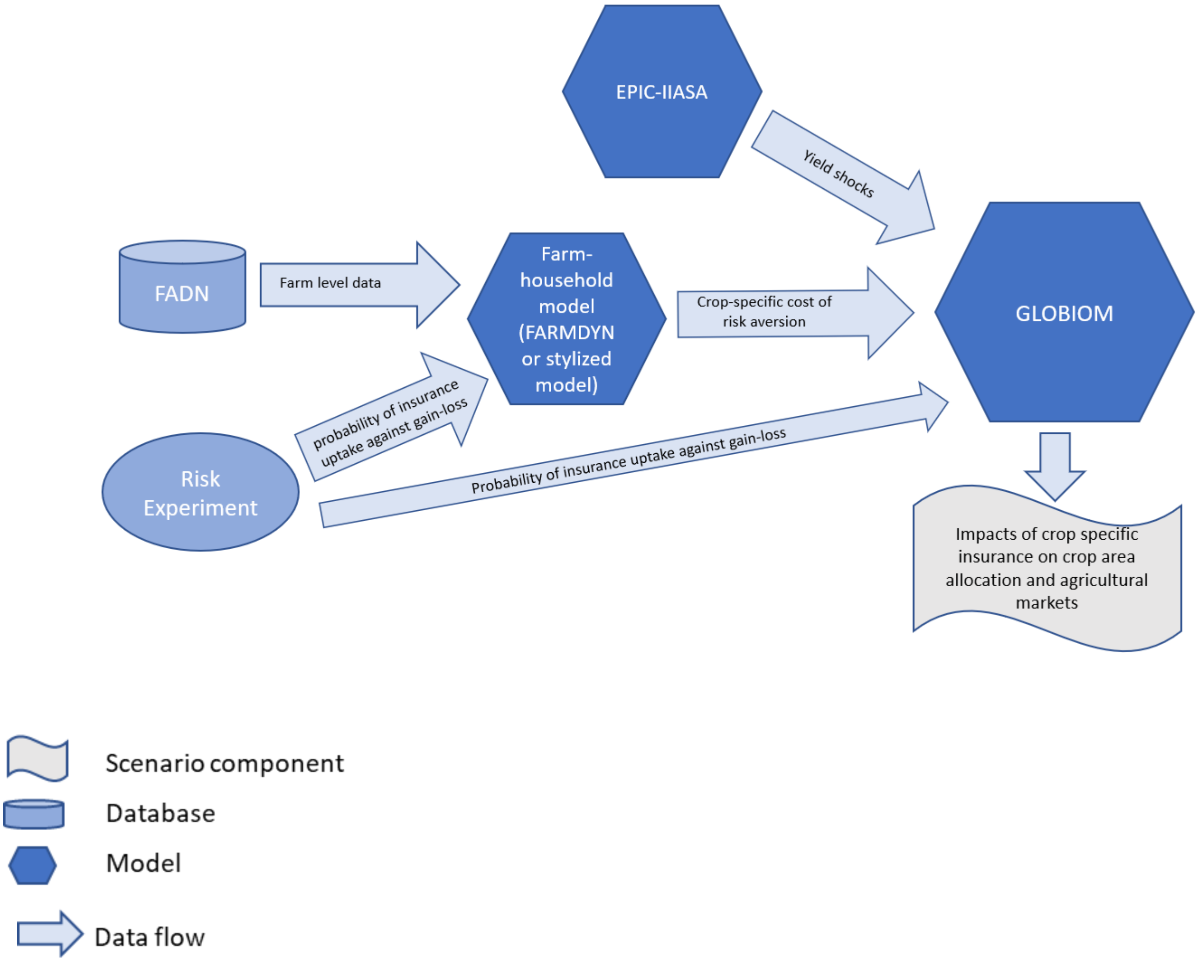

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Figure 6 Schematic presentation of the modelling framework for risk representation in GLOBIOM

Discussion

The analysis is novel in its aim to bridge across scales from revealed risk preferences to individual farm decision making and its impacts on land and markets at a larger scale. Difficulties might arise in the upscaling from very localized risk experiments to decision making of typical farm-households and from farm-household decision making to market-based responses. The results of the experiment on tomato farms in Italy have to be extrapolated to other regions and farm managements in a way that it distils responses to hedge uncertainty independent of the agricultural activity. Subsequently, the uptake of insurance and area allocation of individual farms under the possibility to hedge part of the risk needs to be extrapolated across regions and agricultural activities in GLOBIOM to allow the analysis on land and market responses. As individual farms operate based on expected prices and yields and perceived risk, we will modify GLOBIOM in such a way that land allocation decisions are made based on these expectations and markets are only able to react after land allocation decisions have been made.

3.1.5. Improved representation of mitigation technologies adoption in current models (sT5.2.5)

Description and research questions, policy relevance or applications

The work of this sub-task provides a conceptual framework for bottom-up estimations of Greenhouse gas (GHG) mitigation technologies to be used in the large-scale models GLOBIOM and MAGNET. With two different large-scale models, we will show how the flexible and modular structure of the highly detailed bio-economic single farm level model FarmDyn (WP3, WP 4.5) can be leveraged to parameterize new GHG mitigation options in existing production systems in the large-scale models. To meet the different requirements set by GLOBIOM and MAGNET, the simulation results will be used to estimate on the one hand marginal abatement cost curves for MAGNET and on the other hand to parameterize an add-on technology in GLOBIOM. The conceptual framework will be exemplified for the cattle production system (GLOBIOM)/ raw milk sector (MAGNET)/ dairy branch (FarmDyn) in the case study regions of North Rhine-Westphalia (NRW) (Germany) and the Netherlands. It can then be used to extend the regional and sectoral focus as well as the mitigation technologies for the large-scale models in the future given the availability of data. Eventually, the improved representation of mitigation technologies will improve the analysis of climate change policies with a focus on the agricultural sector by an extended number of mitigation options and regionally refined mitigation potential.

Models and data

The primary database to construct a regional dairy farm population is taken from FSS (Germany) and FADN (Netherlands). For a short description of the databases FSS and FADN please have a look at section 3.1.1. The gathered information from the databases will be used to develop ranges for relevant farm characteristics for the dairy farms. These farm characteristics include, next to the defined farm type: arable- and grassland endowment, animal numbers, and working units.

To identify the GHG mitigation technologies applicable to the dairy production system and implementable in FarmDyn, we gather information from different sources including literature (e.g. Zijstra et al. 2018) and publicly available databases on mitigation technologies (e.g. US EPA database). The resulting list of mitigation technologies will be sorted based on relevance and ease of implementation to determine a reduced list of mitigation measures to be integrated into FarmDyn. This reduced list will be the bundle of mitigation measures to be used in the linkage between **FarmDyn and MAGNET**. Further, the list we be used to identify the most promising add-on technology which is not yet implemented in **GLOBIOM**.

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Adaptation and simulation set-up in FarmDyn deviate between the two large-scale models based on their inherently different approaches to address GHG mitigation technologies in their model. For MAGNET, we introduce non-existing mitigation options from the aforementioned list into FarmDyn. Further, we integrate a carbon tax/price to trigger the adoption of voluntary mitigation measures in the scenario runs. Included in the mitigation measure list is the already chosen add-on technology needed for the linkage to GLOBIOM. In contrast to the MAGNET approach, we introduce this mitigation technology as mandatory in order to determine its exact impact.

For GLOBIOM, the add-on technology module is used to determine reduction potentials for explicitly modelled mitigation options or so-called add-on technologies. Each add-on technology is linked to a production system and requires information on linked adoption costs ($ per head/ha), abatement potential (% in CO2-eq. per head/ha), and optionally changes in productivity (% per head/ha). The add-on technology module will use simulation results from FarmDyn under consideration of the newly chosen technology and parameterize a new add-on technology in GLOBIOM for the given case study regions and dairy production system.

For MAGNET, we construct a marginal abatement cost curve (MACC) estimation module. MAGNET provides the option to use a MACC in order to determine changes in emission intensity (% in CO2-eq.) for any given level of carbon price/tax. While the MACC code is generic to accommodate all economic sectors, the data is currently only available for limited (primarily agricultural) sectors and gases (N2O and CH4). The relationship between carbon price and reduction in emission intensity (% in CO2-eq.) is implemented as a linear MACC function, which implicitly represents available mitigation technology options and related costs to a specific sector. More specifically, it describes percent reduction in emissions as a linear function with non-negative intercept and slope (coefficient associated with carbon price variable). The data used to operationalize the parameters is currently project- and model-aggregation specific. Until now, these parameters were based on USEPA data, but other publicly or through consortium, available sources should be explored in this context. These coefficients are calibrated to a specific carbon price with the aim to match best the cost tech adoption (area under the linear curve) and ensuring benefits (percent reduction in emission intensity). Simulation results from FarmDyn for different carbon price levels are non-linear due to the multitude of mitigation measures and their unrelated costs. In order to use the generated results, the MACC estimation module uses the FarmDyn output and approximates the mentioned linear function of the carbon price and CO2-eq. reduction levels. The linear function will then be used for the raw milk sector in the regions Germany (NRW used as a proxy) and the Netherlands.

Interfacing models across scales

To generate the populations in FarmDyn for NRW (Germany) and the Netherlands, we use farm level data on arable- and grass land, animal numbers, and working units for the dairy branch on the input side. Further, the identified mitigation technologies are implemented and parameterized in FarmDyn.

There are two simulation set-ups in FarmDyn which generate distinct output results in order to fit to the requirements given by the large-scale models. First, for GLOBIOM each dairy farm from the population is simulated two times. The first simulation (baseline) yields result for profits, animal numbers, and CO2-eq. emissions without the add-on technology whereas the counterfactual scenario yields those outputs with the technology. Second, for MAGNET each dairy farm is simulated multiple times with increasing price levels for carbon. FarmDyn provides CO2-eq. results for each farm and each carbon price level given the optimally chosen mitigation options by the dairy farmer. The results for both simulation set-ups are used as input for the add-on technology module and the marginal abatement cost curve module, respectively.

The add-on technology module uses the FarmDyn results to determine associated total GHG reduction and costs of the mitigation measure. In a second step, the results for loss in profits and emission

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reduction are then further broken down on the level of one cow to be used in the cattle production system in GLOBIOM. Once the add-on technology is harmonized with the production system and parameterized it is used as an input for the GLOBIOM model.

The MACC module uses the gathered data on loss in profits (proxy for abatement costs) and change in CO2-eq. emissions to estimate a linear function. The linear MACC function of the raw milk sector reflects implicitly all adopted mitigation measures as one technology taken up by the dairy farmers from the FarmDyn simulation.

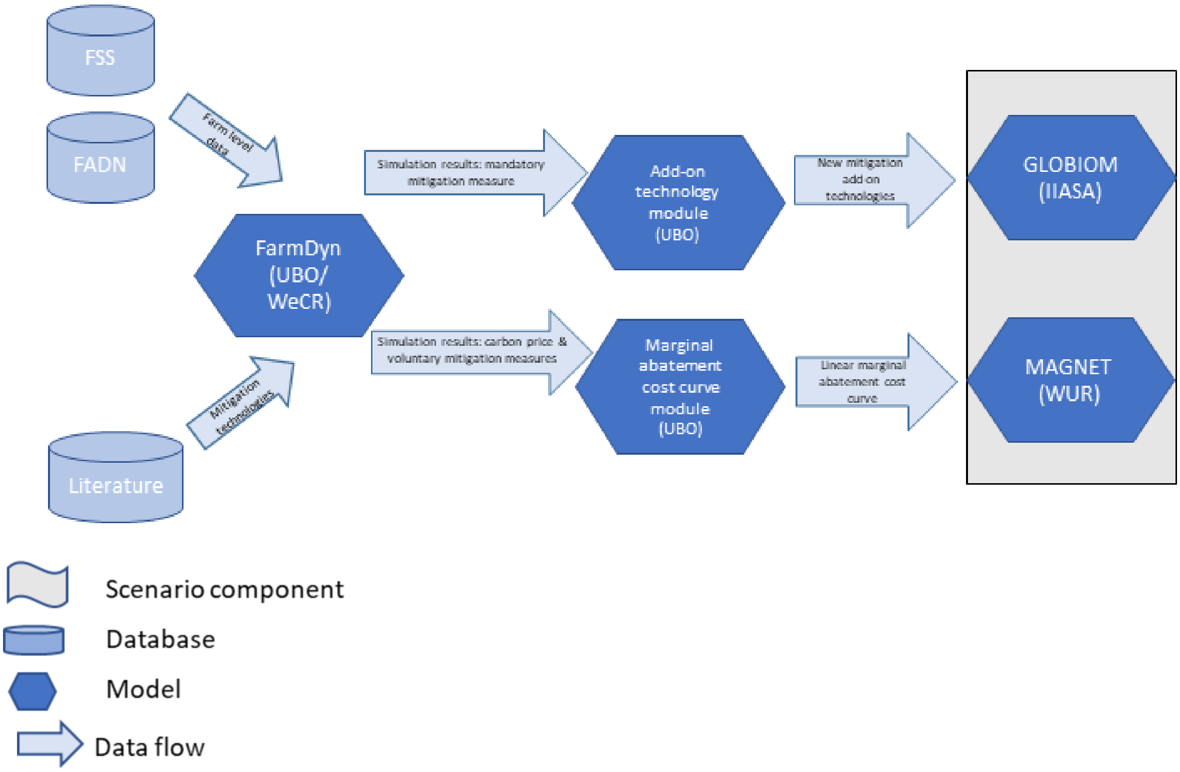

Figure 7 Schematic presentation of the modelling framework for improved representation of mitigation technologies adoption

Discussion

One of the most advantageous aspects of the use of IDMs, and specifically bio-economic single farm level models, is the highly detailed technology representation and possibility to provide simulation results on regional level which can be used for linkages to other large-scale models. However, one of the most advantageous aspects carries along on of the most work-intensive exercises with high data requirements both on the technology side and on the regional level. In order to circumvent this caveat, this sub-task develops a conceptual framework and exemplifies its application with a mitigation technology and case study area.

On the side of the MACC module in MAGNET, it has to be emphasized that the linear approximation of the MAC curves is only valid for the range to which it was fitted and therefore should not be used for eliciting response to carbon tax rates other than to which they are calibrated.

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3.1.6. Improved market power parameters and price transmission elasticities in current models (sT5.2.6)

Description and research questions, policy relevance or applications

The main objective of this sub-task is to think conceptually about the use of the output of task 4.4 for improving the supply chain representation in the CAPRI and MAGNET model. In task 4.4, we develop a model of supply chain mechanisms in modern food markets, by accounting for and parametrizing the extent of market power that raw agricultural commodities suppliers may obtain through the use of coordination tools, such as, contractual agreements and/or producers' organization. Despite the rising use of these instruments by agricultural producers, the role of contractual agreements and/or producers' organization is not adequately represented in the theoretical and empirical literature on price transmission and market power along food chains, where the farm sector is often assumed to be perfectly competitive (e.g., Sexton and Zhang 2001; Acharya, Kinnucan, and Caudill 2011; Assefa et al. 2017; Philippidis and Waschik 2019). However, this assumption may be implausible in modern food markets, where farmers are often able to achieve some extent of market power through the use of vertical contractual agreements and/or the creation of producers' organization (Sheldon 2017). As mentioned by Sheldon (2017), the presence of these coordination tools may significantly affect price transmission along the food chain, for example, by partly removing the ability of food processors to exert monopsony power towards the agricultural sector.

The policy relevance of this analysis is related to one of the key objectives of the CAP, that is strengthening the farmers' bargaining position in order to contrast unfair business practices in the food chain. Supporting farmers in the creation of producers' organization is one of the actions for achieving this objective, and such support has been confirmed and extended in the new CAP 2023-2027. Thus, potentially by improving the supply chain representation in the CAPRI and MAGNET model, the results from this analysis may help policy makers to obtain more reliable estimates of the potential effects of policy interventions and/or market-shocks on farm prices and income (i.e., top-down approach), and so, to design cost-effective policies to support the agricultural sector.

Models and data

To evaluate how differences in the supply chain organization and in the bargaining position of farmers may affect price transmission, and so, farm prices and incomes, specific models are developed for different actors within the food chains for certain products and regions (i.e., the pigs/pork and tomatoes for processing chains in Italy and the pigs/pork and sugar beet/sugar chains in Germany). In details, following the framework developed by Sexton and Zhang (2001) and Assefa et al. (2017), we analyse price transmission along a three-stage supply chain where farmers supply agricultural raw commodities to food manufacturers, which, in turns, sell food products to the retail sector, that delivers final products to consumers. However, contrary to previous works on price transmission mechanisms along food chains (i.e., Sexton and Zhang 2001; Verreth et al. 2015; Assefa et al. 2017), our model allows for the presence of bargaining power also at the farm level, which may derive from the use of contractual agreements or the creation of producers' organization.

While price data at different stages of the supply chain are usually widely available (e.g., official statistics, chambers of commerce data), one challenge that one could face in estimating the conjectural elasticities parameters is to collect data about costs for all the market players as these are usually not observed by the econometrician. One potential approach to overcome this issue is to collect cost data from different data sources, such as producers' surveys, experts, or other empirical works analysing the same supply chain. On the other hand, one can also adopt an empirical specification that allows to indirectly estimates marginal cost, for example using widely available key input cost data as in Soregaroli, Sckokai, and Moro (2011), or make some simplifying assumptions that enable to estimate them from the estimated price equations parameters as in Verreth et al. (2015).

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Interfacing models across scales

Changes in the competitive environment that characterizes agri-food industries, due for example to the development of vertical coordination tools, such as contracts between food-processors and farmers or the creation of producer organizations, may reduce the predictive power of current model platforms, where there is only little representation of regional supply chains, as well as of the presence of bargaining power along the chain. This work could potentially contribute to integrate these features into well-known partial equilibrium and CGE models as CAPRI and MAGNET. General equilibrium models generally assume perfect competition. It is possible to include imperfect competition and price markups however this requires extensive model changes. As time is limited for this task, ad-hoc shocks and cost structure changes will be considered to simulate price transmissions.

The parameters estimated in task 4.4 (i.e., conjectural and/or price transmission elasticities) could be used for improving the parametrization of the CAPRI and/or MAGNET model and obtain relevant policy scenario outcomes. Although CAPRI and MAGNET are different types of models conceptually the different steps could be as follows:

a. change the equations and production structures in the CAPRI and/or MAGNET model;

b. obtain different changes in farm level prices under different assumptions about market structure (including the presence of contracts/producer organizations) from the CAPRI and MAGNET model;

c. use different price levels from CAPRI and/or MAGNET to simulate the impact on farm income (and potentially on other target variables, such as environmental indicators) in the IDM models (i.e., IFM-CAP).

Until now profit margins per sector are included in the capital sector in MAGNET. Given data limitations and limited time and resources in MINDSTEP for this task, it is not foreseen to split the profit margins from the capital sector and change the equations in MAGNET accordingly. The same accounts for CAPRI.

Discussion

The analysis carried out in this sub-task will concern only a few selected supply chains in Germany and Italy. Results obtained in the selected supply chains cannot be automatically extended to other products and regions. This actually means that although conceptually feasible, the upscaling to CAPRI and/or MAGNET would not be very promising. A method could be developed which could serve as a proof of concept for future research. However, the order of magnitude of the impacts related to the presence of contracts/producer organizations coming from the estimated supply chain model are already relevant for policy makers, at least as a first approximation.

3.2. Downscaling EU/Global agricultural sector models to IDMs and ABMs

3.2.1. EU/Global agricultural sector models providing context variables to IDMs and ABMs (T5.3)

Description and research questions, policy relevance or applications

The farm-level IDM and ABM models within the project lack representation of the global economy, trade linkages, displacement effects and macro-level policy decisions. Such effects of EU policies and global events at farm and regional level can be direct and indirect. An EU regulation limiting GHG

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emissions or a drought event, will impact the farmer directly through increased cost or reduced yield but also indirectly through higher commodity prices.
As part of the top-down integration of the models, EU and global level models, such as GLOBIOM, MAGNET and CAPRI will be used to provide information on such direct and indirect linkages. This will be achieved by using adapted downscaling mechanisms to pass output parameters from current models corresponding to particular scenarios of EU policies or global events on to the farm level and regional models. The downscaled data will provide input parameters, "drivers", representing market mediated effects of EU policies or global events, for the IDM models. Such a link will enable farm-level models to simulate future, projected farm level behaviour dependent on global shocks and adaptations. This linkage supports policies impact assessment by providing the link of farms to global impacts climate change impacts and policy developments.

Models and data

To provide the national and global direct and indirect impacts to IDM model level downscaling models will be used. Such downscaling mechanisms will inform farm level and regional models and complement the sustainability assessment at the EU level and globally. Two such models will be mainly utilized: **CAPDIS** and **DownScale**.

Downscaling of the CAPRI model will be done using the CAPRI – **CAPDIS** module. This module has been specifically developed to allow monitoring and ex-ante assessment of environmental impacts of agriculture at a 10×10 km spatial scale. The model relies on regional NUTS2 time series, with particular focus on the feed to provide more realistic spatial distributions. The CAPDIS model can downscale of crop shares, livestock numbers, yield and nitrogen flows from the CAPRI model. This is done after running the CAPRI model and it is weakly time-dependent in the sense that the driver of the downscaling of a CAPRI output is also the downscaled output from the previous time step.

GLOBIOM and MAGNET downscaling will be done using the **DownScale** model. The DownScale model is an econometric downscaling model developed at IIASA, which will be used to downscale land-use and land-cover data from agricultural models at a resolution of 5 arcminutes. The model downscales NUTS2 or country level outputs from GLOBIOM and MAGNET, respectively. Downscaling is based on an econometric prior module, which is projected forward using a bias correction algorithm to raise its levels to NUTS2 or country level targets.

Interfacing models across scales

The downscaling needs of the farm level modelling teams were assessed by an Excel questionnaire based on SUPREMA models mapping. Three modelling teams indicated that they will require additional data from GLOBIOM, MAGNET and/or CAPRI. The specific variables and the required resolutions are presented in ***Table 5***.

Table 5 - Downscaling requirements of MIND STEP modelling teams

Variable	Descr.	Unit	Bonn	WUR
EXRD	exchange rate	euro/dollar	Country	
GDPD	GDP deflator (national/general inflation rate in year t, compared to base year)	index (2015=100)	Country	
sFINC	farm sector income (gross income: sector returns -/- intermediate costs)	th euro/farm	Country	

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XPRP	Real producer price/input price	USD/t	Country	Country
XPRR	world prices	usd/1000 kg		
XPRX	Real export price	USD/t	Country	Country
ENRG	energy use	*PJ*	NUTS2	
ESOC	Soil organic carbon balance	kg C/ha/year	NUTS2	
WATR	water use	*1000 m3*	NUTS2	
WEAT	weather volatibility/climate change	*index*	NUTS2	
FEED	Feed use	1000 t	NUTS2	
FRTN	Fertiliser N	1000 t	NUTS2	
LYLD	Livestock yield (endogenous)	kg prt/ha	NUTS2	NUTS2
LYXO	Exogenous livestock yield trend	kg prt/ha	NUTS2	NUTS2
PREC	precision/smart farming	index	NUTS2	
PROD	Production	1000 t	NUTS2	
YEXO	Exogenous crop yield	dm t/ha, fm t/ha	NUTS2	NUTS2
YILD	Crop yield	dm t/ha, fm t/ha	NUTS2	NUTS2

The framework of the top-down downscaling model linkage is presented in **Error! Reference source not found.**. The DownScale and CAPDIS models provide the linkage to the individual decision maker models. Particularly the yields, prices and land-use change outputs will be downscaled and provided to the IDM model FarmDyn at the NUTS2 or lower-level resolution. Observations on prices, land-use and farm structure will be used from the FADN database as drivers of the DownScale model. This is expected to improve the downscaling accuracy and will allow for improved model output.

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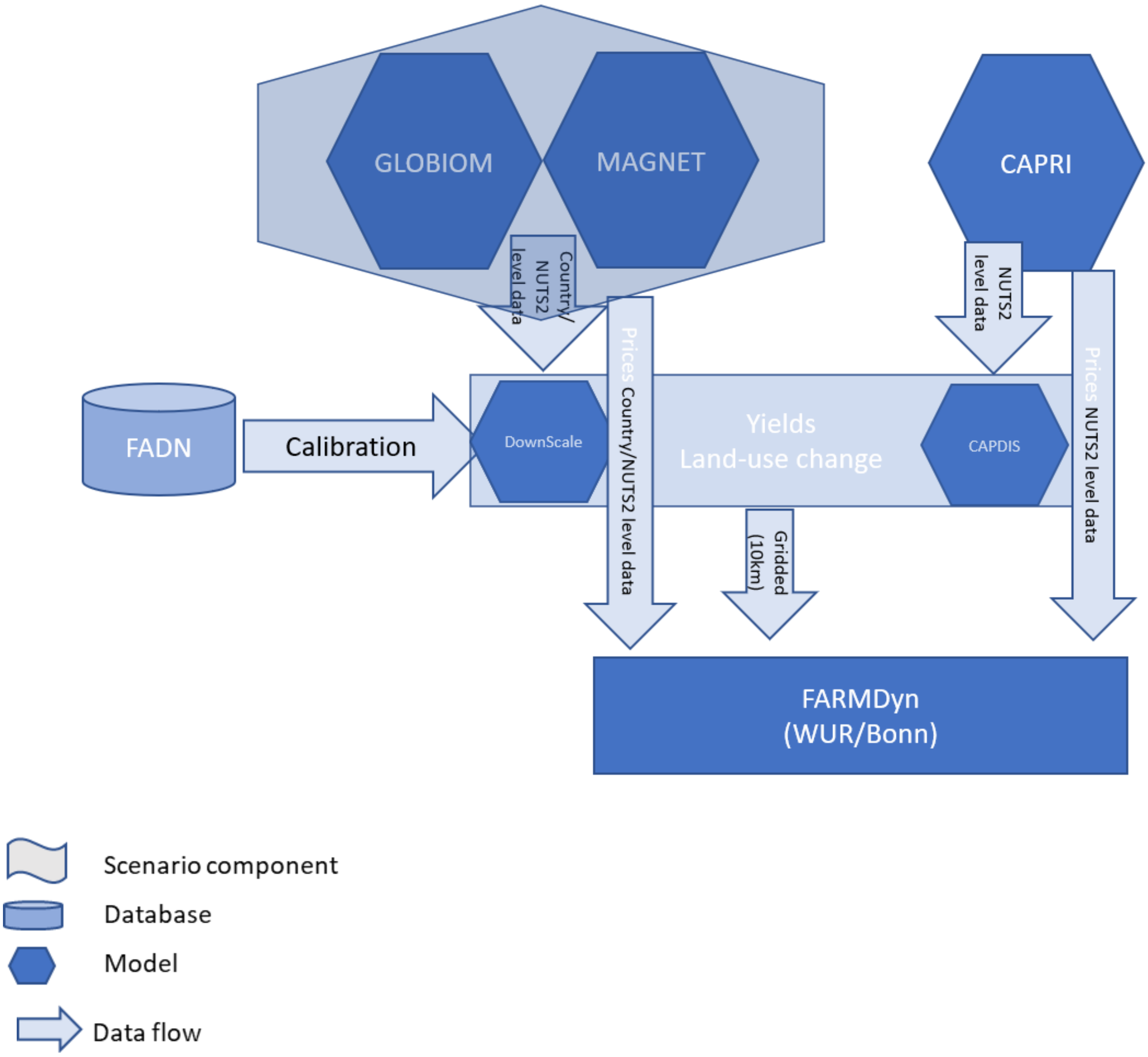

Figure 8 Schematic presentation of the modelling framework for top-down linkage to IDM and ABM models

Discussion

The linkage provides a crucial link between farm-level economic models. The main challenge of downscaling applies: the data will need to be carefully checked for consistency. Additionally, GLOBIOM downscaling only covers 17 major global crops, which does not include vegetables or fruits.

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3.2.2. EU/Global agricultural sector models filling the geographical gaps of IDMs and ABMs (T5.3)

Description and research questions, policy relevance or applications

Individual decision-making models (IDMs and ABMs) require a rich set of available data, additional calibration and are computationally expensive. For this reason, their geographical coverage is limited to certain selected and policy relevant countries (France, Germany, Italy, Netherlands, Norway). Given this limited geographical coverage of most of the farm and regional level models, to allow for a truly cross scale policy impact assessment, the detailed indicators provided by these models for a particular geographic area or farm type need to be complemented by indicators from the macro-level models which at a lower level of resolution cover the whole EU and the rest of the world. These models already cover several indicators related to the impacts of farming on climate and environment incl. ecosystem services.

The particular policy relevance of this exercise is to complement the local-level sustainability assessment of EU policies. This complement of the thematic and geographic coverage of IDM models allows for a comprehensive cross-scale assessment across different sustainability dimensions. This further supports the MIND STEP top-down linkages.

Models and data

The DownScale and CAPDIS models will be used for downscaling (See 3.2.1).

Interfacing models across scales

Land-use and land-use change outcomes will be the main indicators that will be downscaled. The downscaling will be to a 10 x 10km grid, both for the CAPRI, as well as for the GLOBIOM and MAGNET models. The grid will cover all countries and regions of the EU-27, where MIND STEP results are not available. The downscaling linkages and coverages are illustrated in **Error! Reference source not found.**.

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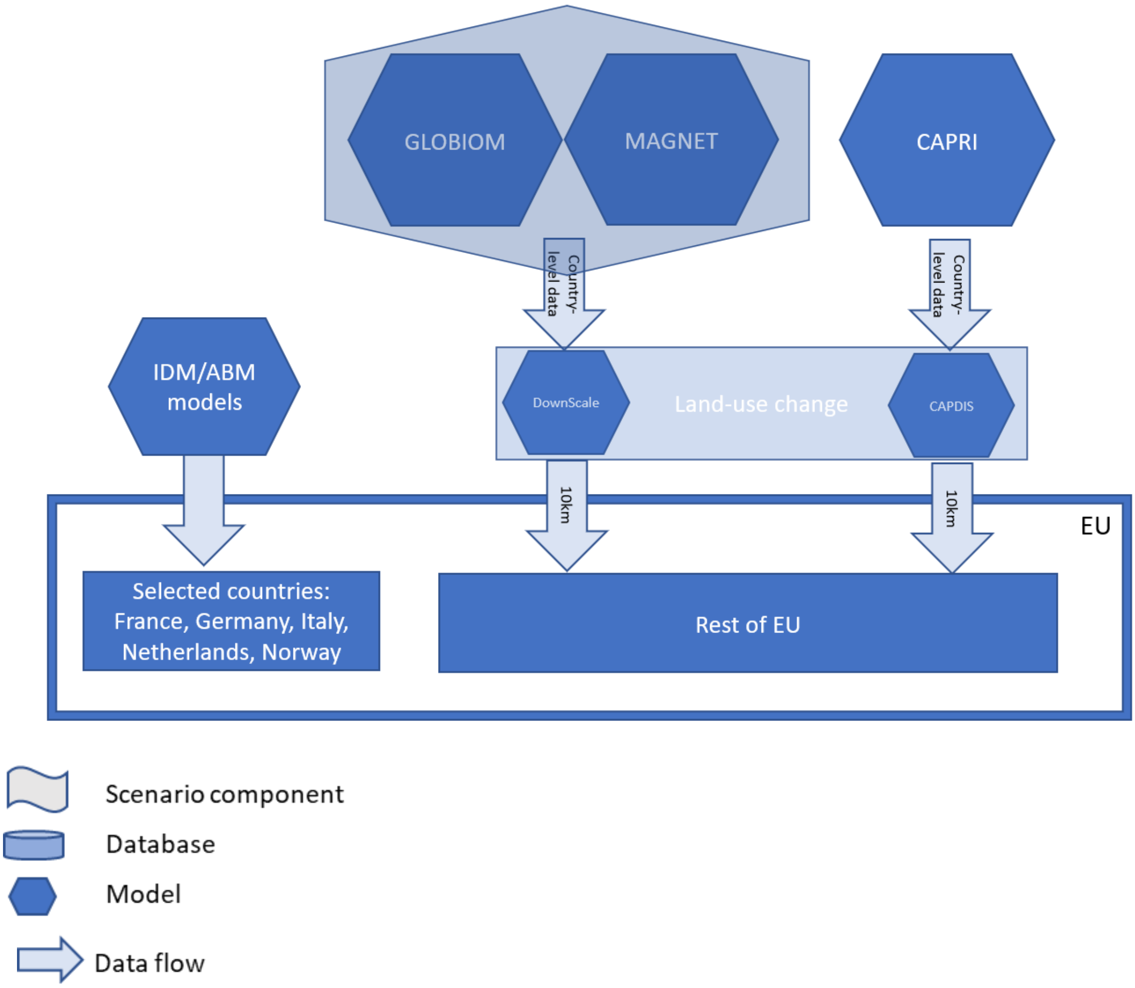

Figure 9 **Schematic presentation of the modelling framework for d*ownscaling in regions not covered by IDM models***

To validate the downscaling modelling link and the EU-wide coverage, the output of the FARM-DYN model in terms of land-use and land-use change implications will be compared to the results of the DownScale model. Multiple configurations in terms of DownScale drivers and priors will be explored, and the final reporting will be based on the one that is closest to the FARM-DYN output. This will ensure that the rest of the European coverage in terms of top-down, downscaled results is as close to the IDM dynamics as possible.

Discussion

The downscaling of GLOBIOM, MAGNET, and CAPRI only operates in terms of land-use and land-use change and does not give the full range of outputs that the IDM/ABM models provide. Nonetheless, through the consistency link in the downscaling process the results of land-use and land-use change decision can be compared across the EU.

4. SUMMARY AND DISCUSSION

MIND STEP project develops a modelling toolbox to provide policy makers with both timely and relevant evidence on the impact of agricultural policies on various outcomes across environmental and socio-economic domains and taking into account complex linkages across-scales. The innovation

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of the MIND STEP modelling toolbox consists of improving the linkages of macro-level models to econometric models, IDM models and ABMs. Improved model communication is achieved thanks to harmonization of the definitions for the existing classifications, and improved representation of production systems in macro level-models. Model improvements in GLOBIOM, include development of a bottom-up costing module, improved dynamics of land-use change and production in response to price-changes, and inclusion of farmers' risk aversion representation. Bottom-up linkage of FarmDyn with GLOBIOM and MAGNET allows to parameterize new GHG mitigation options in existing production systems. Finally, CAPRI and MAGNET models will have improved supply chain representation in the future. The top-down integration allows for GLOBIOM, MAGNET and CAPRI to provide information to farm-level IDM and ABM models on direct and indirect impacts on farmers of the global economy, trade, displacement effects and macro-level policy decisions. Furthermore, all downscaled data from the three large-scale models complement the thematic and geographic coverage of IDM and ABM models.

This is an important improvement over the current situation where a 'one-size-fits-all' model is quickly outdated or unmanageable due to the many additions to the model. As a result of the introduced innovations, much more detailed, timely and policy-relevant analyses of the CAP and other policies related to agriculture will be available. The following are the examples of the impacts that can be analysed with the MIND STEP modelling toolbox (components):

- Land-use effects of energy or labour market spill-overs in the future agricultural input use scenarios (GLOBIOM + Costing module);
- Wider consequences of the European farm-oriented policies resulting in structural land-use change and farm structure as a result of adaptation. This will result in the improved understanding of the final impacts of the policies on the socio-economic and environmental indicators (GLOBIOM + econometric models);
- Impact of different structural change pathways on the supply response of various production activities in the presence of farm degressive payments (Agrispace + CAPRI)
- Farm adaptation through structural change (IFM CAP + Land market module + Farm exit module)
- Impacts of agricultural business risk management and adaptation options, such as crop insurance, on land allocation and markets (risk experiment+ risk management model + GLOBIOM);
- Improved understanding of climate change policies with a focus on the agricultural sector by an extended number of mitigation options and regionally refined mitigation potential (FarmDyn + GLOBIOM + MAGNET);
- Effects of policy interventions strengthening the farmers' bargaining position (e.g., creation of producers' organization) on farm prices and income (model of supply chain mechanisms in modern food markets + potentially CAPRI and MAGNET);
- Potential effects of policy interventions and/or market-shocks on farm prices and income (i.e., top-down approach), which can be used to design cost-effective policies to support the agricultural sector (MAGNET and GLOBIOM with DownScale + FarmDyn);
- Complete thematic and geographic coverage of the local-level sustainability assessment of the EU policies (MAGNET and GLOBIOM with DownScale).

Models in the toolbox can be either applied in parallel, based on aligned scenarios, or in an integrated manner, using and generating one stream of inputs and outputs. The first method would provide impact assessment across spatial and temporal scales and actors in a coherent way. One example of a broad scenario assessment identified by stakeholders that can be analysed this way is mandatory reduction of input use. Several models can be applied to analyse different aspects of this scenario. For example, FarmDyn can assess impacts of fertilizer use reduction on environmental outputs on a farm level, while MAGNET and GLOBIOM can inform about the country- or the EU-wide environmnetal and socio-economic consequences of large-scale reduction of the fertilizer use. Another policy scenario identified by the stakeholders is reduction of the GHG emissions. It can be analyzed by integrated models – FarmDYN with GLOBIOM and MAGNET. FarmDyn will parameterize new GHG mitigation options in existing production systems in the two large-scale models. This will allow for analysis of climate change policies with a focus on the agricultural sector by an extended number of mitigation options and regionally refined mitigation potentials. These policy scenarios will be further developed and proposed to the stakeholders in WP6 as part of the validation of the toolbox.

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SUPPLEMENTARY MATERIAL

ANNEX I: FARM HOUSEHOLD LEVEL MODEL TO CALIBRATE PARAMETERS FOR GLOBIOM

INCLUSION OF RISK AND INSURANCE IN GLOBIOM

In this section we discuss the implementation of risk aversion and the possibility to adopt insurance in GLOBIOM.

GLOBIOM’s objective function is defined as the integral under the demand functions minus the sum of all production, resource and trading costs (Havlik et al., 2011):

$$
\begin{aligned}
& MaxOBJ_t = \\
& \sum_{r,y}\left[\int \varphi^{dem}_{r,t,y}\left(D_{r,t,y}\right)d(.)\right] - \sum_{r}\left[\int \varphi^{splw}_{r,t}\left(W_{r,t}\right)d(.)\right] - \sum_{r,m}\left(\tau^{proc}_{r,m}\cdot P_{r,t,m}\right) \\
& -\sum_{r,l,\tilde{l}}\left[\int \varphi^{lucc}_{r,l,\tilde{l},t}\left(\sum_{c,g} Q_{r,t,c,g,l,\tilde{l}}\right)d(.)\right] - \sum_{r,c,g,l,s,m}\left(\tau^{land}_{c,g,l,s,m}\cdot A_{r,t,c,g,l,s,m}\right) \qquad (1) \\
& - \sum_{r,c,g,l,s,m}\left(\tau^{calib}_{c,g,l,s,m}\cdot A_{r,t,c,g,l,s,m}\right) - \sum_{r,c,g,a,m}\left(\tau^{calib}_{c,g,a,m}\cdot B_{r,t,c,g,a,m}\right) \\
& -\sum_{r,\tilde{r},y}\left[\int \varphi^{trade}_{r,\tilde{r},t,y}\left(T_{r,\tilde{r},t,y}\right)d(.)\right]
\end{aligned}
$$

Where MaxOBJ represents the sum of consumers and producers’ surplus, ϕ^{dem} the constant elasticity demand function, d the final demand, ϕ^{splw} represents the constant elasticity water supply function, *W* represents the water use, τ^{proc}: the processing cost by unit of primary product, P the processed quantity, ϕ^{lucc} the land use/cover change cost function with rising marginal costs, Q the amount of land use/cover change, τ land the management cost per hectare of land use (except for water), A the land use activities, τ^{calib}: the calibrated production cost per hectare of land use activities or per livestock unit, B the livestock numbers, ϕ^{trade} the constant elasticity international trade cost function, T the international shipments. The indices r represent the region, t the period, c the country, g the spatial grid, l the land use type, s the primary product, a the animal type, y the final product and m the management system.

For a producer, the resulting shadow prices of land derived from solving equation (1) represent the land's marginal contribution to profit. If a producer has no constraints on land use, profit maximization occurs at the point where shadow prices are equal among all alternative land uses.

However, the equality of shadow prices among land uses only accounts for expected output prices and yields because producers do not know output prices and yields at the time they choose their production activities, and must base their expectation on past experience. This causes uncertainty for the producer about the difference between the actual and expected output price, which may differ per activity and through time. Producers may therefore prefer a situation where they give up part of their revenue to get a certain income. To accommodate for the differences between allocation decisions based on preferred revenues (i.e., expected revenues including a cost component to

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quantify risk aversion) and the outcomes of these decisions, we solve equation (1) first by replacing the part of the constant elasticity demand function belonging to crop production in equation (1) by the expected revenues based on risk preferences related to crop production:

$$\begin{aligned}\text{MaxOBJt} = \sum_{r,y}\left[\int \varphi_{r,t,y}^{dem}(D_{r,t,y})d(.)\right] \sum_{r,c,g,l,i,m} \left(p_{r,t,i}^{*} \cdot A_{r,t,c,g,l,i,m} - C_{r,c,l,s}\right) \\ - \sum_{r}\left[\int \varphi_{r,t}^{splw}(W_{r,t})d(.)\right] - \sum_{r,m}\left(\tau_{r,m}^{proc} \cdot P_{r,t,m}\right) \\ - \sum_{r,l,l^*}\left[\int \varphi_{r,l,l^*,t}^{lucc}\left(\sum_{c,g} Q_{r,t,c,g,l,l^*}\right)d(.)\right] - \sum_{r,c,g,l,s,m}\left(\tau_{c,g,l,s,m}^{land} \cdot A_{r,t,c,g,l,s,m}\right) \\ - \sum_{r,c,g,l,s,m}\left(\tau_{c,g,l,s,m}^{calib} \cdot A_{r,t,c,g,l,s,m}\right) - \sum_{r,c,g,a,m}\left(\tau_{c,g,a,m}^{calib} \cdot B_{r,t,c,g,a,m}\right) \\ - \sum_{r,r^*,y}\left[\int \varphi_{r,r^*,t,y}^{trade}(T_{r,r^*,t,y})d(.)\right] - \sum_{r,y}\left(\beta_c^{p*} \cdot S_c^{p*}\right) + \sum_{r}\left(\beta_{c,r,y}^{d*} \cdot S_{c,r,y}^{d*}\right)\end{aligned}$$

Where *MaxPOBJ* represents the producers' surplus based on expected revenues including risk preference of crop production and the consumers surplus of animal and forest products, $p^* * A - C$ represents the expected revenue of crop production minus risk aversion coefficient *C*, and the index i represents crop products.

Where

$$S_{c,r,y} = \begin{cases} 1 \text{ if } \sum_{c=1}^{C} p_{r,t,i}^{*} \cdot A_{r,t,c,g,l,i,m} - C_{r,c,l,s} < S_{c,r,y}^{*} & \text{(insurance adoption)} \\ 0 \text{ if } \sum_{c=1}^{C} p_{r,t,i}^{*} \cdot A_{r,t,c,g,l,i,m} - C_{r,c,l,s} \geq S_{c,r,y}^{*} & \text{(no insurance adoption)'} \end{cases} \tag{3}$$

$S*$ represents the revenue obtained from potential payout – premium. If this is higher than the expected revenue minus the cost of the risk aversion coefficient then there's adoption of the insurance. If this is lower than the expected revenue minus the cost of the risk aversion coefficient then there's no adoption of the insurance. The cost of the risk aversion coefficient is defined by agricultural product and would come either from FarmDyn or are determined as described in Annex I.

After the producer's land allocation and management decision based on expected revenues including risk preference and the possibility for insurance has taken place, production has an upper bound: it's defined as the goods harvested based on the land allocation and the outcome of the yields. With the fixed allocation we solve MaxOBJ in equation (1), with the indemnity and payout of adopted insurance now directly included:

$$\text{MaxOBJt} = \sum_{r,y}\left[\int \varphi_{r,t,y}^{dem}(D_{r,t,y})d(.)\right] - \sum_{r}\left[\int \varphi_{r,t}^{splw}(W_{r,t})d(.)\right] - \sum_{r,m}\left(\tau_{r,m}^{proc} \cdot P_{r,t,m}\right) - \sum_{r,l,l^*}\left[\int \varphi_{r,l,l^*,t}^{lucc}\left(\sum_{c,g} Q_{r,t,c,g,l,l^*}\right)d(.)\right] - \sum_{r,c,g,l,s,m}\left(\tau_{c,g,l,s,m}^{land} \cdot A_{r,t,c,g,l,s,m}\right) - \sum_{r,c,g,l,s,m}\left(\tau_{c,g,l,s,m}^{calib} \cdot A_{r,t,c,g,l,s,m}\right) - \sum_{r,c,g,a,m}\left(\tau_{c,g,a,m}^{calib} \cdot B_{r,t,c,g,a,m}\right) - \sum_{r,r^*,y}\left[\int \varphi_{r,r^*,t,y}^{trade}(T_{r,r^*,t,y})d(.)\right] - \sum_{r,y}\left(\beta_c^{p*} \cdot S_c^{p*}\right) + \sum_{r}\left(\beta_{c,r,y}^{d*} \cdot S_{c,r,y}^{d*}\right) \tag{4}$$

Where MaxOBJ$_t$ represents the sum of consumers' and producers' surplus, $S^{p*}{}_c$ the indemnities paid in case insurance is chosen, $S^{d*}{}_{r,c,y}$ the payout in case insurance is chosen and revenues drop below threshold X. $\beta^{p*}_{r,y}$ and $\beta^{d*}_{r,y}$ represent the cost for indemnities and the payouts respectively.

To analyse the impacts of crop specific insurance on crop area allocation, production, and agricultural markets (prices and trade) we will iterate the model as described above along various possible yield outcomes based on climate events.

BASE MODEL AND FLAT-RATE PAYMENTS

We assume that producers maximize income while accounting for risk in their production decisions. Representative arable farmers with fixed amounts of land and facing exogenous input and output prices aim to maximize expected utility from total revenues by allocating land to various crops. Currently, producers receive a direct payment per hectare that varies by crop based on historic entitlements. However, a flat-rate payment was introduced with the 2015 crop year; it provides the same payment regardless of the crops planted by the producer, and is referred to as the single farm payment (SFP). Based on prior payments based on historic entitlements and crop allocations in our 2012 base year, the average direct payment was €310 per hectare (Doorn *et al.,* 2011).
To analyse the crop allocation decision, we develop the following model:

$$\text{Maximize } U = \sum_{k=1}^{K} E[R_k] - \tfrac{1}{2}\,\varphi\,\sigma^2 \tag{1}$$

Subject to:

$$R_{k,t} = [p_{k,t}\, y_{k,t} - c_k(w) + SPS_k]\, x_k, \ \forall\ k \tag{2}$$

$$\sigma^2 = \sum_{k=1}^{K}\sum_{i=1}^{K}\left[x_k \times CV(R_k, R_i) \times x_i\right] \tag{3}$$

$$CV(R_k, R_i) = \frac{1}{T}\sum_{t=1}^{T}\left(R_{k,t} - E[R_k]\right)\left(R_{i,t} - E[R_i]\right) \ \forall\ k,i \tag{4}$$

$$E[R_k] = \frac{1}{T}\sum_{t=1}^{T} R_{k,t} \ \forall\ k \tag{5}$$

$$\sum_{k=1}^{K} x_k \le \overline{X} \tag{6}$$

U represents the producer's utility; ∑E[R_k] is the expected total revenue minus variable costs from crop production; φ is the risk aversion coefficient, that takes the form $-\dfrac{U''(I)}{U'(I)}$, where *I* refers to the farm

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household's income;[3] σ^2 is the variance associated with the total crop portfolio; $p_{k,t}$ and $y_{k,t}$ represent the respective output price and yield for crop k in period t; $c_k(w)$ is the per unit-area variable cost of producing crop k as a function of exogenously-determined input prices w; and *SPS* is the flat-rate payment based on historic entitlements (€/ha). Further, $CV(R_k,R_i)$ refers to the covariance matrix, where R_i and R_k are the respective realized gross margin to crops i and k, and $E[R_k]$ is the farmer's expected gross margin (€/ha) from planting crop k; x_k denotes the number of hectares allocated to produce crop k; and $\overline{X}$ represents the total area (ha) the farmer has available to allocate to crops. There are K crops that can be planted in any given period and there are T periods.

Equation (2) calculates the farmer's gross margin accruing to each crop in each period given the allocation of land to crops, which is endogenously chosen in the model. SPS is included in (2) but fixed production cost is not because fixed costs are part of the PMP term (as explained next). Equation (3) specifies the risk associated with the total crop portfolio, while equation (4) provides the variance-covariance matrix. Equation (5) calculates the expected gross margin that accrues to each crop over all periods (simulations). Finally, constraint (6) indicates that the farmer's cultivated area does not exceed the available area. In each period, the producer must decide how to allocate her $\overline{X}$ hectares among the K different crops so as to maximize utility over the total set of crops.

CROP-SPECIFIC REVENUE INSURANCE

Now we assume that agricultural producers have the option to insure the gross margin for any specified crop. The payout and premiums are defined by the risk experiment. We assume that there is a similar target or reference margin for each crop, denoted M_k, which is the expected gross margin for each crop across all random states T.

With crop-specific insurance, the objective function specified in equation (1) can now be written as:

$$R_t = \sum_{k=1}^{K} \left(E[R_k] - ½\,\phi\sigma^2\right) + Z_k \times \mathrm{Max}\big(0, XM_k - \left(p_{k,t}y_{k,t} - c_k\right)x_k\big)$$

$$-\frac{\delta}{T}\textstyle\sum_{t=1}^{T} \mathrm{Max}\big(0, XM_k - \left(p_{k,t}y_{k,t} - c_k\right)x_k\big), \qquad (9)$$

where the dummy variable is specified as:

$$Z_k = \begin{cases} 1 \text{ if } \sum_{k=1}^{K} R_{k,t} x_k < M_k & \text{(payout)} \\ 0 \text{ if } \sum_{k=1}^{K} R_{k,t} x_k \geq M_k & \text{(no payout)} \end{cases}, \tag{10}$$

where $R_{k,t}\, x_k = (p_{k,t}\, y_k - c_k)\, x_k$. M_k signifies the reference gross margin associated with crop *k*, while $\mathrm{Max}\big(0, XM_k - \big(p_{k,t}y_{k,t} - c_k\big)x_k\big)$ is the pay-out to crop enterprise *k* when outcome *t* occurs as the realized gross margin is 70% or less of the reference margin. Both the realized gross margin and the reference gross margin are calculated from Monte-Carlo iterations. The premium the farmer pays for hedging crop *k* is given by $\frac{\delta}{T}\sum_{t=1}^{T} \mathrm{Max}\big(0, XM_k - \big(p_{k,t}y_{k,t} - c_k\big)x_k\big)$, where δ represents the share of the premium that the farmer pays with the government subsidizing the remainder.

We use the annual results of the CMIP6 EPIC-IIASA yields for RCP4.5 over the period 2000-2100 to generate 100 potential outcomes (states of nature) for each crop alternative used in the current application. In determining gross margins, the observed average costs of planting, tending and harvesting are employed; these costs are fixed at the observed value (c_k^0) when calculating insurance premiums and indemnities. The difference in realized and expected total revenue or the quantification of the risk component in terms of costs is transferred to the cost component in the expected revenue part of the objective function in GLOBIOM.

ANNEX II: DATA EXCHANGE PROTOCOLS FOR BOTTOM-UP MODEL INTEGRATION

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	Source							Destination					
sub-task numbe	Description	Data	Spatial scale	Temporal scale	Spatial coverage	Temporal coverage	Transformation needed	Description	Data	Spatial scale	Temporal scale	Spatial coverage	Temporal coverage
5.2.1	FADN	Production data	farm-level	annual	EU-27	2008 - 2018	Harmonization of crop and livestock product classifcation	Aggregate production data	Production data	Simulation Unit	annual	EU-27	2008-2018
5.2.1	FADN	Farm type production	farm-level	annual	EU-27	2008 - 2018	Derivation of relevance of standing herd in farm assets	Aggregate herd shares in capital stock	Herd shares	Simulation Unit	annual	EU-27	2008-2018
5.2.1	FSS	costing data (e.g. fertilizer expenditure and quontities purchased)	NUTS-3	annual/triennial	EU-27	2008 - 2018	Estimation of input parameters for the module and its integration in GLOBIOM trunk code	Bottom-up costing module for GLOBIOM	GLOBIOM cost parameters	Simulation Unit	decennial	EU-27	2000-2050
5.2.1	FADN	costing data (e.g. fertilizer expenditure and quontities purchased)	farm-level	annual/triennial	EU-27	2008 - 2018	Estimation of input parameters for the module and its integration in GLOBIOM trunk code	Bottom-up costing module for GLOBIOM	GLOBIOM cost parameters	Simulation Unit	decennial	EU-27	2000-2050
5.2.2	FADN	production data, crop area data, income and costing data	farm-level	annual/triennial	EU-27	2008 - 2018	Aggregation and statistical processing of individual units	estimation of maximum expansion for crop area parameters and management system parameters in GLOBIOM	Parameter maxcrop and maxcropsys	NUTS-2	decennial	EU-27	2000-2020
5.2.2	INRAE output	own- and cross-crop elasticities	NUTS-2	cross-sectional (one	EU-27	2008 - 2018	Mapping to GLOBIOM crops and regions	estimation of	Own- and cross-crop	NUT-2	decennial	EU-27	2000-2020
5.2.2	IDM output	own- and cross-crop elasticities	NUTS-2	?	EU-27	2008 - 2018	Mapping to GLOBIOM crops and regions	Calibration of GLOBIOM to parameters	Own- and cross-crop elasticities	NUTS-2	decennial	EU-27	2000-2020
5.2.2	FSS	production data, crop area data, income and costing data	NUTS-2	annual/triennial	EU-27	2008 - 2018	Aggregation and statistical processing of individual units	estimation of maximum expansion for crop area parameters and management system parameters in GLOBIOM	Parameter maxcrop and maxcropsys	NUTS-2	decennial	EU-27	2000-2020
5.2.3	IFM-CAP output	shadow prices of land	farm-level	annual	EU-27	2017	No transformation needed	Land Market module	Land shadow prices	farm-level	annual	EU-27	2017
5.2.3	Farm exit module	Available land	farm-level	annual	Germany	2017	No transformation needed	Land Market module	Available land	farm-level	annual	EU-27	2017
5.2.3	Land Market	New land endowment	farm-level	annual	Germany	2017	No transformation needed	IFM-CAP	New land endowment	farm-level	annual	EU-27	2017
5.2.4	FarmDyn/stylized farm household model output	cost of risk aversion	farm-level		EU-27 or localized		Estimation of crop-specific cost of risk-aversion coefficient	Implementation of risk in GLOBIOM	cost of risk aversion parameter	NUTS-2	annual/decadal	EU-27	2000-2050
5.2.4	Risk experiment output	Insurance adoption varying with payout and premium	farm-level		Italy		Parameterization of insurance as a climate-adaptation option	Populating a region and production system specific add-on technology	Insurance payout, premium and slope of uptake parameters	NUTS-2	annual/decadal	EU-27	2000-2050
5.2.4	EPIC-IIASA output	climate-induced yield fluctuations	NUTS-2		global	2000 - 2100	Annual yield shocks	Impacts of annual yield shocks in GLOBIOM	crop-specific annual yield shifters	NUTS-2	annual	EU-27	2000-2050
5.2.5	FarmDyn output	production data, economic indicators, emission quantities	farm-level	annual	NL/DE	2018	Merging farm-level results to NL/DE datasets	Populating a region and production system specific add-on technology	GLOBIOM add-on technology	NUTS-2	annual	NL/DE	2018
5.2.5	FarmDyn output	CO2 prices, percent reduction in emission intensity (in CO2 equivalent)	farm-level	annual	NL/DE	2018	Aggregation of FarmDyn results (CO2 prices emission levels) to national level,	Point-slope calibration of MAGNET MACC curve to the FarmDyn Results	MAGNET	NUTS-2	annual	NL/DE	2018
5.2.5	FSS	structural data (farm type, size, animal numbers, etc.)	farm-level	annual	NL/DE	2018	Define population based ranges for all relevant variables	FarmDyn simulation	FarmDyn GUI farm-setting parameters	farm-level	annual	NL/DE	2018
5.2.5	FADN	structural data (farm type, size, animal numbers, etc.)	farm-level	annual	NL/DE	2018	Define population based ranges for all relevant variables	FarmDyn simulation	FarmDyn GUI farm-setting parameters	farm-level	annual	NL/DE	2018
5.2.5	Mitigation measure literature	CO2-eq. emission and cost data	technology	-	-	-	Mapping of units to FarmDyn parameters	FarmDyn simulation	Mitigation technology parameters	farm-level	annual	NL/DE	-
5.2.6	UCSC/Thunen output	Conjectural elasticites	Country level	Estimated parameters	Italy/Germany	2000-2018	Mapping to CAPRI representation of price transmission	Calibration of CAPRI equations	Conjectural elasticities	NUTS-2 level	decennial	EU-27	2000-2050
5.2.6	UCSC/WECR output	Conjectural elasticites	Country level	Estimated parameters	Italy/Germany	2000-2018	Mapping to MAGNET representation of price transmission	Calibration of MAGNET equations	Conjectural elasticities	country level	decennial	EU-27	2000-2050