D1.5: DOCUMENTATION OF THE SUPREMA MODEL TOOLS

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Executive summary

The primary objective of the deliverable is to facilitate access to the SUPREMA models to potential users. To that end, the report offers insights into the main features and capacities of each model and gathers relevant references from the extensive and dispersed model documentation. In addition, the deliverable provides an overview of model interlinkages and platforms, as well as of model developments that are underway in the framework of SUPREMA.

Changes with respect to the DoA

No changes with respect to the DoA

Dissemination and uptake

The deliverable is publicly available. SUPREMA will not necessarily open up all research data. In a sense, the document explains which of the research data generated and/or collected will be open access.

Short Summary of results (<250 words)

This report provides a brief description of the models AGMEMOD, CAPRI, GLOBIOM, IFM-CAP, MAGNET and MITERRA-Europe, as well as references to recent applications in the fields of agriculture, climate, water and bioenergy. Furthermore, the report highlights previous cooperation efforts among modelling teams, illustrating the importance of model interlinkages and platforms to deliver integrated and comprehensive impact assessments.

Evidence of accomplishment

The deliverable itself can act as the evidence of accomplishment.

Glossary / Acronyms

AGMEMOD	AGRICULTURE MEMBER STATES MODELLING
AGMIP	AGRICULTURAL MODEL INTERCOMPARISON AND IMPROVEMENT PROJECT
CAP	COMMON AGRICULTURAL POLICY
CAPRI	COMMON AGRICULTURAL POLICY REGIONALISED IMPACT MODELLING SYSTEM
EDGAR	EMISSIONS DATABASE FOR GLOBAL ATMOSPHERIC RESEARCH
EU	EUROPEAN UNION
EUROCARE	EUROPEAN CENTRE FOR AGRICULTURAL, ENVIRONMENTAL AND REGIONAL RESEARCH
FADN	FARM ACCOUNTANCY DATA NETWORK
FSS	FARM STRUCTURE SURVEY
GAINS	GREENHOUSE GAS - AIR POLLUTION INTERACTIONS AND SYNERGIES
GHG	GREENHOUSE GAS
GLOBIOM	GLOBAL BIOSPHERE MANAGEMENT MODEL
GTAP	GLOBAL TRADE ANALYSIS PROJECT
HPD	HIGHEST POSTERIOR DENSITY
IFM-CAP	INDIVIDUAL FARM MODEL FOR COMMON AGRICULTURAL POLICY
IIASA	INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
IMPACT	INTERNATIONAL MODEL FOR POLICY ANALYSIS OF AGRICULTURAL COMMODITIES AND
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
JRC	JOINT RESEARCH CENTRE
LULUCF	LAND USE, LAND-USE CHANGE, AND FORESTRY
MAGNET	MODULAR APPLIED GENERAL EQUILIBRIUM TOOL
NUTS	NOMENCLATURE OF TERRITORIAL UNITS FOR STATISTICS
SUPREMA	SUPPORT FOR POLICY RELEVANT MODELLING OF AGRICULTURE
TRQ	TARIFF RATE QUOTAS

1 Introduction

SUPREMA includes a set of models that support policy impact assessments in the fields of agriculture, trade, climate and bioenergy in Europe. These assessments are increasingly based on integrated approaches that require connecting models to cover the wide range of policy objectives. SUPREMA addresses this challenge by proposing a meta-platform that supports modelling groups connected already in different platforms. SUPREMA is expected to contribute to bridge the gap between decision-makers expectations and the current capacity of models to provide relevant policy assessments.

In this framework, it is essential to gain insights on models features and capacities, as well as to be aware of previous cooperation efforts among modelling teams. Nevertheless, model documentation is extensive and often scattered in different sources (e.g. model and projects websites, scientific journals) and type of documents (e.g. deliverables, technical reports, publications). Hence, the objective of this deliverable is to briefly describe each modelling system and to gather main model references to facilitate access to models and models' outcomes to potential users (e.g. modellers, decision-makers, researchers or participants in model trainings). This document also highlights the model developments that are taking place in the course of SUPREMA project.

This report is structured as follows: section 2 presents main features and description of each model, as well as some recent applications; section 3 offers an overview of relevant model interlinkages and platforms; section 4 summarises recent model developments under SUPREMA; and section 5 outlines future follow-up activities.

2 Overview of the models

2.1 AGMEMOD

2.1.1 Main features and description of the model

AGMEMOD (Agricultural Member State Modelling)	
Model type:	EU member state agro-food commodity model
Purpose:	Impact assessments of EU/national policies and macro-economic changes
Spatial coverage:	EU28 and Rest of the World
Spatial resolution:	EU member states, Macedonia, Turkey, Russia, Ukraine
Temporal scale:	Recursive dynamic, year-by-year calculations, until 2030
Website:	http://www.agmemod.eu (update in progress)

At its core, AGMEMOD is an econometric, dynamic, partial-equilibrium, multi-country, multi-market model, initially developed for EU agri-food markets covering most EU Member States (Luxembourg is combined with Belgium) at national level (main source of this section refers to Salamon et al. 2017). Based on a set of commodity-specific model templates, **country-specific models** are developed to reflect the details of agriculture at Member State level and at the same time to allow their combination in an EU model (Chantreuil et al. 2012). Later, the model has been extended to capture other countries (i.e. Turkey, Ukraine and Russia), which also contain details on their specific domestic policies. It has also been enlarged with a stylised version of the Rest of the world (ROW), however this neglects any detailed market representation and policies. A close adherence to templates assures analytical consistency across the country models, essential for aggregation purposes.

Further, AGMEMOD provides significant detail on the **main agricultural sectors** in each EU Member State. Generally, the system has been econometrically estimated at individual Member State level and provides results for the EU as a whole, the EU-15 and the EU-N13, as well as for individual countries. In some cases, parameters have been calibrated, where estimation was not feasible or meaningful. The country models contain the behavioural responses of economic agents to changes in prices and in policy instruments and to other exogenous variables in the agricultural market. AGMEMOD has built a country based set of historical data (often from 1975) that coherently integrates information from official data sources (e.g. EUROSTAT), national sources and market experts.

The models comprise equations for those commodities that represent the majority of the agricultural output in each country: six types of cereals, three types of oilseeds and their processed products — oil and meal — sugar beet and sugar, protein crops and potatoes are depicted. For animal sectors, live animals (cattle, pigs, sheep and goats) and meats (beef, pig meat, poultry, sheep and goat meat) are covered separately, while the dairy sector covers raw milk as well as processed products (drinking milk, cream, fresh dairy products, butter, skimmed milk powder (SMP), whole milk powder (WMP) and cheese, plus other dairy products). Vegetables and fruit commodities are currently build in. For each crop mentioned, figures are projected on area and yield and implicitly on production, use, trade, stocks and domestic prices (see Figure 1).

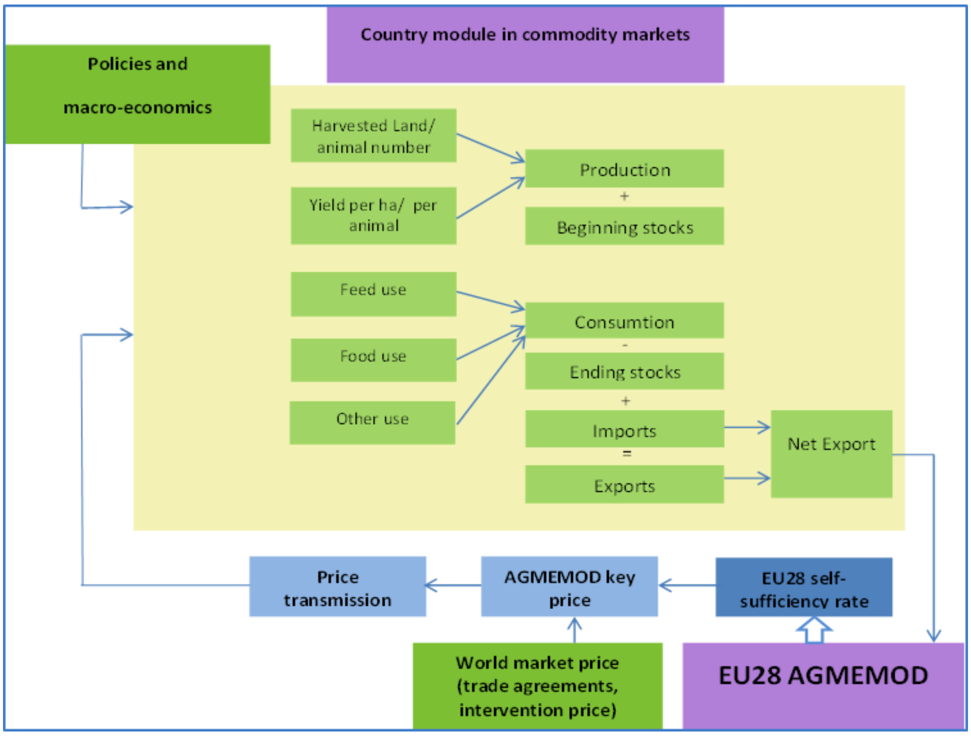

Figure 1: Stylized market representation in AGMEMOD

Source: Salamon et al. 2017

In general, equations to determine endogenous variables describe the **behavioural responses of economic agents** (farmers, consumers, etc.) to changes in, for example, market prices, policy instruments and other exogenous variables, as well as in lagged endogenous variables. The lagged variables induce a recursive model structure. For each commodity, sets of behavioural equations describe the supply side (beginning stocks, production and imports) and demand sides (domestic use, exports and ending stocks) of the market. Supply and demand equations define how, in any given year, equilibrium (i.e. supply equals demand) is found within the single commodity market. Lagged endogenous variables introduce (recursive) dynamic behaviour when entered as determinants in the next period's equilibrium supply and/or demand (Chantreuil et al. 2012). Different sectors are linked in supply and demand (see Figure 2). Detailed information on the general structure of the AGMEMOD country model equations are in Hanrahan (2001), Esposti and Camaioni (2007) and Chantreuil et al. (2012).

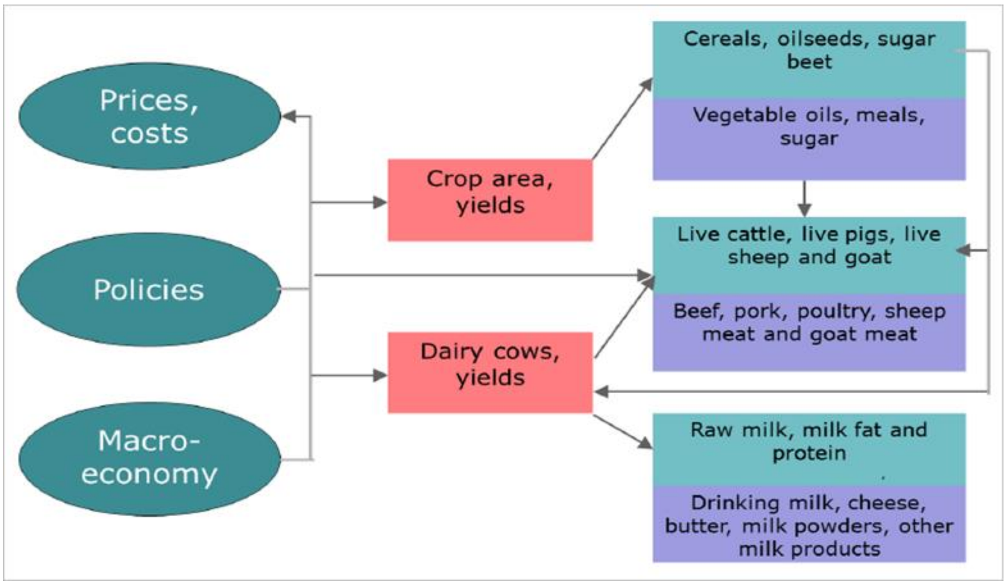

Figure 2: Linkages in AGMEMOD

Source: Salamon et al. 2017.

The behavioural equations for **land allocation** are expressed as proportions of the higher level. For example, changes in forest area or other land determines the usable agricultural area, all expressed as a proportion of total land. Usable agricultural area is then further split into subcategories, until finally the producers choose the proportion allocated to the various crop products, e.g. soft wheat. The most important explanatory variables are expected (moving average) gross margins of the categories or crops, as well as competing categories or crops at the same level. These expected gross margins include expected yields and expected prices, including a policy support component. Further explanatory variables in the land proportion equations can be trend variable, own-lagged proportions and others.

Animal products cover projections on stocks of live animals, slaughter and trade in live animals. The key in all livestock models is to determine the ending numbers of breeding animals, considering among other things price and cost variables, such as coupled or decoupled payments, and specific national policy instruments. Also essential is the number of animals produced by breeding under consideration of the productivity. Ending stocks of each type of animals (breeding and non-breeding) are derived by capturing beginning stocks, animals produced, exports and imports of live animals, slaughtering and other losses (Chantreuil et al. 2012).

The **dairy product** models comprises two levels: on the first level, milk production, milk imports, exports, on-farm use and deliverables to dairies are determined, with the last of these closing the balance. Milk production is defined by an equation considering prices, costs, an assumption on quota rents under the pre-quota abolition phase and assumptions on elasticities. In addition, milk yield per cow is determined by an equation capturing productivity by a trend and a price. As a consequence, dairy cow ending numbers are defined as an identity.

To solve the modelling system in **prices**, the supply and utilisation balances of each product at both the EU and the Member State level must hold and take into account the international trade and other commitments of the EU, such as tariff rate quotas (TRQs). The AGMEMOD composite model requires equations that impose the market equilibrium or closure (supply equals demand) for any commodity at global level, which is achieved by the integration of a stylised RoW model, where international prices are formed by closing global balances. Various domestic commodity markets are linked to each other by substitution or complementary parameters on the supply or demand side. There is competition between the various crops to use the available land. Interactions between the crops and livestock sub-models are captured via the derived demand for feed. In addition to raw milk and dairy products, the dairy sector provides calves that are exported or raised as cattle to produce beef. The various meat types, dairy products and crops are partly substitutes in demand, while cattle, pig, sheep and goat, and poultry compete for feed.

In total, the combined AGMEMOD solving process intends to provide a core competency in the economic modelling of agricultural commodity markets and agricultural policy analysis, enhancing the quality of analytical results available for policymaking and decision-making at all levels (Chantreuil et al. 2012). Quantitative baseline projections are generated for a medium-term horizon on an annual basis. The **AGMEMOD baseline** depicts the projected agricultural situation up to 2030 under a status quo policy setting. It builds on the short-term and medium-term outlooks for EU agricultural markets and income (EC 2018b). The adherence to model templates and a common modelling approach also facilitates comparisons of the impact of a policy change across different countries (Salamon et al. 2008, Salamon et al. 2017) in terms of scenario analysis.

2.1.2 Recent model applications

AGMEMOD agricultural market outlook at MS level

Salamon et al. (2017) described that the AGMEMOD model is an integral part of the Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (iMAP) hosted by the JRC (M'barek and Delincé 2015). It is one of the three core partial equilibrium (PE) models in the platform, together with CAPR and AGLINK. First, from a spatial point of view, it provides projections at the Member State level, establishing a bridge between AGLINK's aggregate projections and CAPRI's regional ones. Second, from a calibration perspective, AGMEMOD combines the information provided by AGLINK for the various EU aggregates, together with market intelligence gathered by the modelling teams in direct discussion with national market experts and at a specific validation workshop, organised by the European Commission together with the AGMEMOD consortium. At an annual basis two workshop, i.e. one at national level in Brussels and one at regional level in one of the EU13 countries, to best capture the specific differences between market outlook projections of Member States (see Figure 3).

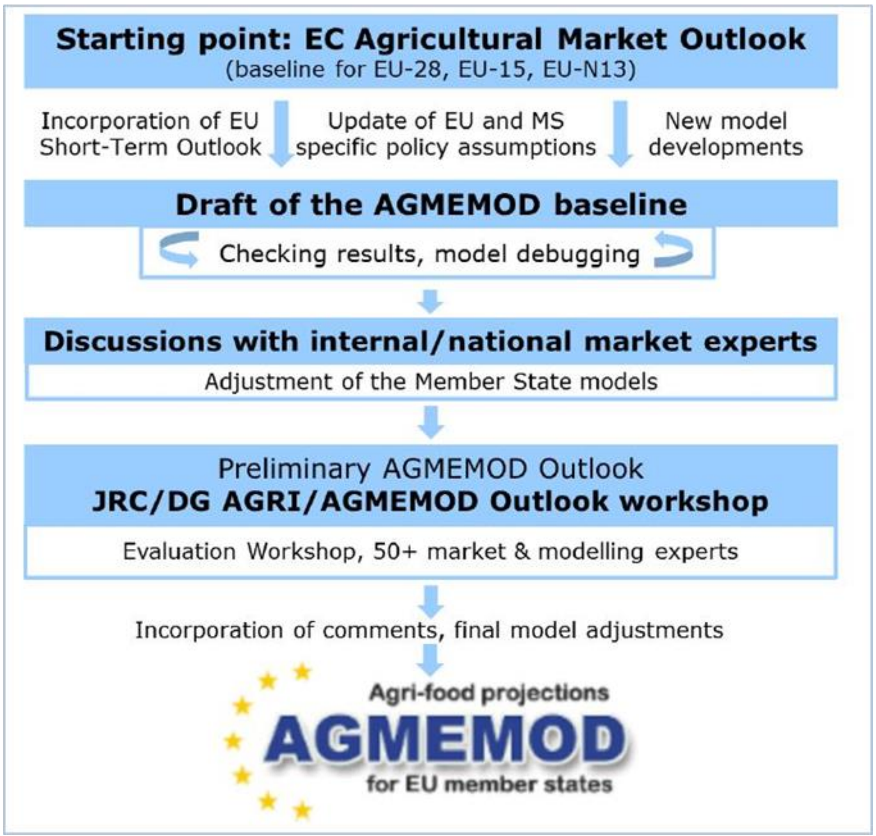

Figure 3: Process to achieve AGMEMOD agri-food projections for EU MS.

Source: Salamon et al. 2017.

The latest version of the 'Medium-term development of agri-food markets in EU Member States' is published under Salamon et al. (2019) covering the AGMEMOD Outlook for Agricultural and Food Markets in EU Member States 2018-2030. The full set of projection results at annual base is available under the following here.

German market outlook

In addition to this AGMEMOD outlook, which even-handedly set a focus on all EU Member States, there also exist country-specific outlooks based on different, country specific assumptions addressing individual purposes. Either they are fully based on AGMEMOD (see Dutch Agricultural Outlook) or apply a range of models (model family) comprising among other models also AGMEMOD (Offermann et al. 2018).

Dutch Agricultural Outlook

AGMEMOD is used to generate an annual market outlook for Dutch agriculture. This outlook is generated as a joint effort of Wageningen Economic Research, the Dutch Ministry of Agriculture and some Dutch agribusinesses, who work together on this using a public-private partnership-arrangement. Also the funding is shared (50% public, 50% private). The project crates and annual baseline for Dutch agriculture, taking into account expected market and policy conditions form the EU and the rest of the world, with a detailed representation of Dutch agricultural, environmental and trade policy measures. The outlook is published via a website and discussed and disseminated using business roundtables.

Brexit study for National Farmers Union

The AGMEMOD model has been used to assess the implications of a UK exit from the EU for British agriculture, which has been published in advance of the British referendum in 2016 (Van Berkum et al. 2016, Jongeneel et al. 2016). The study has been used by the National Farmers Union to discuss with their members the position they together should take with regard to Brexit. For this study, the AGMEMOD tool has been combined with a farm income module, which allowed assessing the impacts of market and policy impacts at farm level, for several farm types and regions within the UK. The study offers quantification of effects of possible trade and agricultural support scenarios on the UK agricultural production, trade, farm gate prices and farmers' income levels in case of the UK leaving the EU. The results of each scenario show that for most sectors the biggest driver of UK farm income changes is the level of public support payments available. The positive price impacts on farm incomes seen through both the FTA and WTO default scenario are offset by the loss of direct support payments. A reduction of direct payments, or their complete elimination, would exacerbate the negative impact seen under the UK Trade Liberalisation scenario.

Consequences of Milk quota abolition for The Netherlands

The 2015 study (Jongeneel and Van Berkum 2015) provides an assessment of what will happen after the EU milk quota system has expired in April 2015. For the study, a medium term outlook has been made, using AGMEMOD, taking into account the conditions in world dairy markets as these are foreseen by the OECD-FAO in their Agricultural Outlook as well as the medium and the EU Commission's medium term outlook. The Dutch milk supply is projected to increase by about 17 per cent in the coming decade (including quota-abolition anticipating impacts). The projected increase is related to expected market conditions (e.g. milk price), but also to other drivers and structural issues characterizing the Dutch dairy sector. With the milk quota no longer being a constraint also the milk production in the EU member states neighbouring The Netherlands is estimated to increase. More generally, milk production in northern EU (excluding Scandinavia) is expected to increase in the coming decade by about 12 million tons. The assessment is based on a modelling exercise, using the AGMEMOD model, while the outcomes of this have been discussed with experts inside and outside The Netherlands: the study synthesises modelling and expert inputs.

Consequences of Brexit for Dutch agriculture

The AGMEMOD model has been extended with respect to its trade representation for selected products and countries, including The Netherlands (distinguishing trade into three different channels: the UK, the remainder of the EU and non-EU). The study provides a quantification of the effects of two possible post-Brexit trade scenarios on Dutch agricultural trade. Dutch exports to the UK and the rest of the world will be affected only marginally under a Free Trade Agreement between the EU and the UK. A WTO-scenario will have more yet still relatively modest impacts on Dutch exports. With total agricultural exports slightly declining, Dutch exports of pig meat and tomatoes to the UK even increase as a result of Dutch price competitiveness at the UK market and greater price responsiveness of production (and exports) in other EU MS countries. The agricultural production value in the Netherlands is estimated to decline by around 2%, mainly because of declining prices that are the result of price pressure at the EU-market as a consequence of Brexit related trade distortions (Van Berkum et al. 2017, Van Berkum et al. 2018).

New products – Fish and aquaculture

In the H2020 SUCCESS project (2014-2018), and with additional support by German funds, the AGMEMOD model has been extended with capture fish and aquaculture markets (depending on the topic up to 11 species) in EU member states. Due to their importance for the European fishery sector, the model was also extended with two new countries i.e. Norway and Iceland. A baseline outlook for fishery and aquaculture up to 2030 was provided at country level (Angulo 2017a), while the integration of market expert knowledge into a modelling system was analysed in Angulo (2017b), and the impact of changes in oil price and consumer preferences on the country’s economic competitiveness were analysed as well (Fridriksson et al. 2018). Impacts of technical innovations were elaborated with respect to plaice in Angulo et al. (2018), depicting also a representation with respect to the cost structure.

Improved/new Products – Sugar and isoglycose

To improve the coverage of AGMEMOD the commodity representation was recently revised and extended by sugar beet, sugar and isoglycose. Details of approach can be found in Haß (2018), full implementation was conducted for the Outlook 2019-2030 (Haß, 2019a), and some scenario analysis has been described in Haß (2019b). Further work to enhance and revise the product coverage towards fruits and vegetables has been commissioned.

Some efforts have been attributed to differentiating the use side within AGMEMOD to gain more insights into the category of other uses. First results have been presented (Banse et al. 2018a) and published (Banse et al. 2018b).

Model linkages

In all applications, linkages were implemented under aligned assumptions. The approach to link models can be one way or two ways. In a one-way linkage, one model provides information to the other model that treats this information exogenous and simulates its scenarios. The Thünen Baseline provides a joint projection with harmonized assumptions reflecting the status-quo of policies and aligns outcomes conducted with the models of the Thünen model family. It is generated every second year (Offermann et al. 2018). Based hereon, linkages between MAGNET and AGMEMOD applies a top-down approach whereas AGMEMOD received output from MAGNET serving as exogenous input for AGMEMOD in a simulation while there is no feedback from AGMEMOD into MAGNET (see Banse et al. 2016, Gonzalez Mellado et al. 2016).

2.2 CAPRI

2.2.1 Main features and description of the model

CAPRI (Common Agricultural Policy Regional Impact Model)	
Model type:	Global agro-economic model
Purpose:	Policy impact assessment of EU policies
Spatial coverage:	Global
Spatial resolution:	National and regional within the EU
Temporal scale:	Until 2050 in flexible time steps
Website:	http://www.capri-model.org

CAPRI is a global spatial partial equilibrium model for the agricultural sector developed for ex-ante impact assessment of agricultural, environmental and trade policies with a focus on the European Union. It is a comparative static model solved by sequential iteration between supply and market modules (for a detailed description see Britz and Witzke 2014):

- The **supply module** consists of independent regional agricultural nonlinear programming models for EU-28, Norway, Turkey and Western Balkans. Supply models depict farming decisions in detail at subnational level (NUTS 2 level or farm type level) by means of a mathematical programming approach, which captures a wide range of interactions between production activities and the environment. *CAPRI-Spat* downscales regional results to a grid of 1x1 Km based on statistical distribution (Leip et al. 2008, Britz et al. 2011). In addition, the model is also able to compute results at the farm level to capture diversity in farming specialisation and economic size. The *CAPRI farm type layer (CAPRI-FT)* is especially suitable to simulate farm-specific policy instruments (Gocht and Britz 2011).
- The **market module** is a static, deterministic, partial, spatial model with global coverage, depicting about 60 commodities (primary and secondary agricultural products) and 40 trade blocks. It simulates supply, demand, and price changes in global markets considering bilateral trade flows, following the Armington assumption (Armington 1969), as well as trade policies. Demand and supply quantities are endogenous and driven by behavioural functions depending on endogenous prices. Prices in different regions are linked via a price transmission function, whereas prices in different markets in any one region are linked via cross-price terms in the behavioural functions. The parameters of behavioural functions are derived from elasticities obtained from studies and other modelling systems, and calibrated to projected quantities and prices in the simulation year. Trade policy instruments cover TRQs, intervention stock changes and subsidised exports.

CAPRI is based upon a complete and consistent database that coherently integrates information from different official data sources (e.g. EUROSTAT, FAOSTAT). Simulation results cover crop areas, herd sizes, production, consumption, trade, income indicators and environmental indicators (NPK balances, greenhouse gas emissions, water use).

Agricultural GHG emissions are calculated in CAPRI according to the Intergovernmental Panel on Climate Change (IPCC) guidelines. For EU regions, emissions per activity are computed endogenously in the supply module based on activity yields and the through nutrient flow, which considers feeding and fertilisation activities. The emissions per activity are computed as the sum of different activity items multiplied by an emission factor. CAPRI normally applies IPPC Tier 2 methods to calculate the GHG emissions, which consider detailed country-specific information on technology and livestock characteristics. Nevertheless, a Tier 1 approach is applied for activities where there is a lack of information, which is the direct calculation by multiplying activity level with emission factor. For non-EU regions, emissions are estimated per product for marketable agricultural commodities using emissions factors of EU countries as a prior, production data from FAOSTAT, and total emissions for non-EU countries from the Emissions Database for Global Atmospheric Research (EDGAR) database (Pérez Dominguez 2006, Leip et al. 2010, Pérez Dominguez et al. 2012).

The model has been upgraded with the introduction of **endogenous GHG emissions mitigation** technologies (Van Doorslaer et al. 2015, Pérez Dominguez et al. 2016). Costs of mitigation efforts enter in the total cost function that is split into costs related to mitigation efforts and other costs. Mitigation technologies can reduce emissions according to a factor that depends on the mitigation share and a reduction factor per emission type and activity when a certain mitigation option is fully adopted. The mitigation potential of these technologies is based on the marginal abatement cost curve (MAC), which relates the reduction in emissions in CO_2 equivalents with the cost of reduction per tonne of CO_2 equivalents. The model optimises the cost of achieving a certain level of CO2 equivalents reduction for each NUT2 region. The model allows for simultaneous use of different mitigation options to reduce emissions. Mitigation options included in CAPRI are based on the Greenhouse gas - Air pollution INteractions and Synergies (GAINS) database (for more detail see Pérez Dominguez et al. 2016).

Irrigated and livestock water use are computed at the NUTS 2 level in the *CAPRI water module* within the supply module (Blanco et al. 2015, Blanco et al. 2018). CAPRI water differences irrigable land (land equipped for irrigation) and non-irrigable land in the existing land balance in CAPRI. Crop activities are split into rain-fed and irrigated variants and corresponding input-output coefficients are estimated for each variant. Water is considered a production factor both for rain-fed and irrigated agriculture. Irrigable activities are divided in rain-fed and irrigated variants before solving the regional supply models and aggregated before solving the market model. Regarding livestock water use, CAPRI water uses data on water requirements (drinking water and services water) from different sources for each livestock category per head and per day to compute water requirement per head based on the production period. Livestock water requirements are introduced as a new constraint in the equation systems within the supply model.

CAPRI represents global **biofuel markets** considering endogenous supply, demand and trade flows for biofuels and biofuel feedstocks (Blanco et al. 2013). The biofuel module builds on an ex-post database that includes all market balance positions for biofuels and biofuel feedstock in each EU Member State and non-European region. Behavioural functions for biofuel supply and feedstock demand as well as fuel and biofuel demand and global biofuel trade are specified and calibrated. The reference scenarios draw on trend estimates based on the database and external expert knowledge.

The **CAPRI baseline** depicts the projected agricultural situation up to 2050 under status quo policy setting (Himics et al. 2013). The baseline builds on the medium-term outlook for EU agricultural markets and income (EC 2018b) for mid-term projections and other sources for long-term projections (e.g. GLOBIOM, IMPACT). The baseline represents in detail the CAP 2014-2020, both direct payments instruments (i.e. basic payment scheme, coupled payments, green payment, capping and convergence) and rural development measures (i.e. agri-environmental measures, less favoured area payment, Natura 2000). In terms of agricultural trade policies, the baseline considers the commitments under the Uruguay Round Agreement on Agriculture regarding market access and subsidies.

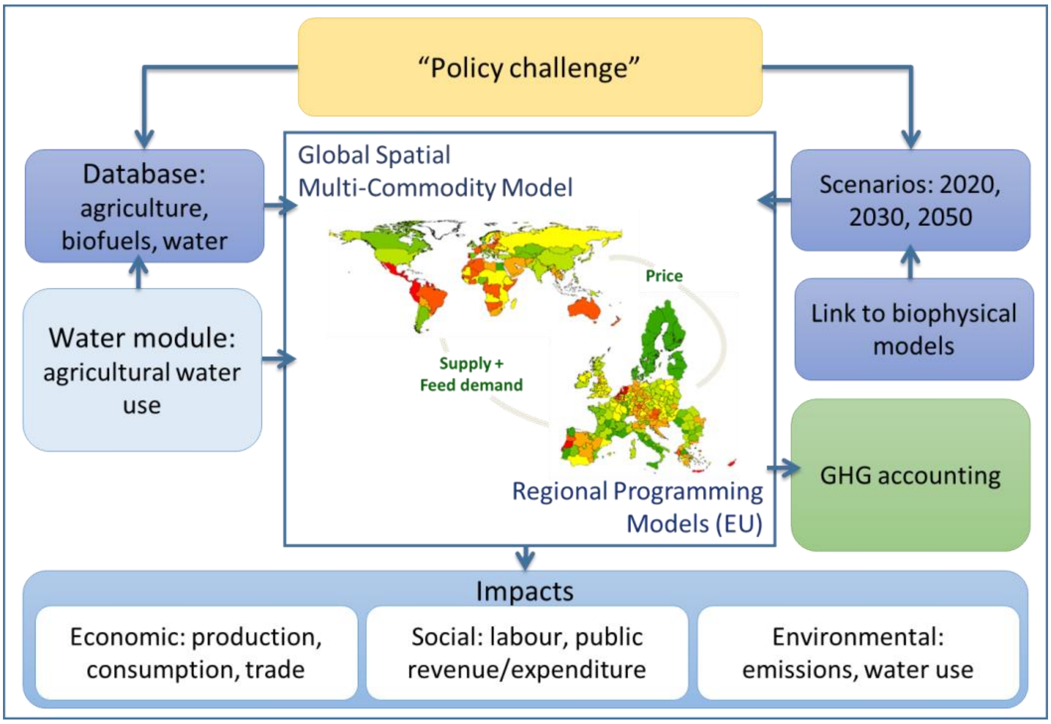

Figure 4: CAPRI modelling system.

2.2.2 Recent model applications

Agricultural policy impact assessment

The impact assessment of the proposals on the post-2020 CAP applies a multi-model approach that includes CAPRI to determine effects on production, prices, trade, GHG emissions and nitrogen balance (EC 2018c). Furthermore, different policy strategies have been analysed such as decoupling payments (Britz et al. 2013), direct payment harmonisation (Gocht et al. 2013), CAP greening (Gocht et al. 2016a), and an EU-wide policy to extend grassland areas in order to increase carbon sink capacity (Gocht et al. 2016b). The model has also contributed to the assessment of potential impact of agricultural and trade policy reform on land-use across the EU, with a particular focus on land abandonment (Renwick et al. 2012). CAPRI not only support the assessment of Pillar I measures but also Pillar II instruments (Schroeder et al. 2015).

Climate change impacts and mitigation

CAPRI enables the assessment of the potential impact of climate change in EU agriculture. In doing so, climate-induced changes in crop yields from biophysical models are introduced in CAPRI as exogenous shift in production for non-EU (market model) and exogenous crop yield shock in EU-regions (supply model). This enables to analyse regional changes in production within the EU while considering market feedback, as well as the role of trade to counterbalance uneven effects of climate change across the world (Shrestha et al. 2013, Delincé et al. 2015, Blanco et al. 2017b, Pérez Dominguez and Fellmann, 2018a).

With regard to mitigation, the model allows the assessment of mitigation policies for EU agriculture, such as emission targets and subsidies for the adoption of mitigation technologies, as well as their implications for food production (Van Doorslaer et al. 2015, Pérez Dominguez et al. 2016). Recent applications cover the analysis of challenges of including agriculture in climate change mitigation strategies (Fellmann et al. 2018) and the assessment of trade liberalisation impacts on GHG emissions abatement in the agricultural sector (Hymics et al. 2018).

Agri-environmental indicators

CAPRI computes a number of relevant environmental indicators (e.g. nitrogen balance, ammonia emissions, greenhouse gas emissions, etc.) that makes the model highly suitable for environmental impact assessment of the agricultural sector. The detailed nutrient flow in CAPRI has been exploited to estimate nitrogen budgets for agriculture in Europe (Leip et al. 2011), to measure nitrogen footprint of food products in the EU (Leip et al. 2014), and to assess the impacts of European livestock production (Leip et al. 2015).

Water-food nexus

The CAPRI water module has been applied to assess water pricing scenarios, as well as the impact of climate change on yields and water availability for agriculture (Blanco et al. 2015). The module not only enables the analysis of changes in water availability for irrigation, but also the effects of changes in precipitation in rain-fed and irrigated agriculture (Blanco et al. 2018).

Consumption patterns

CAPRI has been used to analyse environmental impacts of changing diets in Europe, linked with the environmentally extended input–output model E3IOT (Tukker et al. 2011, Wolf et al. 2011). Economy-wide impacts of food waste reduction have been also assessed based on CAPRI simulations (Britz et al. 2014).

Biofuels

CAPRI has been applied to assess the impact of EU biofuel targets on agricultural markets and land use (Blanco et al. 2010). The combination of CAPRI and GTAP enabled the analysis of the impact of EU biofuel policies on global markets and EU environmental quality (Britz and Hertel 2011).

2.3 GLOBIOM

2.3.1 Main features and description of the model

GLOBIOM (Global Biosphere Management Model)	
Model type:	Global partial equilibrium model for the forest and agricultural sectors
Purpose:	Explore trade-offs and synergies around land use and ecosystem services
Spatial coverage:	Global
Spatial resolution:	Simulation Units
Temporal scale:	10-year-step intervals up to 2050
Website:	http://www.globiom.org/

GLOBIOM (Havlík et al. 2014) is a global recursive dynamic partial equilibrium model of the forest and agricultural sectors, where economic optimization follows the spatial equilibrium modelling approach (Takayama and Judge 1971). The model is based on a bottom-up approach where the supply side of the model is built-up from the bottom (land cover, land use, management systems) to the top (production/markets) for an overview of the model framework). The agricultural and forest productivity is modelled at the level of Simulation Units (SimU), aggregates of 5 x 5 to 30 x 30 minutes of arc pixels belonging to the same country, altitude, slope, and soil class (Skalský et al. 2008).

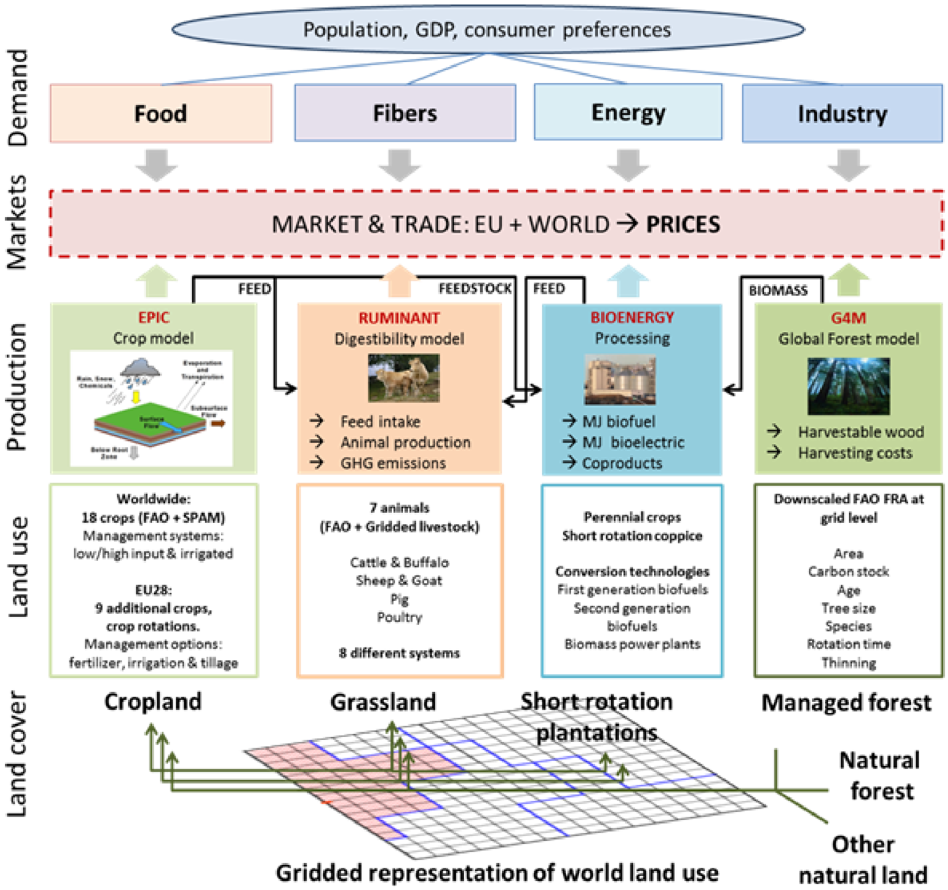

Figure 5: Illustration of the GLOBIOM model.

Demand and international trade occur at regional level 57 regions. Besides primary products for the different sectors, the model has several final and by-products, for which the processing activities are defined. The model computes market equilibrium for agricultural and forest products by allocating land use among production activities to maximize the sum of producer and consumer surplus, subject to resource, technological, demand, and policy constraints. The level of production in a given area is determined by the agricultural or forestry productivity in that area (dependent on suitability and management), by market prices (reflecting the level of demand), and by the conditions and cost associated to conversion of the land, to expansion of the production and, when relevant, to international market access. Trade is modelled following the spatial equilibrium approach, which means that the trade flows are balanced out between different specific geographical regions based on cost competitiveness and goods are assumed to be homogenous. This allows tracing of bilateral trade flows between individual regions.

By including not only the bioenergy sector but also forestry, cropland and grassland management, and livestock management, the model allows for a full account of most important agriculture and forestry GHG sources. GLOBIOM accounts for ten sources of GHG emissions, including crop cultivation N_2O emissions from fertilizer use, CH_4 from rice cultivation, livestock CH_4 emissions from enteric fermentation, CH_4 and N_2O emissions from manure management, N_2O from manure applied on pasture, above and below ground biomass CO_2 emissions from biomass removal after converting forest and natural land to cropland or dedicated energy plantations. These emissions inventories are based on IPCC accounting guidelines.

GLOBIOM endogenously represents three major **mitigation mechanisms** in the agricultural sector: i) technological mitigation options, ii) structural changes such as switches in production systems or international trade, and iii) feedback on the demand side through consumers' response to price changes. Technical non-CO_2 mitigation options based on the mitigation option database from EPA (Beach et al., 2015) and include: improved fertilizer management, nitrogen inhibitors, improved feed, conversion efficiency, feed supplements (i.e. propionate precursors, anti-methanogen), changes in herd management (i.e. intensive grazing), improved manure management(i.e. anaerobic digesters). Structural mitigation options (Havlík et al. 2014) are explicitly represented in the model via four different crop management systems ranging from subsistence farming to high input systems with irrigation technology. For the livestock sector, an extensive set of production systems from extensive to intensive management practises is available based on Herrero et al. (2013). This allows the model to switch between management practises in response to e.g. a carbon price and hence decrease emissions through GHG efficient intensification. The model may also reallocate production to more productive areas within a region or even across regions through international trade. The impact of changes in commodity prices on the demand side is explicitly considered and consumers' react to increasing prices by decreasing consumption depending on the region specific price elasticities (Muhammad et al. 2011).

The model includes six **land cover types**: cropland, grassland, other natural vegetation land, managed forests, unmanaged forests, and plantations. Other land cover types i.e. other agricultural land, wetlands, and not relevant (bare areas, water bodies, snow and ice, and artificial surfaces) are currently not modelled and kept constant over time. Initial land cover is based on Global Land Cover 2000 (GLC 2000). Economic activities are associated with the first four land cover types. Depending on the relative profitability of primary, by-, and final products production activities, the model can switch from one land cover type to another. Land conversion over the simulation period is endogenously determined for each gridcell within the available land resources. Such conversion implies a conversion cost – increasing with the area of land converted - that is taken into account in the producer optimization behaviour. Land conversion possibilities are further restricted through biophysical land suitability and production potentials, and through a matrix of potential land cover transitions (**Error! Reference source not found.**).

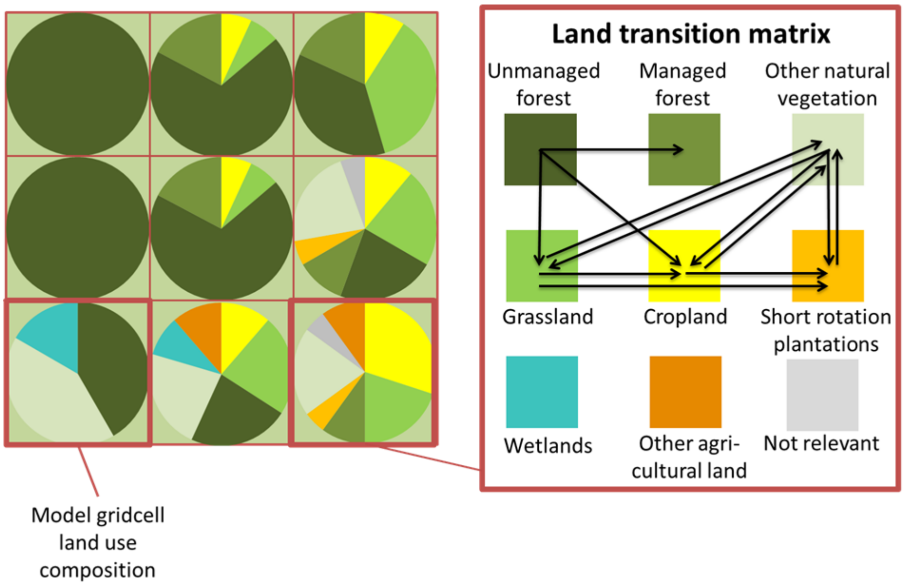

Figure 6: Land cover representation in GLOBIOM and the matrix of endogenous land cover change possibilities.

Land use change emissions are computed based on the difference between initial and final land cover equilibrium carbon stock. For forest, above and below-ground living biomass carbon data are sourced from G4M which supplies geographically explicit allocation of the carbon stocks. The carbon stocks are consistent with the 2010 Forest Assessment Report (FAO, 2010), providing emission factors for deforestation in line with that of FAOSTAT. Carbon stock from grassland and other natural vegetation is also taken into account using the above and below ground carbon from the biomass as of Ruesch et al. (2008). When forest or natural vegetation is converted into agricultural use, the GLOBIOM approach consider that all below and above ground biomass is released in the atmosphere.

GLOBIOM represents a number of conventional and advanced **biofuels feedstocks**:

- 27 different crops including 4 vegetable oil crop (Palm oil, rapeseed, soya, and sunflower);
- Co-products: 3 oilseed meal types, wheat and corn DDGS;
- Perennials and short rotation plantations: miscanthus, switchgrass, short rotation coppice;
- Woody biomass from management of forest;
- Woody by-products from forest based industries.

Various **energy conversion processes** are modelled in GLOBIOM and implemented with specific technological costs, conversion efficiencies, and co-products:

- Woody biomass (forestry): combustion, fermentation, gasification;
- Lignocellulose (energy crop plantations): combustion, fermentation, gasification;
- Conventional ethanol: corn, sugar cane, sugar beet, and wheat ethanol processing;
- Conventional biodiesel: rapeseed oil, sunflower oil, soybean oil, soya oil and palm oil to FAME processing.

This allows ethanol, methanol, biodiesel, heat, electricity and gas to be distinguished and traced according to their feedstocks. Furthermore, competition for biomass resources as considered is also taken into account between the various sectors in term of the demand for food, feed, timber, and energy. Each crop can be produced under different management systems depending on their relative profitability: subsistence, low input rainfed, high input rainfed, and high input irrigated, when water resources are available. Crop yields are generated at the grid cell level on the basis of soil, slope, altitude, and climate information, using the EPIC model (Williams, 1995). Within each management system, input structure is fixed following a Leontief production function. However, crop yields can change in reaction to external socio-economic drivers through switch to another management system or reallocation of the production to a more or less productive gridcell. Besides the endogenous mechanisms, an exogenous component representing long-term technological change is also considered. For the crop sector in the European Union member states, EPIC simulations are performed with three alternative tillage systems (conventional, reduced, and minimum tillage) with statistically computed fertilizer rates and irrigation management. Initial distribution of tillage systems are calibrated using country level data from the PICCMAT project (PICCMAT 2008). Crop rotations and additional crops have been incorporated for Europe. The model covers currently 18 crops i.e. barley, corn, corn silage, cotton, fallow, flax, oats, other green fodder, peas, potato, rapeseed, rice, rye, soybeans, sugar beet, sunflower, soft- and durum wheat. Crop rotations have been derived from crop shares calculated from EUROSTAT statistics on crop areas in NUTS2 regions using the crop rotation model CropRota (Schönhart et al. 2011). CropRota explicitly takes into account data on relative crop shares, agronomic constraints such as maximum frequency in a rotation and a score matrix of the agronomic desirability of a pre-crop – main-crop sequence.

The GLOBIOM model also incorporates a particularly detailed representation of the **global livestock sector**. With respect to animal species, distinction is made between dairy and other bovines, dairy and other sheep and goats, laying hens and broilers, and pigs. Livestock production activities are defined in several alternative production systems adapted from Seré and Steinfeld (1996): for ruminants, grass based (arid, humid, temperate/highlands), mixed crop-livestock (arid, humid, temperate/ highlands), and other; for monogastrics, smallholders and industrial. For each species, production system, and region, a set of input-output parameters is calculated based on the approach in Herrero et al. (2013). Feed rations in GLOBIOM are defined with a digestion model (RUMINANT, see (Havlík et al. 2014) consisting of grass, stovers, feed crops aggregates, and other feedstuffs. Outputs include four meat types, milk, and eggs, and environmental factors (manure production, N-excretion, and GHG emissions). The initial distribution of the production systems is based on Herrero et al. (2013). Switches between production systems allow for feedstuff substitution and for intensification or extensification of livestock production. The representation of the grass feed intake is an important component of the system representation as grassland productivity is explicitly represented in the model. Therefore, the model can represent a full interdependency between grassland and livestock.

Total forest area in GLOBIOM is calibrated according to FAO Global Forest Resources Assessments (FRA) and divided into **managed and unmanaged forest** utilizing a downscaling routine based on human activity impact on the forest areas (Kindermann et al., 2008). The available woody biomass resources are provided by G4M for each forest area unit, and are presented by mean annual increments. Mean annual increments for forests are then in GLOBIOM divided into commercial roundwood, non-commercial roundwood and harvest losses, thereby covering the main sources of woody biomass supply. The amount of harvest losses is based on G4M estimates while the share of non-commercial species is based on FAO (2010) data on commercial and non-commercial growing stocks. Plantations are covered in GLOBIOM in the form of energy crop plantations, dedicated to produce wood for energy purposes. Plantation yields are based on NPP maps and model's own calculations, as described in Havlík et al. (2011). Plantation area expansion depends on the land-use change constraints and economic trade-offs between alternative land-use options. Land-use change constraints define which land areas are allowed to be changed to plantations and how much of these areas can be changed within each period and region (so-called inertia conditions). Permitted land-cover types for plantations expansion include cropland, grassland, and other natural vegetation areas, and they exclude forest areas. Within each land-cover type the plantation expansion is additionally limited by land suitability criteria based on aridity, temperature, elevation, population, and land-cover data, as described in Havlík et al. (2011). Plantation expansion to cropland and grassland depends on the economic trade-off between food and wood production. Hence, the competition between alternative uses of land is modelled explicitly instead of using the "food/fiber first principle," which gives priority to food and fiber production and allows plantation to be expanded only to abandoned agricultural land and wasteland (Smeets et al. 2007, Hoogwijk et al. 2009, Van Vuuren et al. 2010 Beringer et al. 2011).

2.3.2 Recent model applications

GLOBIOM has been applied across a wide spectrum of research questions reaching from outlook studies on crop-, livestock- and timber markets, through climate change impact and mitigation challenges in agriculture, to policy support to reduction of deforestation or bioenergy/biofuel deployment. The model is regularly used to provide global and regional agricultural and forestry market outlooks and contributes the land use projections for the EU Reference scenario (EC 2013, EC 2016). Foresight studies assessed for example market implications of EU feed supply chains (Deppermann et al. 2018), the connection between land-use policies and agricultural development in Brazil (Cohn et al. 2014, Soterroni et al. 2018), the agricultural potential of abandoned lands in Russia and Ukraine and market implications (Deppermann et al., 2018), the impact of biomass use for energy (Lauri et al. 2014, Frank et al. 2016, Lauri et al. 2017), and improved resource efficiency and material wood substitution on forest supply chains and markets (Forsell et al. 2016, Rüter et al. 2016).

GLOBIOM was applied to inform EU climate policies on land use related issues (EC 2011, EC 2014, EC 2016) and recently quantified EU land use mitigation pathways and costs for emissions from the LULUCF sector in the EU's Long Term Strategy on climate change mitigation "A Clean Planet for All" (EC 2018). GLOBIOM was also used to quantify the indirect land use change effect of EU first and second generation biofuel policies in the transport sector (Valin et al. 2015, Leclère et al. 2016) and for aviation fuels for the US EPA.

The model represents the land component of IIASA's Integrated Assessment Model MESSAGE-GLOBIOM (Fricko et al. 2016) which is one of six global IAM's that regularly provide climate stabilization pathways to the IPCC (Riahi et al. 2016, Popp et al. 2017, Grubler et al. 2018, Rogelj et al. 2018). GLOBIOM regularly participates in model inter-comparison exercises such as the Agricultural Modelling Intercomparision and Improvement Project (AgMIP) (Nelson et al. 2014, Valin et al. 2014) and was used to quantify agricultural mitigation potentials (Havlík et al. 2014, Frank et al. 2015, Frank et al. 2018, Frank et al. 2018) and related trade-offs with food security (Frank et al. 2017, Fujimori et al. 2018, Hasegawa et al. 2018), biodiversity (Leclère et al. 2018), or other SDGs (Obersteiner et al. 2016).

GLOBIOM was recently applied to quantify climate change impacts on agricultural markets and international trade (Mosnier et al. 2014, Baker et al. 2018, Van Meijl et al. 2018) as well as adaptation strategies such as climate smart investment plans (World Bank 2019), irrigation investment needs (Palazzo et al. 2019) at regional or global scale (Palazzo et al. 2017). A GLOBIOM model version that is able to deal with yield variability related to extreme weather events but also other stochastic shocks has been recently developed (Ermolieva et al. 2016, Boere et al. 2018).

2.4 IFM-CAP

2.4.1 Main features and description of the model

IFM-CAP (Individual Farm Model for Common Agricultural Policy Analysis)	
Model type:	EU-wide farm model
Purpose:	Policy impact assessment at the farm level
Spatial coverage:	Europe
Spatial resolution:	Farm
Temporal scale:	2030

IFM-CAP is a micro model designed for the ex-ante economic and environmental assessment of the medium-term adaptation of individual farmers to policy and market changes (Elouhichi et al. 2015). IFM-CAP was developed by Joint Research Centre (JRC) in close cooperation with DG Agri starting from 2013 for the purpose to improve the quality of agricultural policy assessment upon existing aggregate (regional, farm-group) models and to assess distributional effects of policies over the EU farm population. Rather than providing forecasts or projections, the model aims to generate policy scenarios, or 'what if' analyses. It simulates how a given scenario, for example, a change in prices, farm resources or environmental and agricultural policy, might affect a set of performance indicators important to decision makers and stakeholders.

IFM-CAP is a comparative static positive mathematical programming model applied each individual farm from the Farm Accountancy Data Network (FADN) to guarantee the highest possible representativeness of the EU agricultural sector (83 292 farms). It assumes that farmers maximise their expected utility at given yields, product prices and CAP subsidies, subject to resource endowments (arable land, grassland and feed) and policy constraints, such as CAP greening restrictions. Farmers' expected utility is defined following the mean-variance approach with a constant absolute risk aversion specification. Following this approach, expected utility is defined as expected income and the associated income variance. Effectively, it is assumed that farmers select a production plan that minimizes the variance in income caused by a set of stochastic variables for a given expected income level. The main strengths and capabilities of the model include the possibility to conduct a flexible assessment of a wide range of farm-specific policies and to capture the full heterogeneity of EU commercial farms in terms of policy representation and impacts (e.g. small versus big farms).

Farmer's expected income is defined as the sum of expected gross margins minus a non-linear (quadratic) activity-specific function. The gross margin is the total revenue including sales from agricultural products and direct payments (coupled and decoupled payments) minus the accounting variable costs of production activities. Total revenue is calculated using expected prices and yields assuming adaptive expectations (based on the previous three observations with declining weights).

The accounting costs include the costs of seeds, fertilisers and soil improvers, crop protection, feeding and other specific costs. The quadratic activity-specific function is a behavioural function introduced to calibrate the farm model to an observed base-year situation, as usually done in positive programming models. This function intends to capture the effects of factors that are not explicitly included in the model, such as farmers' perceived costs of capital and labour, or model misspecifications.

Regarding income variance, most of the models in the literature incorporate uncertainty in the gross margin per unit of activity or in the revenues per unit of activity. The former models assume that prices, yields and costs are stochastic. The latter models either consider that costs are non-random because they are assumed to be known when decisions are made, or are less stochastic than revenues from the farmer's perspective. Thus, the variance in the gross margin can be approximated by the variance in revenues. In the IFM-CAP framework, the second approach is applied by considering uncertainty only in prices and yields (i.e. revenues) but without differentiating between sources of uncertainty.

A **single model template** was applied for all the modelled FADN farms in order to ensure a uniform handling of all the individual farm models and their results. That is, all the individual farm models have an identical structure (i.e. they have the same equations and variables but the model parameters are farm-specific). No cross-farm constraints or relationship are assumed in the current version of the model, except in the calibration phase where all individual farms in each region are pooled together to estimate the behavioural function parameters.

IFM-CAP is calibrated for the base year 2012 using cross-sectional analysis (i.e. multiple observations) and Highest Posterior Density (HPD) approach with prior information on regional supply elasticities and dual values of resources (e.g. land rental prices). The calibration to the exogenous supply elasticities is performed in a non-myopic way by taking into account the effects of changing dual values on the simulation response. All farms represented in the FADN sample for the year 2012 (83 292 farms), are included in the model. However, to improve the model parameterisation, past observations (2007–2012) on yields, prices and input costs for these farms are also exploited.

One needs to be aware when applying IFM-CAP that the policy simulations obviously reflect the **assumptions in the model**. First, the current version of IFM-CAP assume a fixed farms structure, implying that land can be reallocated only within farms in response to the simulated policy changes. A second potential caveat of the model is that market feedback effects (output price changes) are not taken into account. Third, certain crops are defined in the model as an aggregation of a set of individual crops (e.g. 'other cereals'). Fourth, FADN includes only commercial farms; small non-commercial farms are underrepresented in the database. A careful analysis of each of these limitations of the current version of IFM-CAP model is needed to be taken into account when analysing the simulation results.

The primary **data source** used to parameterize IFM-CAP is individual farm-level data from the FADN database complemented by other external EU-wide data sources such as Farm Structure Survey (FSS), CAPRI database and Eurostat. Most of these external data are not used directly in the model but used as an input (i.e. prior information) in the estimations. Before using FADN data in IFM-CAP, they are adjusted to the format required by the modelling framework (including addressing the outliers and the missing values). Data on unit input costs of crops, animal feeding and sugar beet quota are not directly available in the FADN database but estimated based on FADN data combined with external data sources. The HPD estimation approach was used to estimate these missing data.

For each farm, the following **variables** are derived from FADN: levels (hectares or number of animal heads), yields, product prices for all crop and animal activities, available farmland (utilised agricultural area, arable land and grassland), rental prices, and coupled and decoupled subsidies. Data on labour and capital costs are not included; they are implicitly captured by the behavioural activity function.

The **main outputs/indicators** generated by IFM-CAP for a specific policy scenario are land allocation/crop area, herd size/animal number, livestock density, share of arable land in UAA, share of grassland in UAA, land use change, agricultural production, intermediate Input use. In terms of economic indicators, IFM-CAP derives agricultural output, CAP first pillar subsidies, CAP second pillar subsidies, intermediate input costs, variable costs, total costs, gross farm income, and net farm income. Regarding environmental indicators, the model provides biodiversity index and soil erosion.

2.4.2 Recent model applications

The IFM-CAP model is designed to simulate EU-wide impacts of the Common Agricultural Policy. The IFM-CAP can also be used to model environmental impacts of policies at farm level. The model provides detailed policy impacts at individual farm level on various economic and environmental indicators. More precisely, the IFM-CAP model allows a flexible assessment of a wide range of farm-specific policies; reflects the full heterogeneity of EU farms in terms of policy representation and impacts; covers all main agricultural production activities in the EU; provides a detailed analysis of different farming systems; and estimates the distributional impacts of policies across the farm population.

IFM-CAP was applied to support different policy initiatives such as the DG Agri assessment of CAP greening used in the Commission Staff Working Document (CSWD) on the review of greening after one year (EC 2016c), impact assessment of "CAP post 2020" (EC 2018c), analysis of economic impacts of CAP greening (Elouhichi et al. 2018a, 2018b) and evaluation of crop diversification effects (Elouhichi et al. 2017) and farmers behaviour toward risk (Arribas et al. 2017).

2.5 MAGNET

2.5.1 Main features and description of the model

MAGNET (Modular Agricultural GeNeral Equilibrium Tool)	
Model type:	Global computable general equilibrium model
Purpose:	Economic Impact Assessment
Spatial coverage:	Global
Spatial resolution:	National
Temporal scale:	Until 2050 in flexible time steps (2100 is possible)
Website:	http://www.magnet-model.org/ (currently updated)

MAGNET takes a modular approach, with main features being available for the simulation depending on the question for the analysis (see below). The MAGNET model is fully documented in Woltjer and Kuiper (2014). The modular set-up of MAGNET is based on the core of the GTAP model such that all model extensions can be switched on by choices of modules to include, sometimes in combination with changes in closure file. This allows new users to start with the GTAP model and then add extensions as needed. The modular approach facilitates the possibility to tailor the model structure to the research question at hand and eases debugging when developing the model. In comparison to GTAP, a notable change is the distinction between production sectors and produced commodities throughout the model, including the introduction of by-products. See figure 7 for a simple drafting of the components of the MAGNET model.

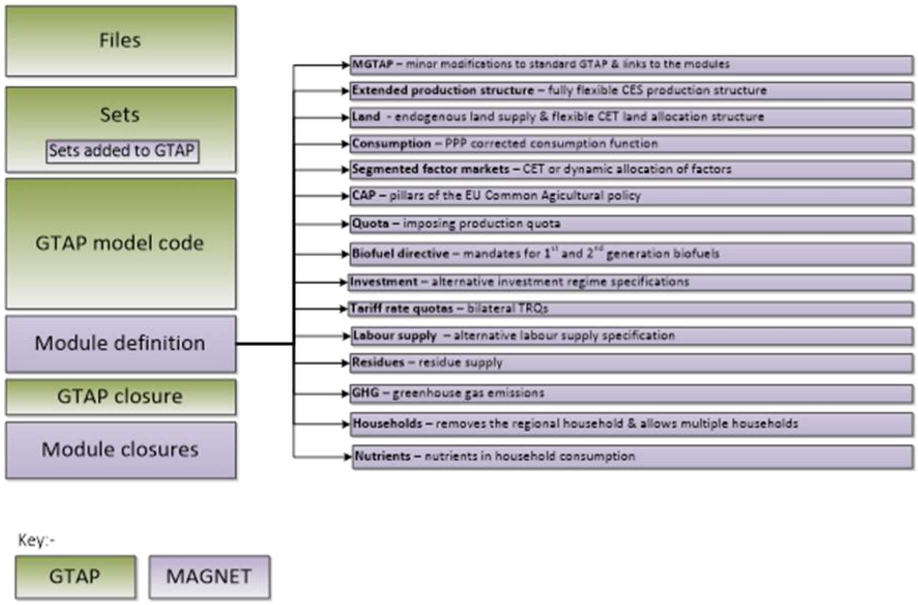

Figure 7: Overview of the structure of the MAGNET model.
Source: Woltjer et al. (2014).

The data adjustment in MAGNET means an improvement of the GTAP data as provided by adding satellite accounts with additional data needed by MAGNET (for example, land use data), by adding additional accounts to the SAMs (for example, adding biofuel sectors or adding new countries). To maintain the flexibility of the system all adjustments are made at the most disaggregated GTAP regional level. In essence, the MAGNET model is kept independent of any specific aggregation, and all databases are used in their original form as provided by the respective sources.

MAGNET is coded in GEMPACK software. This is includes all data changes and adjustments. A key principle for the coding in GEMPACK is tractability and quality control. In addition to enhancing tractability and quality updating of datasets is facilitated by the software, with the same code being applied to the updates.

Flexible production structure

The MAGNET production structure uses a nested CES production structure commonly used in general equilibrium models. In contrast to other models, users can define each production structure through a limited number of parameters. This greatly facilitates the possibilities for tailoring the production structure to the research question being addressed or compare the impact of various production structures.

Endogenous land supply

Understanding how land use changes over time and with different policies is not only a concern for agricultural analysis but it also features prominently in the discussions on climate change. Most CGE models do not account for possible changes in the total amount of agricultural land. The land supply module in MAGNET uses a land supply curve to describe the relationship between average real agricultural land rent and the area of land in a country that is used for agriculture.

Allocation land over sectors

Moving land from one use to another involves adjustments costs. To capture this, land is treated as a sluggish input in the GTAP model. A nesting structure was developed for the CET function to allow for differences in the ease of land use change between different land use types. Also the possibility of perfect competition on the land market is made available. This module offers two alternative options for land allocation: CET allocation treating land as sluggish with more nests than in the standard GTAP model and treating land as a perfectly mobile endowment.

Consumption function (adjusted for real GDP changes)

The MAGNET consumption module provides long-term projections of consumption by households, including dietary patterns, by adjusting income elasticities as GDP per capita changes over time. When performing long-term projections, incomes may change considerably and, as a consequence, the composition of consumption may also change. In the consumption module, MAGNET uses the CDE function from the standard GTAP model. Unlike in the GTAP model, the MAGNET consumption module calibrates the price and income elasticities in each optimisation step, based on a functional relationship between real (PPP-corrected) GDP per capita and income elasticities, and on exogenously given price elasticities that are normally taken from the GTAP database.

Mobile endowments and segmented factor markets

In MAGNET, the segmented mobile factor market module introduces separate agricultural and non-agricultural markets for mobile factors, i.e. labour and capital. Three types of factor markets for mobile factors are implemented in MAGNET: unsegmented, segmented with mobility between the two sectors governed by a CET function, and segmented with a dynamic migration function.

The module adds to the results produced by the MAGNET model by including different factor prices and quantities for agricultural and non-agricultural labour and capital. Divergent developments in agricultural and non-agricultural wages and capital returns can be considered to play an important role in long-term projections. In addition, the introduction of the dynamic version of the segmented mobile factor market improves the insight in medium and long-term dynamics in simulations and makes it possible to show the effects of different timings of reforms on agricultural income and employment. Note that MAGNET provides a static variant that may be used for medium term policy experiments and a dynamic variant that shows the difference between long term and short-term effects of different timings of reforms and policies on farm income and employment.

Production quota

Production quota is an important part of (agricultural) policies. For example, they are one of the policy instruments employed in the EU Common Agricultural Policy. The main challenge when modelling quota is to assure that the quota is endogenously switched off when it is not binding. This can be achieved through a complementarity condition, where either the quota is binding (i.e. production equals the upper bound imposed by the quota and a positive quota rent exists) or production is below the quota and quota rents are zero. In MAGNET, the production quota module introduces the imposition of an upper bound on production of selected sectors in selected regions. Following Harrison et al, (2004), a two-step procedure is used in the modelling: the first step in the modelling determines which quota is binding, while the second step determines the final solution. This two-step procedure increases time needed for solving the model and solutions need to be checked carefully.

2.5.2 Recent model applications

Climate change

Climate change is expected to have an overall negative impact on food security and alter trade flows in multiple dimensions: exports and imports in different regions and different sectors may respond to climate change differently. On the other hand, changes in trade environment via removing border tariffs are expected to mitigate to some extent the overall negative impacts of climate change to global economy and food security. MAGNET has a climate module that implements climate variables and related equations, i.e. CO_2 concentration, radiative forcing, potential temperature and actual temperature – to the model and introduces a function linking change in the temperature to impact on agricultural yields productivity.

For emissions, MAGNET is solved either with a CO_2 tax or with an emission reduction target. Carbon tax driven adoption of new technology by producers is implemented as means to reduce emissions. This is done by means of abatement curves. Costs of adopting a new technology enter the production function. The approach enables use of alternatives (tax or subsidy) to incentivize emission cuts. A system of emissions permit trading is incorporated into the model.

Most recent model applications cover the analysis of climate change impacts and mitigation policies on agriculture under different scenarios (Wiebe et al. 2015, van Meijl et al. 2017, Hasegawa et al 2018, van Meijl et al. 2018, Frank et al. 2019). In addition, analyses related with this area include studies on trade options (Philippidis et al. 2018b), land supply elasticities (Tabeau et al. 2017) and model linkages (Philippidis et al. 2017). With a focus on climate and land use change, MAGNET has been involved in different assessment on the implications of SSPs (Riahi et al. 2017, Doelman et al. 2018, Lotze-Campen et al. 2018)

Land use change (LUC)

MAGNET has been applied to explore future changes in land use and their impacts of land change projections in Europe (Stürck et al. 2018) and their impacts on food, water, climate change and biodiversity (van der Esch et al. 2017).

Water

An explicit accounting of water use in agriculture has been included in the MAGNET model as an ex-post analysis to assess the change in water demand. In the coming year this will be linked to an explicit agricultural water endowment. In addition, in the coming year a framework to trace virtual water flows and assess a water (and land) footprint will be included.

Recent applications comprise an analysis of virtual crop water export in Greece at river basin scale (Mellios et al. 2018), as well as the analysis of water scarcity from climate change and adaptation response in an international river basin context (Koopman et al. 2015).

Bio-economy

MAGNET has a module on blending mandates for biofuels that impose target blending rates of biofuels with fossil fuels. Whether these biofuels are produced using first or second generation technology depends on the chosen production structure of the biofuels sector. Blending mandates stipulate the quantity demanded and may affect the entire supply chain. While farmers would increase the production of e.g. rapeseed, oil mills will increase processing capacities. Additional investments will be made and additional labour forces will be employed. Thus, the growth of a whole economic sector relies on the blending mandates.

MAGNET has been applied to analyse socio-economic impacts of bioenergy production (Achterbosch et al. 2014), biofuel policy and forest conservation (Dixon et al. 2014), effects of increased bioenergy demand on global food markets (Lotze-Campen et al. 2014), implications of first generation biofuels in the EU on greenhouse gas emission (Smeets et al. 2014a) and economic impacts of bio-based applications (Smeets et al. 2014b, van Meijl et al. 2018).

CAP module

In MAGNET, the CAP module employs detailed auditing data supplied by the European Commission (DG Agri). The data covers the split of pillar 1 payments (market support) between coupled (including article 68/69) and decoupled payments, whilst the coverage of pillar 2 (rural development) covers Axis 1 to 6. From this data, a CAP baseline has been developed, although the coverage of years is limited. In addition, the modelling of the CAP budget module has been modified to permit more detailed policy shocks by specific CAP measures as well as the creation of an 'own-resources' component where CAP expenditure is explicitly co-financed by Member States. The rebate component of this module will also be updated with the change of benchmark years from 2007 to 2011.

MAGNET has been used to assess the economic and environmental effects of agricultural labour subsidies under the CAP in the European Union (Helming et al. 2018).

Food security and healthy diets/nutrition

In MAGNET, the link with micro-level diet data has been developed. This provides a new set of challenges with the need to simultaneously account for diversity in the population (age, sex and education) while the micro detail lack socio-economic detail needed for detailed demand modelling.

Recent applications comprise assessments on the impacts of different drivers on food security (Tabeau et al. 2017b, Cui et al. 2018, Rutten et al. 2018), analysis of future food demand (Valin et al. 2014, Tabeau et al. 2014), impact of population projections on prices and poverty (Kuiper et al. 2018), household coverage in global simulation models (Kuiper and Shutes 2014)

Food loss and waste

Recent references of applications in this field include the impact analysis of reducing food losses and waste (Rutten 2013a), contributions to the agricultural growth strategy in Egypt (Rutten 2013b), as well as the analysis of the food waste reduction in households and retail in the EU (Rutten et al. 2013c).

Sustainable development goals (SDGs)

The module embeds sixty indicators, covering 12 of the 17 SDGs for each region of the world. The MAGNET modelling results can thus be made accessible through translation into SDG indicators, which have become commonly accepted indicators in global impact assessment (Shutes et al. 2017, Philippidis et al. 2018a).

2.6 MITERRA-Europe

2.6.1 Main features and description of the model

MITERRA-Europe	
Model type:	Deterministic emission and nutrient flow model for agriculture
Purpose:	Environmental Impact Assessment
Spatial coverage:	EU28
Spatial resolution:	National and regional (NUTS2)
Temporal scale:	2030
Website:	Not available yet

MITERRA-Europe is a deterministic emission and nutrient flow model, which calculates greenhouse gas (CO_2, CH_4 and N_2O) emissions, nitrogen emissions (N_2O, NH_3, NO_x and NO_3), nutrient flows and soil organic carbon stock changes on annual basis, using emission factors and leaching fractions. The model was developed to assess the effects and interactions of policies and measures in agriculture on N losses on a NUTS-2 (Nomenclature of Territorial Units for Statistics) level in the EU-28 (Velthof et al. 2009, de Vries et al. 2011). Input data consist of activity data (e.g., livestock numbers and crop areas and yield from Eurostat and FAO), spatial environmental data (e.g., soil and climate data) and emission factors (IPCC and GAINS). For soil carbon the calculation rules of the well-known soil carbon model RothC are used. The model includes measures to simulate carbon sequestration and mitigation of GHG and NH_3 emissions and NO_3 leaching. The model can also assesses all GHG and nitrogen emissions following a LCA approach until the farm-gate (Lesschen et al. 2011). Effects of mitigation policies and measures can be assessed, as are long-term scenarios, based on activity inputs from other economic models (e.g. CAPRI) (e.g. de Wit et al. 2014).

The MITERRA-Europe is originally based on the models CAPRI and GAINS and supplemented with a N leaching module, a soil carbon module and a module for greenhouse gas mitigation measures. MITERRA comprises the same 35 crops as in CAPRI and in addition five perennial energy. The GAINS model estimates current and future gaseous N and C emissions from agriculture (and other sectors) in Europe. NH_3 emission factors, excretion factors and manure management system data from GAINS are used in MITERRA-Europe.

For **N_2O and CH_4 sources** the Tier 1/2 emission factors from the IPCC 2006 guidelines are used. Alternatively, for enteric fermentation member state specific emission factors can be used, as derived from the National Inventory Reports. CH_4 emissions from agriculture comprise enteric fermentation, manure management and rice cultivation. N_2O emissions from agriculture comprise manure management and soil emissions. N_2O emissions from agricultural soils consist of i) direct soil emissions from the application of N fertilizer and animal manure, crop residues and the cultivation of organic soils, ii) urine and dung produced during grazing, and iii) indirect emissions from N leaching and runoff, and from volatilised and re-deposited N. The N_2O emissions were calculated with emission factors taken from the IPCC (2006). MITERRA-Europe has its own approach for calculating N leaching and N surface runoff. Leaching fractions are based on soil texture, land use, precipitation surplus, soil organic carbon content, temperature and rooting depth and surface runoff fractions are calculated based on slope, land use, precipitation surplus, soil texture and soil depth (Velthof et al. 2009).

To assess CO_2 emissions from **changes in soil organic carbon (SOC)** a SOC balance approach was developed in the FP7 SmartSoil project, inputs of carbon (manure, crop residues, and other organic inputs) and the losses of carbon from decomposition were quantified. The RothC model (Coleman et al. 1999) was used to calculate the SOC balance. RothC (version 26.3) is a widely used model of the turnover of organic carbon in non-waterlogged soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. Soil organic carbon is split into four active compartments and a small amount of inert organic matter in RothC. The four active compartments are Decomposable Plant Material, Resistant Plant Material, Microbial Biomass, and Humified Organic Matter. Each compartment decomposes by a first-order process with its own characteristic rate. RothC requires the following input data: 1) monthly rainfall, 2) monthly open pan evaporation, 3) average monthly air temperature, 4) clay content of the soil, 5) an estimate of the decomposability of the incoming plant material – the DPM/RPM ratio, 6) soil cover, 7) monthly input of plant residues, 8) monthly input of manure, and 9) soil depth. Initial carbon content can be provided as an input or calculated according to long term equilibrium (steady state). The initial carbon content and clay content are derived from the LUCAS soil survey (Toth et al. 2013). LUCAS collected soil samples in 2009 at about 22000 locations across the EU, which were analysed for a range of soil properties, including soil carbon and clay content. Carbon input from manure are derived from MITERRA-Europe, following the allocation of manure nitrogen to crops and a livestock type specific CN ratio. Carbon input from crop residues was derived from the crop areas and crop yield in MITERRA-Europe and the harvest index.

The model includes **measures to enhance carbon sequestration and mitigation** of GHG and NH_3 emissions and NO_3 leaching. Measures to reduce N_2O emissions include balanced fertilization, nitrification inhibitors and measures to reduce N leaching and runoff. Within the PICCMAT project a range of agronomic mitigation measures were included (e.g. cover crops, reduced tillage, crop residue management) (Lesschen et al. 2008). Koslowski (2016) parameterised in MITERRA a range of measures for the EU dairy sector including grazing period, feed additives and covering manure storages.

2.6.2 Recent model applications

Climate change mitigation

MITERRA-Europe was used in different projects to assess the potential of different mitigation options for greenhouse gas emissions. In the EU PICCMAT project a range of options to enhance soil carbon sequestration and options to reduce soil N2O emissions were assessed. In a more recent project for JRC the effectiveness of precision agriculture was simulated, where information from derived from farmer surveys, was upscaled to assess the mitigation potential for the EU member states.

Soil carbon management

The FP7 EU project SmartSOIL focused on arable and mixed farming systems in Europe and developed an innovative approach using the soil C flow and stocks concept to assess the impact of C management on crop productivity, soil organic C stocks and other ecosystem services. In this project the soil carbon RothC model was incorporated in MITERRA for the assessment of soil carbon stock changes for the EU and a farming systems approach was developed for the assessment of different soil management options.

Impact of biomass use

The carbon impact biomass use project for DG Energy had the objective to deliver an assessment of the direct and indirect GHG emissions associated to different types of solid and gaseous biomass used in electricity and heating/cooling in the EU under a number of scenarios. Here MITERRA-Europe was used to quantify the GHG impact of agricultural biomass use. The model has also been used in another project to estimate the potential of anaerobic digestion of manure and agricultural residues and the carbon savings.

Nutrient flows and circular agriculture

The H2020 project Nutri2Cycle, which started at the end of 2018, will provide important developments for the sustainable and efficient management of natural resources in agriculture. The Nutri2Cycle project will assess the current Nitrogen, Phosphorus and Carbon flows looking into existing management techniques in different farms across Europe and analysing their related environmental problems. MITERRA-Europe will be used to provide the baseline against which a range of innovative systems and techniques will be assessed.

3 Model interlinkages and platforms

3.1 DG-Agri - Agricultural Outlook

The EU agricultural outlook for the agricultural markets and income (EC 2018b) draws on model projections and expert knowledge (Pérez Dominguez et al. 2018). Model projections are derived from AGLINK model at different aggregated levels for the EU. AGMEMOD contributes with results for the cereal sector at Member State level, whereas CAPRI provides outcomes related to the environmental dimension, such as greenhouse gas emissions, ammonia and nitrogen losses to water, at Member State and NUTS 2 levels.

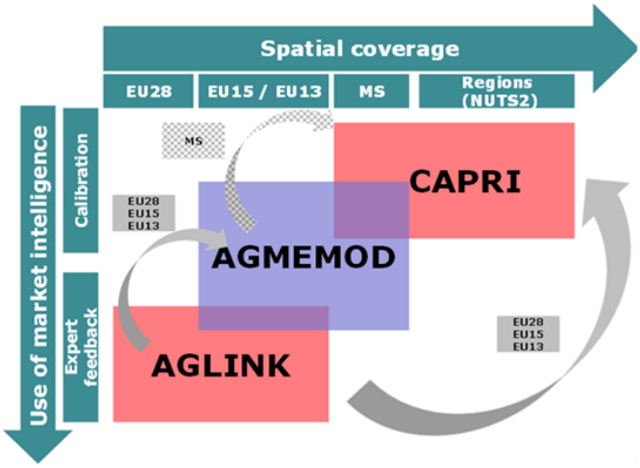

Figure 8: EU agricultural outlook modelling framework.

3.2 DG-Clima – Reference scenario for energy and climate action

The EU Reference Scenario for energy, transport and GHG emissions trends to 2050 (EC 2016a) applies a multi-model framework that incoporates CAPRI and GLOBIOM. CAPRI delivers results for the agricultural sector, which includes livestock, fertiliser use and biofuel demand. GLOBIOM offers results on the EU LULUCF sector, in particular land use changes and associated CO_2 emissions. CAPRI and GLOBIOM exchange information on livestock, crops, forestry and LULUCF effects in a consistent way, which is ensured through cross checks ex-ante and ex-post.

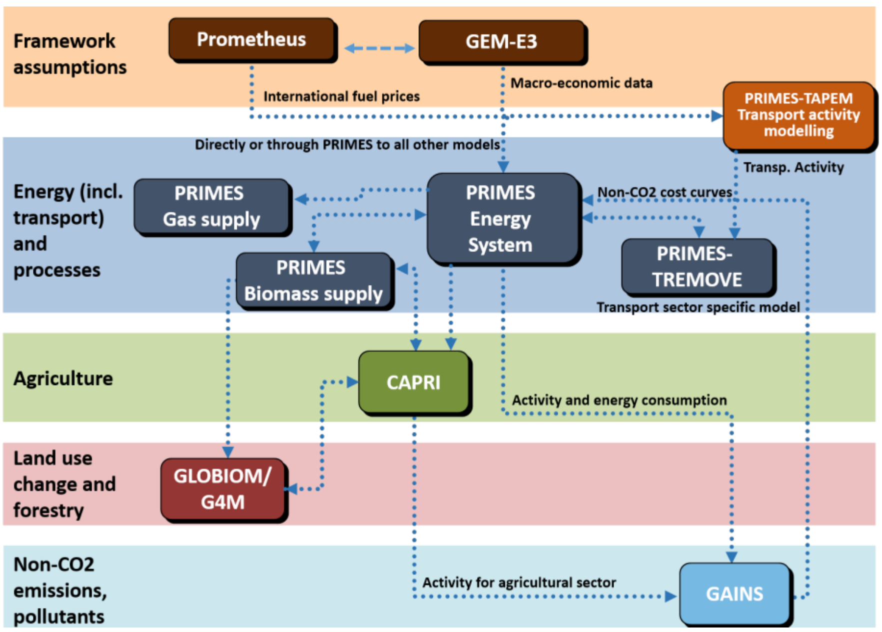

Figure 9: Modelling framework for the EU Reference Scenario for energy, transport and GHG emissions. Source: EC (2016a).

3.3 Scenar 2030

"Scenar 2030 – Pathways for the European agriculture and food sector beyond 2020" is a work elaborated by the JRC of the European Commission and outside experts to assess the impact of potential future CAP scenarios on the EU agricultural sector. The analysis uses the iMAP (integrated Modelling Platform for Agro-economic Commodity and Policy Analysis), particularly the models CAPRI, IFM-CAP and MAGNET, to link global markets to individual farms, as well as to consider different policies that affect agricultural development (M'barek et al. 2017).

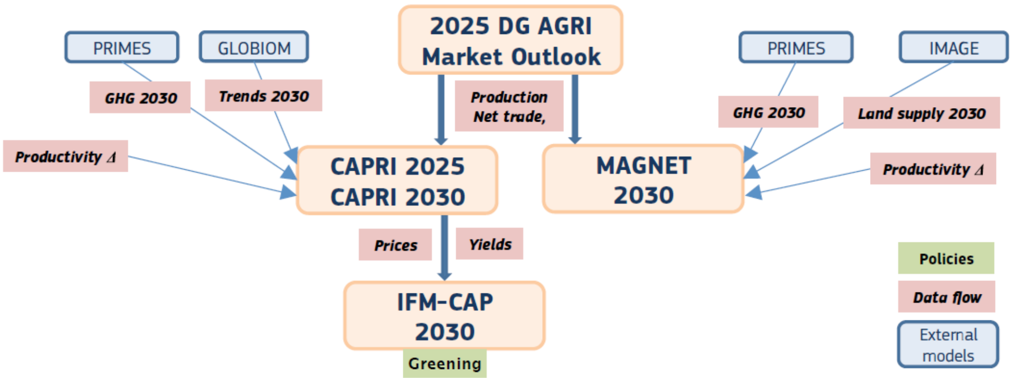

Figure 10: Scenar 2030 modelling framework.
Source: (M'barek et al. 2017).

3.4 AgMIP

AgMIP is an international network linking the research community active in the fields of climate, crop, and economic modelling to improve assessments on the impacts of climate change in food security (Rosenzweig et al. 2013).

In the framework of AgMIP, the project Challenges of Global Agriculture in a Climate Chang Context by 2050 (AgCLIM50) analyses the impacts of climate change and mitigation strategies on the agricultural sector over the horizon 2050 (van Meijl et al. 2017). The assessment is based on a multi-model approach that includes, inter alia, CAPRI, GLOBIOM and MAGNET.

3.5 Other combined applications of the SUPREMA tools

3.5.1 AGRICISTRADE

The EU 7th Framework Programme project AGRICISTRADE explores the impact of potential developments of the food, feed and biomass sectors in Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Moldova, Russia and Ukraine, members of the Commonwealth of Independent States (CIS) with the exception of Ukraine and Georgia, as well as consequences for trading relations between the EU and these countries.

The quantitative assessment of likely agricultural development is based on the combination of AGMEMOD, GLOBIOM and MAGNET. To enable the link among the three models, AGMEMOD has been updated for EU Member States and CIS countries, and MAGNET and GLOBIOM has been extended. Likewise, common assumptions and exchange data are harmonised between models for a common baseline and scenario analysis (Berkum et al. 2016).

Model linkage builds on a two-way approach (Wolf et al. 2016). Each model provides information to the other model. In a first step, a focus was on agriculture production (GLOBIOM and AGMEMOD). In a second step, a linkage between AGMEMOD and MAGNET in the processing sectors of agricultural products was included as well. Before the actual linking i.e. common exogenous drivers and endogenous variables have to be identified, assumptions of all sorts and starting values have to be harmonized and the different sectoral and regional aggregation of the models have to be mapped to each other (see Banse et al. 2014, Section 5). A tool was developed to 'translate' data from one model specification into the format of another model to avoiding errors and save time. This Model Junction linkage Tool (MOJITO) allows with some additional efforts to link different models to each other and is not designed to only link GLOBIOM, AGMEMOD, and MAGNET (see Wolf and Bouma 2016).

3.5.2 FOODSECURE

The EU 7th Framework Programme project FOODSECURE attempts to support the design of coherent policies that tackle food and nutrition security challenges. The project develops a modelling toolkit to assess long-term policies at different scales up to 2050, enabling the analysis of food availability and access, and dietary change at household level under climate change. The toolkit builds upon four models, including MAGNET and GLOBIOM, a set of harmonised economic-biophysical drivers in line with the SSPs, and a group of indicators related to food and nutrition security. The FOODSECURE Navigator offers combined results for an integrated MAGNET-IMAGE framework and the GLOBIOM model.

3.5.3 SIM4NEXUS

The EU Horizon 2020 project SIM4NEXUS (Sustainable Integrated Management FOR the NEXUS of water-land-food-energy-climate for a resource-efficient Europe) aims at developing innovative methodologies to bridge knowledge gaps and support policy-decision making in the water-land-food-energy-climate Nexus under climate change. In particular, the project attempts to develop a Serious Game as a tool for the integrated assessment of potential policy scenarios in the nexus at different spatial scales (from global to regional) and time horizons (from short- to long-term).

The development of the Serious Game builds on 12 case studies (global, European, and different national, regional and transboundary cases within Europe) and Systems Dynamics Modelling. This modelling methodology combines stakeholder knowledge and quantitative information from statistics and model projections. To cover potential future developments on the different nexus sectors, SIM4NEXUS applies a multi-model approach that includes seven models, inter alia, CAPRI and MAGNET. The models provide baseline results and case study-specific scenario results up to 2050.

As part of the project, a common simulation setting has been developed to harmonise as much as possible the outcomes from the models, in order to ensure the feasibility of combining results from such different modelling systems (Blanco et al. 2017a).

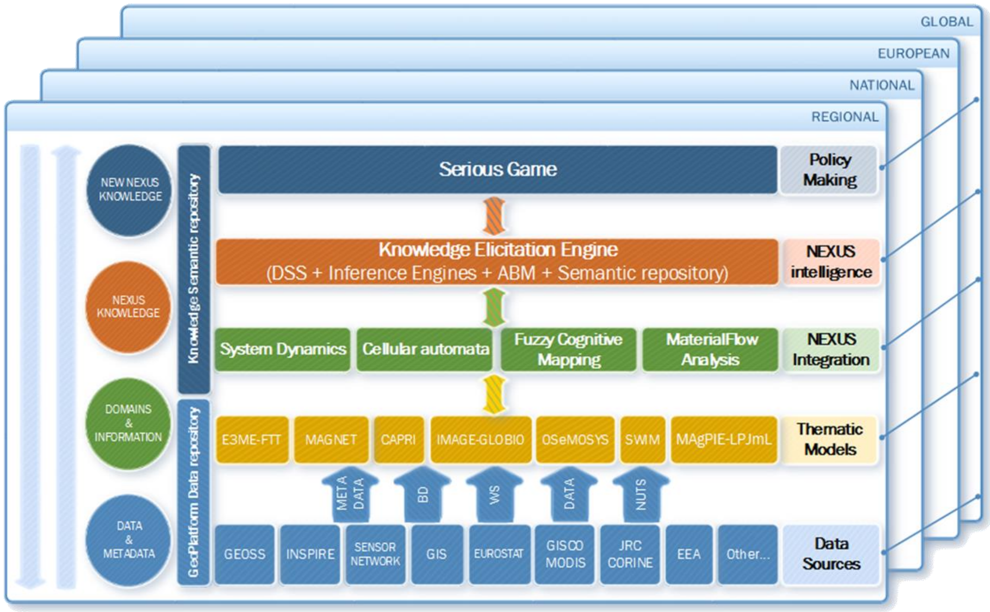

Figure 11: SIM4NEXUS project approach.
Source: SIM4NEXUS website.

3.5.4 SUCCESS

SUCCESS (Strategic Use of Competitiveness towards Consolidation the Economic Sustainability of the European Seafood Sector) is an EU H2020 project aiming to enhance the competitiveness of the fisheries and aquaculture sectors in Europe. In particular, the project explores two strategies to boost employment and innovation in these sectors: 1) technological and structural innovations and 2) removal of competitiveness barriers in the supply chain. The SUCCESS toolbox developed within the project integrates AGMEMOD and MAGNET to build mid-term projections on the competitiveness of the European fisheries and aquaculture sectors up to 2030, as well as to facilitate the economic impact assessment of innovations and trade policies (Van Leeuwen et al. 2016).

In the framework of the project, AGMEMOD has been upgraded to include new countries (Norway and Iceland) and to capture the fisheries and fish farming sectors. Likewise, MAGNET has been improved to disaggregate the standard fishery sector into fishery sector and aquaculture sectors for EU member states, Iceland, Norway and Vietnam. Furthermore, fishmeal and fish oil processing sectors have been incorporated to the model.

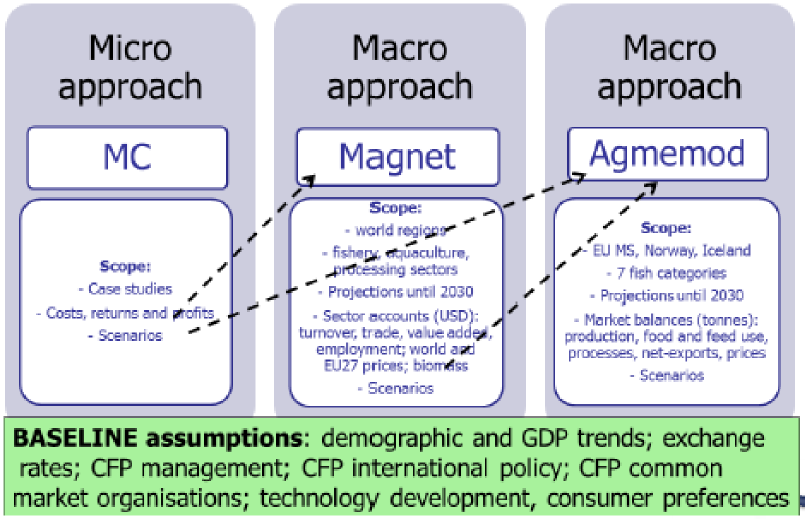

Figure 12: SUCCESS toolbox.
Source: Van Leeuwen et al. (2016).

3.5.5 SUSFANS

The EU H2020 project SUSFANS (Strengthening European Food and Nutrition Security) seeks to develop evidence-based and analytical tools for framing EU-wide food policies that consider impacts on consumer diet and arisen consequences for nutrition and public health, the environment, the competitiveness of agri-food sectors.

SUSFANS applies CAPRI, GLOBIOM and MAGNET to assess long-term impacts of interventions on the food system. Within the scope of the project, CAPRI has been improved to capture regional heterogeneity responses to fertilizer. In addition, micronutrients have been entered into the product-based accounting system to assess nutrition security. GLOBIOM has been upgraded to better represent crop intensification and crop expansion responses, through new crop-modelling results and empirical estimates of crop supply elasticities. This improvement allows for a more precise assessment of production, resource use and environmental sustainability. Likewise, both models have developed a fish and aquaculture module to capture a wider range of interdependencies within the food systems, as well as to enable a more comprehensive assessment of food and nutrition security (Heckelei et al. 2017). Regarding MAGNET, the model has been improved to include further details on household and meat and fish products, as well as on aquaculture and fish processing sectors (Kuiper et al. 2017)

SUSFANS toolbox builds on a soft-linking approach based on parameter harmonisation and data exchange, in order to bring additional benefits to the individual application of the models. The model outputs are mapped to metrics by considering the comparative advantage of each model when selecting the outputs used. Differences across models are addressed in discussions among modelling teams and might result in model adjustments (Rutten et al. 2016).

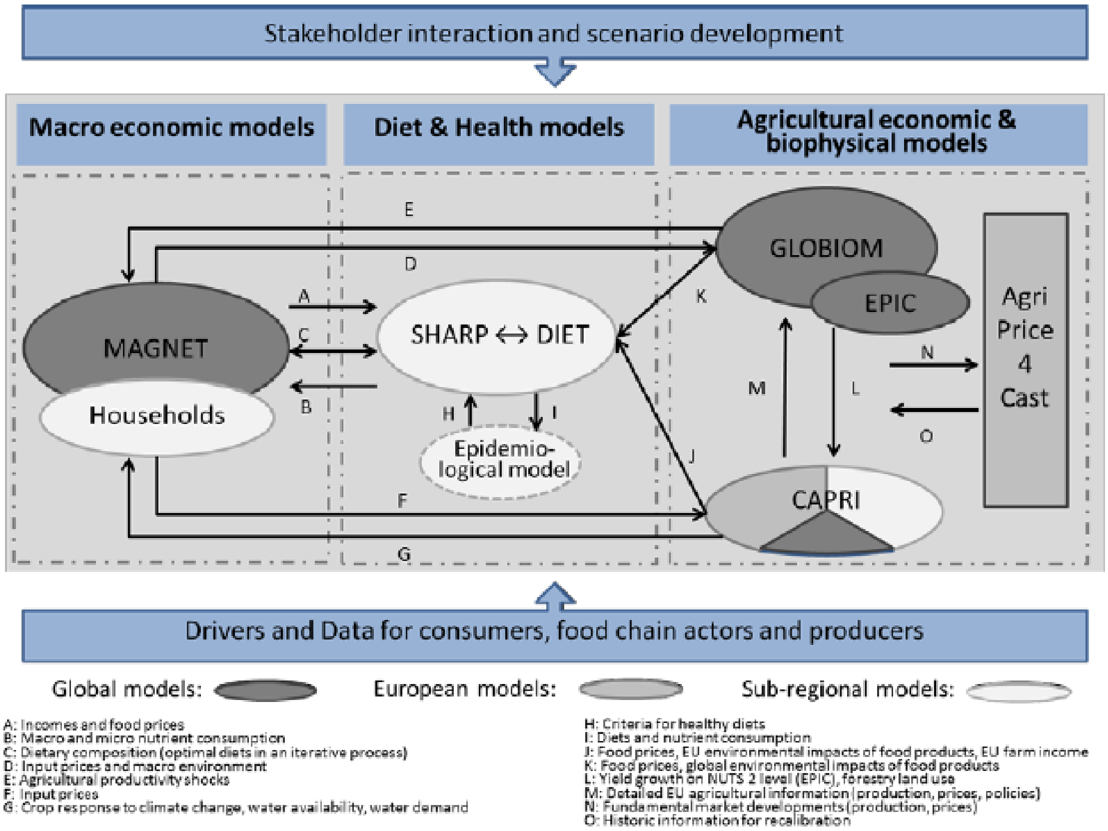

Figure 13: SUSFANS toolbox.

Source: Rutten et al. 2016.

4 Recent model developments under the SUPREMA project

In the course of SUPREMA project, different improvements are underway to address limitations in each modelling system and enhance models linkage:

- AGMEMOD enhancements focus on the representation of agricultural policies, the enlargement of the market expert network and related validation tools; and the mechanisms of price transmission across regions and products.
- CAPRI developments aim at enhancing the integration across spatial scales, approaching activity and land-use representation in non-EU countries, upgrading mitigation modelling and improving the representation of new technologies introduction by farmers.
- GLOBIOM and MAGNET upgrades attempt to cover extreme weather events and to improve the representation of SDGs, land use change and introduction of new technologies by farmers.
- MITERRA-Europe enhancements focus on improved implementation of LULUCF emissions and accounting for post-2020 climate policies and the additions of indicators for biodiversity.

Model developments are described in detail in Deliverable 2.3, whereas advancements on model linkages are reported in Deliverable 2.2.

5 Follow-up activities

This deliverable represents a comprehensive but synthetic source of information on the models engaged in SUPREMA, which is expected to be useful for current and potential model users. The document is primarily an information resource for modellers involved in SUPREMA and might be part of the training materials used in the training sessions planned in the project.

Beyond the scope of SUPREMA, this report constitutes a knowledge base that decision makers and stakeholders can used to gain insights into the capabilities and limitations of the SUPREMA models.

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