D5.1 - Modelling scope and data needs

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Abstract:	The overarching objective of Work Package (WP) 5 is to provide a model-based assessment of scenarios that depict a transition of European livestock production systems (ELPS) towards more economically, ecologically, and socially sustainable systems, as defined in WP6. To achieve this objective, the modelling framework combines three models: MAFSEU, AGMEMOD and CAPRI. The description of each model outlines its specific modelling approach and highlights its strengths. The particular role of each model in the STEP UP modelling framework is then defined based on this information. AGMEMOD is the only recursive-dynamic model that delivers year-by-year projections. It will be used to make initial projections for a number of mainly trend-driven variables (e.g. yields, stocks) over a defined time horizon. Also, operating at the level of member states, it can focus on simulating country-specific policy measures. The MAFSEU model, with its envisaged explicit representation of antibiotic use and use of other chemical inputs, serves as a tool for simulating changes in their use. MAFSEU also encompasses the link between food consumption and health indicators, and can be used to assess the health consequences of dietary shifts. CAPRI provides a highly detailed representation of greenhouse gas emissions and nutrient flows, including depictions of mitigation options, and will be used for respective assessments. Additionally, operating on the NUTS2 level (supply module), CAPRI will be used to assess regionalised effects. For other main results (production, consumption, trade), efforts will be made to provide consistent outcomes across all three models. This should be achieved through data exchange, harmonisation of shock implementation, and adjustment of model parameters where appropriate. To ensure a smoother implementation of scenarios defined in WP6 in models, it is important to have a common understanding regarding the way scenarios are simulated in models. To address this issue, we provide an overview of some of the potential storyline elements that could be captured by the modelling framework. We also provide more details on the specific scenarios that could be implemented by the individual models. Finally, we outline the essential data and information required for scenario simulation and for differentiating between livestock production systems in models. The latter is also key to successfully enhancing the AGMEMOD and MAFSEU models, as well as calculating aggregated effects.

Document Revision History

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4.	STICHTING WAGENINGEN RESEARCH	WR	Netherlands
5.	IFIP-INSTITUT DU PORC ASSOCIATION	IFIP	France
6.	EUROPEAN FORUM OF FARM ANIMAL BREEDERS	EFFAB	Netherlands
7.	AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS	CSIC	Spain
8.	UDRUZENJE ZA PREDUZETNISTVO I INOVACIJE FOODSCALE HUB	FSH	Serbia
9.	INSTITUT DE L'ELEVAGE	IDELE	France
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List of Abbreviations and Acronyms	
AGMEMOD	Agricultural Member State Modelling
BFP	Biodiversity-Friendly Farming Practices
CAPRI	Common Agricultural Policy Regional Impact model
DIA	Diet Impact Assessment
ELPS	European Livestock Production System
ESVAC	European Surveillance of Veterinary Antimicrobial Consumption
EU	European Union
GAMS	General Algebraic Modelling System
GBD	Global Burden of Disease
GHG	Greenhouse Gas
GVA	Gross Value Added
MAFSEU	Modelling the Transition of Food Systems in the European Union
NUTS	Nomenclature of Territorial Units for Statistics
PIF	Population Impact Fractions
ROW	Rest of the World
SJOS	Safe and Just Operating Space
SSR	Self-Sufficiency Rate
T	Task
UAA	Utilised Agricultural Area
WHO	World Health Organization
WP	Work package

1. Introduction

The overall objective of Work Package (WP) 5 is to provide a model-based assessment of scenarios that depict a transition of European livestock production systems (ELPS) towards more economically, ecologically and socially sustainable systems as defined in WP6 (Task (T) 6.2 'Definition of scenarios to be assessed within the SJOS for EU livestock').

Future projections for a number of indicators will be presented, including those characterizing the livestock sector and the markets for animal-based products (T5.4 'Modelling different scenario options'). To perform this task, a modelling framework based on three models - CAPRI, AGMEMOD, MAFSEU - will be established (T5.1 'Framing the modelling scope and data needs').

Considering the need to better capture the diversity of livestock production systems in the EU, the AGMEMOD and MAFSEU models will be enhanced (T5.2 'Enhancement of the AGMEMOD model' and T5.3 'Enhancement of the MAFSEU model') building on the typology proposed in T1.1 ('Mapping and analysis of livestock farming systems across Europe'). In addition, where appropriate and possible, model improvements may include the generation of additional outputs (indicators) that could be used for the overall assessment of scenarios in the context of the concept of a Safe and Just Operating Space (SJOS) for EU livestock (as conceptualised in T6.1 'Definition of a Safe and Just Operating Space (SJOS) for EU livestock'). The extent of model improvements depends on the availability of data, including those compiled in T1.4 'Attributing the data of impacts and externalities (T1.4) to types of livestock systems'.

The modelling results will be further used to estimate aggregated effects and monetization of externalities for environmental, social and economic impacts and externalities of the most relevant selected typical production systems from T1.1 (T5.5 'Estimating aggregated effects and monetization of externalities, synergies and trade-offs'). Together, the results of T5.4 and T5.5 will be used for the overall scenario assessment in WP6 (T6.3 'Assessment of scenarios within the SJOS for EU livestock').

This report summarises the work carried out under T5.1 'Framing the modelling scope and data needs'. It describes the modelling framework (Chapter 2) as a whole and provides information on individual models (Chapter 3). Chapter 4 provides an overview of potential storyline elements that could be captured by the modelling framework, followed by more details on the specific scenarios that could be implemented by the individual models. Finally, Chapter 5 outlines the essential data and information required for scenario simulation and for differentiating between livestock production systems in models.

2. STEP UP modelling framework

For modelling different scenario options in WP5 three models –MAFSEU, AGMEMOD and CAPRI - will be used. Each model has its own particular strength, but cannot cover fully topics addressed by other models. Used together in a coherent manner – the STEP UP modelling framework (Figure 1) – these three models enable a consistent scenario assessment.

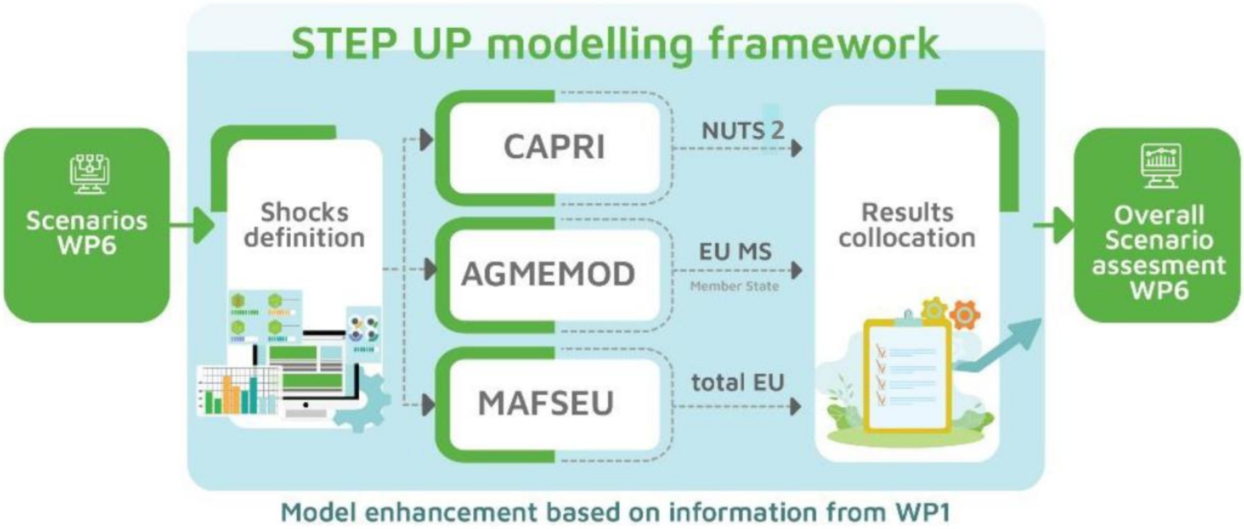

Figure 1: STEP UP modelling framework

Although all three models (MAFSEU, AGMEMOD and CAPRI) focus on the agri-food sector in the EU, they differ from each other in a number of respects. The most obvious difference is the level of spatial detail: MAFSEU operates at EU level, AGMEMOD at EU member state level, and CAPRI at NUTS2 level (supply module EU). With regard to product and activity details, the most comprehensive level of detail on the supply side is provided by CAPRI, followed by AGMEMOD and then MAFSEU. When it comes to final uses/demand, the picture is mixed. Food consumption is the main focus of all three models with MAFSEU using a more aggregated product grouping than AGMEMOD and CAPRI (both operating at the level of EU member state level). However, MAFSEU also encompasses the link between food consumption and health indicators. MAFSEU and CAPRI address losses and waste issues specifically, whereas in AGMEMOD they are part of total food use. Feedstock demand for energy use is modelled in CAPRI and AGMEMOD, while feedstock demand for material use is the unique feature of AGMEMOD (with BioMAT module focusing on bio-based chemicals).

Each model has a particular thematic focus that will be utilised in the STEP UP project to give a coherent analysis on different scenarios. AGMEMOD is the only recursive-dynamic model that provides year-by-year projections and will be used to estimate the magnitude of continuing historical trends (e. g. projections of prices, yields and stocks) over a specific time period. This information could then be passed to MAFSEU and CAPRI to define the magnitude of specific shocks related to these developments. The strength of the MAFSEU model is the detailed depiction of antibiotic use and other chemical inputs (as part of the envisaged model enhancement), it will serve as the primary model for simulating the use of chemical inputs. As it is also very strong in evaluating the impact of diets, this will also be a task primarily handled by this model. CAPRI depicts the emission of GHGs in very great detail with several reduction options for emissions in the livestock sector already modelled, which can give great insight for this project. Additionally, enhancements to AGMEMOD and MAFSEU should help depict the effects of changes in the weight and relevance of different livestock production systems in the EU.

Besides the differences in terms of details (spatial, activity/product coverage) and specific focuses, these three models also differ with respect to the underlying modelling approach. The latter is particularly expected to result in challenges when using scenario analysis. It is a quite usual experience that implementing scenarios in different models results in some differences in outcome. Although establishing direct linkages between the models is beyond our current scope, we will address this issue by:

- data/information exchange between models to give a coherent and clear picture regarding the different scenarios;
- discussing the outcomes of individual models;
- possible adjustments to the way shocks are implemented; and
- adjustment of some model parameters, if reasonable.

This will ensure that the modelling results of all three models undergo a comprehensive internal validation process, ensuring overall scrutiny of the results. The general aim is to achieve consistent results for the main indicators across all models. For specific outcomes, however, the most suitable model, or the only model able to report them, will be used.

While the subsequent Chapter 3 provides an overview of individual models in more detail, Table 1 summarises the key characteristics of each model and shows where overlaps between models are as well as the unique features of each individual model.

		MAFSEU	AGMEMOD	CAPRI
General features	Static/dynamic	Comparative static	Recursive-Dynamic	Comparative static
	Simulation approach	Market balances under constraints	Market balances under constraints	Supply module EU: profit maximizing of representative farms
	Regional representation	EU27 aggregate	Individual EU member states	Supply module EU: NUTS2 level
Land (use)	Total	Yes	Yes	Yes
	Arable land	Yes	Yes	Yes
	Grassland	Yes	Yes	Yes (intensive/ extensive grassland)
	Other uses	Yes (i.e. set-aside)	Yes (i.a. set-aside)	Yes (i.e. set-aside)
Crops	Primary production	Cereal aggregates, Oilseeds, Protein crops, Root crops, Fruits & vegetables, Nuts	Cereals (9 categ.) Oilseeds (3) Sugar beet Potatoes Protein crops Fruit +Vegetable Some other	Cereals (8 categ.) Oilseeds (3) Other arable field crops (4) Veg. &perm. crops (9) Feeding stuff (10) Other ind. crops (3) All other crops (3)
	Processed products	Oils and meals Sugar	Oils and meals Sugar, Isoglucose	Oils and Oil cakes Sugar
Livestock	Stocks	-	Cattle (3) Pigs (2) Sheep and goats (2)	Cattle (12) Pig (2) Sheep and Goat (2) Laying hens, Poultry fattening, Other animals
	Meat	Beef Pork Poultry Eggs	Beef Pork Poultry Sheep and goat	Beef Pork Poultry Sheep and goat
	Milk (collected)	Milk equivalent	Yes	Yes
	Processed prod.	Under construction	Dairy products (7+)	Dairy products (10)
Final uses and losses	Food consumption	13 product categories in final consumption	Food use: 40+ products	List of 51 products
	Bioenergy	-	Crops for bioethanol and biodiesel prod.	Bioethanol Biodiesel
	Biomaterials	-	Crops material use + BioMAT (16 biochem.)	-
	Losses & waste	Yes	Part of ‘food use’	Food loss shares in households and retail

Table 1: Key characteristics of MAFSEU, AGMEMOD, CAPRI

3. Overview of individual models

3.1. MAFSEU

MAFSEU (**M**odelling the tr**A**nsition of **F**ood **S**ystems in the **E**uropean **U**nion) is an original and synthetic partial equilibrium economic model that represents the EU-27 food system as a whole. It explicitly captures the production, feed and food demand of six plant products (cereals, oilseeds, protein crops, root crops, fruits & vegetables, and nuts), three processed products (sugar, oil, and oilcakes) and five livestock products (bovine meat, dairy, pork, poultry, and eggs). Chemical input use in plant production (fertilizers, and pesticides) and in livestock production (antimicrobials) is explicitly modelled. Agricultural land supply is endogenously determined and is allocated among the competing land demands of each production sector. Four agricultural land uses are distinguished, i.e., i) arable land (cropland), ii) permanent grassland, iii) temporary grassland and iv) other fodder areas. Equilibrium market prices for each product (and land) are determined by balancing supply and demand, including trade (imports and exports) for products for which it is relevant. The model includes a comprehensive representation of policy instruments affecting both production, consumption and trade. It encompasses two environmental indicators to assess the impacts of scenarios on GHG emissions and biodiversity. It also makes it possible to analyse the impacts of scenarios on the nutritional and health quality of diets.

MAFSEU is a synthetic model, where output supply, input derived demand and food final demand functions are explicitly derived from theoretical foundations (maximisation of profit functions on the supply side and maximisation of utility functions on the demand side). Theoretical properties of these functions are verified (homogeneity, symmetry, and convexity/concavity). As a result, MAFSEU enables the traceable and transparent analysis of economic mechanisms and the effects of public policies and their instruments. It allows for the assessment of scenario impacts on producer and consumer prices; quantities supplied, traded (imports and exports) and demanded (feed and food); producer income and welfare; and consumer spending and welfare. Non-market indicators include indicators of GHG emissions, biodiversity, as well as the nutritional and health quality of diets. As part of the STEP UP project, a major improvement to the first version of the model (Guyomard et al. 2023) is the calculation of a wider range of indicators that allow assessing the impact of contrasted scenarios on the EU livestock position in the Safe and Just Operating Space (SJOS) for EU livestock, which is developed in WP6 of the project (cf. Deliverable 6.1; Rogel-Gallard et al., 2024).

The first version of the model was developed and used in Guyomard et al. (2023) to evaluate the market and non-market impact of the agri-food components of the European Green Deal. The extended version of the model is calibrated using average data from the years 2019, 2020, and 2021 (referred to as '2020'). This extended version is currently being developed further within the STEP UP project.

3.1.1. Model description

The first version of the model (Guyomard et al. 2023) distinguished three groups of products (plant products, ruminants and monogastrics), and three types of agricultural land uses (arable land, forages, and non-productive agricultural areas). It distinguished producer and consumer prices, modelled imports and exports via net trade, and considered food waste and losses along the whole food chain. It encompassed two ecological indicators related to climate change and biodiversity. It evaluated food consumption quality through a set of nutritional indicators.

The enhancement of the model that will be completed as part of Task 5.3 of the STEPUP project (Enhancement of the MAFSEU model) includes the disaggregation of the three aggregate groups of products into six groups of plant products, two ruminant products and three monogastric products (Figure 2). As with production, demand for land from all plant and ruminant sectors, as well as demand for feed for the different livestock activities, will be coherently disaggregated. We make the simplifying assumption that the various monogastric activities purchase all the animal feed they require. This enables a reduction in the number of parameters that need to be calibrated for the monogastric activities. In the same way, we assume that the two ruminant activities purchase all the concentrate feed they require. The use of chemicals in each sector (fertilisers, pesticides, and antimicrobials) will be modelled explicitly. Finally, the model enhancement will explicitly model main public policy instruments (production, trade and consumption instruments).

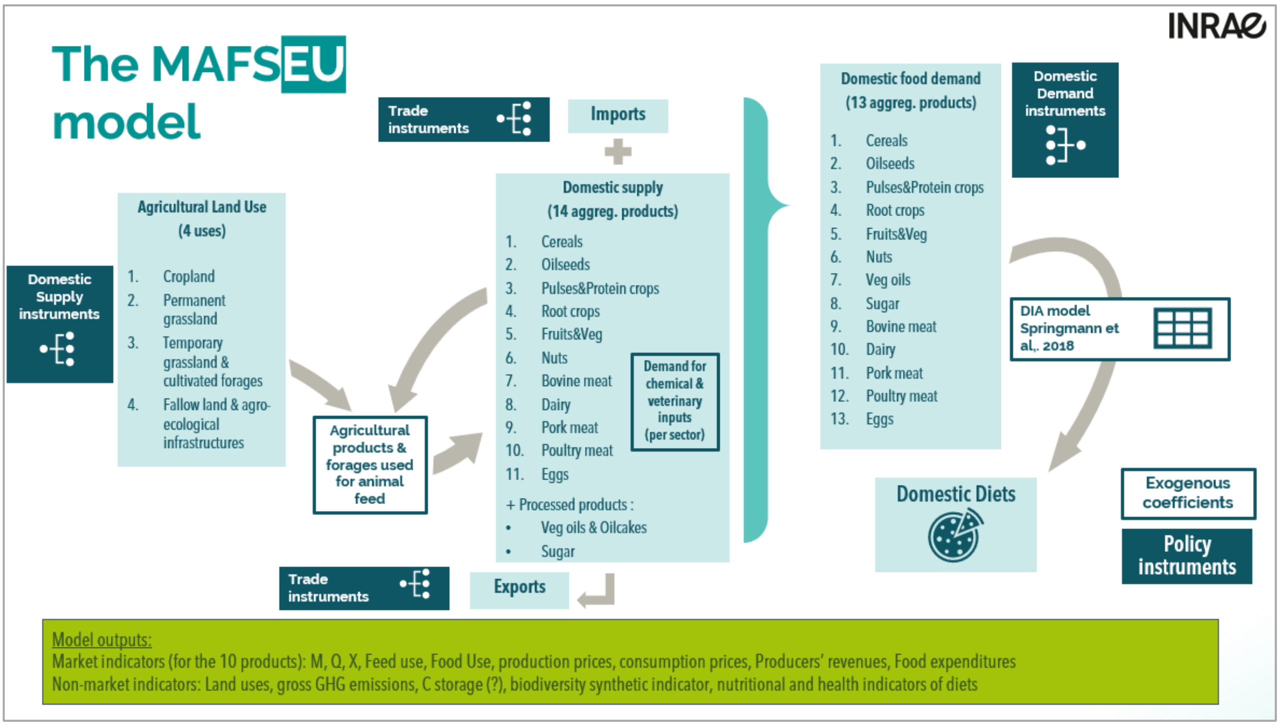

Figure 2: The MAFSEU model in a nutshell

Whereas information would be available during the project's lifetime, MAFSEU could also capture the diversity of European livestock production systems and extend the non-market indicators (based on work developed in WP1 and WP3). In the following, as the development of the model is ongoing, we describe the future enhanced model which is going to be used in STEP UP.

In terms of production, MAFSEU encompasses the following production activities: i) four aggregated annual field crops (cereals, oilseeds, protein crops and root crops); ii) fruit and vegetables (F&V); iii) nuts; and iv) five livestock products (bovine meat, milk, pork, poultry and eggs). The supply of the four annual field crops, F&V, and nuts, as well as the associated demand for chemicals (fertilisers and pesticides), is derived from quadratic profit functions. In this framework, the production of each field crop depends on its producer price, the producer prices of other field crops (including subsidies and/or taxes), the cost of chemical inputs (including taxes and/or subsidies), and the amount of land allocated to the aggregate sector of annual field crops. The aggregate demand for chemical inputs for four annual field crops is a function of the price of each field crop (including taxes and/or subsidies), the prices of chemical inputs (including taxes and/or subsidies), and the total amount of land used for annual field crops. The same structure is used for F&V and nuts. Each of the two sectors is modelled independently. As a result, the sector of, say nuts, depends on the price of F&V and the prices of other plant and ruminant activities only through the allocation of agricultural land among all agricultural uses, including permanent grassland, temporary grassland, and other cultivated forages.

The model explicitly accounts for the processing of oilseeds and sugar beets in order to represent the derived markets for, respectively vegetable oils and oil meals, and sugar.

The production of livestock and the demand for related inputs (chemicals used on forage land areas and antimicrobials used in animal production) are also derived from quadratic profit functions. The supply of ruminant products (beef and milk) and monogastric products (pork, poultry, and eggs) responds to changes in output prices (including subsidies and/or taxes), feed costs (including potential subsidies and/or taxes), and antimicrobial costs (including potential taxed and/or subsidies). The feed requirements of the livestock production sectors for crops and crop products (as well as grass and other forages for the two ruminant activities) are calculated using fixed technical coefficients (assumption of a Leontief technology), based on the GlobAgri-AE2050 model (Forslund et al. 2023).

The total supply of agricultural land is modelled as a linear function of the land price and is allocated among seven uses: land areas devoted to the four annual field crops; land used for F&V; land used for nuts; permanent grassland; temporary grassland; land used for other cultivated forages; and finally, land used environmental purposes. The latter category includes areas set aside and high-biodiversity landscape features, such as field margins, wetlands or peatlands.

In terms of final food demand, the model covers thirteen product groups: cereals, oilseeds, protein crops, root crops, F&V, nuts, sugar, vegetable oils, beef, dairy products, pork, poultry and eggs. They are modelled as a complete food demand system that ensures the compatibility with theory. Consumer demand for each product group responds thus to changes in prices and food spending. Food waste and losses at the final consumption stage are calculated using product-specific coefficients (FAO 2011) as well as waste and loss rates from food availability, ensuring that the resulting quantities actually consumed are compatible with the Diet Impact Assessment (DIA) model (WHO 2023).

International trade is incorporated via import and export functions. Following the Armington approach, it is modelled on the basis of imperfect substitution between domestic and imported goods, as well as between domestic and exported goods. For each product, EU imports and exports are linear functions of relative price ratios. Imports depend on the ratio of import to domestic prices, while exports depend on the ratio of domestic to world prices. Trade-related policy instruments, including import duties and export taxes, are also taken into account.

Equilibrium market prices are determined by balancing the supply of each product (production plus imports) with the demand for that product (food, feed, waste and losses, other uses and stock variations). There are two exceptions to this rule: the prices of sugar beets (within the root crops category) and oilseeds are assumed to be driven by the markets for their processed outputs (sugar on the one side, and vegetable oils and oil meals on the other side). Consumer prices differ from producer prices by margins initially calibrated using reference period data. These margins are exogenous parameters. They can be modified within a scenario.

The data used to calibrate endogenous and exogenous variables for the base year '2020' are drawn from the following sources:

- MAFSEU relies on reports from DG AGRI on market outlooks for supply (harvested areas, yields, and production quantities for crops and livestock products) and market balance sheets for most products. Market balance sheets from FAOSTAT are used for some products when DG AGRI information is incomplete or unavailable. Additionally, where data on food demand is limited, FAOSTAT data on food availability is used for calibration purposes. Consumed quantities in the base year are derived from food demand using coefficients on food losses and waste from FAO (2011). Loss and waste along the food chain (storage, transport and distribution) are recalculated where this information is missing from the balance sheets.

- Data on land cultivated for forage crops, temporary pastures and permanent pastures comes from Eurostat.
- For each product, the EU average producer price is calculated using detailed producer prices per country and item from the FAOSTAT database. Market producer prices for processed products are derived from DG Agri and Oil World data.
- Data on the use of chemicals in crop production are based on FAOSTAT for totals (fertilisers and pesticides), and data from the International Fertiliser Organisation for use per crop. Data on the use of antimicrobials in livestock production sectors are taken from the European Surveillance of Veterinary Antimicrobial Consumption (ESVAC) project's report on total sales of antimicrobials for food-producing animals. The allocation of antimicrobial use between livestock sectors is based on the work of Blomquist et al. (2024).
- Supply, derived demand and final demand elasticities are drawn from the literature. They are calibrated to comply with the theoretical properties of profit, trade and utility functions.

3.1.2. Main variables

Table 2 depicts the relationships between the inputs, activities and outputs of the MAFSEU model's production processes. Table 3 lists the endogenous variables. Table 4 lists the exogenous variables.

Inputs	Activity	Outputs
Chemical inputs (fertilizers & pesticides) used in crop production Land devoted to each crop	**Crop production activities (annual field crops, fruits & vegetables, nuts)**	Primary output products: Cereals, oilseeds, protein crops & pulses, root crops, fruits & vegetables, nuts Processed output products: Vegetal oils & oilcakes from oilseeds Sugar from sugar beets
Feed crops (cereals, oilseeds, protein crops, root crops, oilcakes) Veterinary (antimicrobial) inputs	**Livestock production activities (beef, dairy, pork, poultry, eggs)**	Bovine meat Milk from cows Pork meat Poultry meat Eggs
Forages for feed (permanent grassland, temporary grassland, other cultivated forages) Chemical inputs (fertilizers & pesticides) used on forage land Land devoted to the three types of forages	**Ruminant livestock production activities (beef & dairy)**	Bovine meat Milk from cows

Table 2: Input / output variables in MAFSEU's production activities

	Endogenous variables
Agricultural supply	Quantities produced of the various plant products (crops and forages)
	Quantities produced of the various animal products
	Use of chemical inputs (fertilisers, pesticides, veterinary products)
	Total agricultural land supply and agricultural land allocation to the different uses, including agro-ecological infrastructures
Demand	Feed demand for the different components of animal feed
	Food demand for the different components of diets
	Food consumption for the different components of diets
	Food waste and losses at final consumption level for the different components of diets
Food chain	Waste and losses along the whole food chain
Trade	Exports of each traded product
	Imports of each traded product
Prices	Producer prices
	Consumer prices

Table 3: Insights into the endogenous variables and parameters of the MAFSEU model
(not exhaustive and subject to change in line with the ongoing efforts to enhance the model and utilise it to generate as many indicators as possible that characterise the SJOS for EU livestock)

	Exogenous variables
Derived demand	Feed efficiency (feed intake / ASF output)
Final demand	Other uses of agricultural products (non-feed and non-food uses: industrial uses, energy uses)
	Household waste rates
Food chain	Food waste and loss rates along the food chain
Prices	Margins between final consumption and production prices
Public policy instruments	Decoupled direct subsidies
	Coupled direct subsidies
	Share of agricultural land devoted to agro-ecological infrastructures (with the possibility to differentiate this share according to the type of agricultural use)
	Taxes on chemical inputs (or other regulations targeting their use)
	Taxes/subsidies on the different ingredients of animal feed (to favour or, on the contrary, discourage the use on a given type of feed ingredient)
	Trade policy instruments (taxes/subsidies on imports and/or exports, other regulations targeted on imparts and/or exports)
	Taxes/subsidies on the various final consumption goods (to favour or, on the contrary, discourage the consumption of a given type of food products)

Table 4: Insights into the exogenous variables and parameters of the MAFSEU model
(not exhaustive and subject to change in line with the ongoing efforts to enhance the model and utilise it to generate as many indicators as possible that characterise the SJOS for EU livestock)

3.1.3. Derived Indicators

In line with the definition of a Safe and Just Operating Space (SJOS) for the EU livestock sector proposed in WP6 of the project, MAFSEU will provide both market and non-market indicators.

Market indicators. For each traded product, MAFSEU enables the determination of production prices and quantities, as well as derived demands for chemical inputs (fertilisers and pesticides in crop production, and antimicrobials in livestock production), as well as land allocations between activities (cropland, F&V land, nut land, cultivated forage areas, temporary meadows, and permanent pastures). Market indicators such as producer income (value added) and welfare can thus be provided. Using information on base year levels of subsidies and assumptions about future changes, MAFSEU can also be used to derive indicators concerning the economic resilience of the EU livestock sector by estimating the sensitivity of producers' income and welfare to changing market conditions and/or public policy parameters. For each product, the model determines consumer prices and food demand on the consumer side. Indicators such as consumer expenditure and changes in consumer welfare can be calculated. The final per capita consumption of each product (EU27 average) can also be derived, as will the quantification of food losses and waste at household level.

Finally, for each tradable product, the model estimates the quantities imported and exported according to changes in relative prices and trade policy instruments. Consequently, where necessary, indicators relating to import dependency and self-sufficiency ratios for livestock products or feed can be derived.

Environmental indicators. The current version of the model encompasses two environmental indicators. GHG emissions are calculated at the farm gate based on emission coefficients per kilogramme of product, as calculated by Crenna et al. (2019). These coefficients can be adjusted according to the strategy proposed by Belassen et al. (2021), which enables differentiation of emissions according to production practices (conventional versus agro-ecological) and product origin (domestic versus imported). The improved version of the model will allow us to assess GHG emission impacts using both a production- or consumption-based approach.

The impacts on biodiversity are estimated using coefficients for land-use impacts on plant species richness, as calculated by Knudsen et al. (2017). These impacts on biodiversity are distinguished according to the type of land use (e.g. arable land, temporary pastures, permanent pastures, and agro-ecological infrastructures) and management practices. The model will provide information on the damage to biodiversity linked to domestic agricultural land use, and to the import and export of the different products. Within the framework of the project, efforts are being made to expand the set of environmental indicators so as to encompass a broader range of dimensions of the SJOS for EU livestock.

Nutrition and human health indicators. Thanks to the link between the output of the MAFSEU model in terms of per capita consumption and the DIA (WHO 2023), as described by Springmann et al. (2018), MAFSEU will be able to provide information on the nutritional content of the EU average diet in terms of both macronutrients (e.g., calories, plant and animal proteins, fats, carbohydrates, and fibres) and micronutrients (e.g., essential minerals and vitamins). The DIA model estimates the nutrient content of foods by matching the consumption of seven food groups (processed meat, red meat, F&V, legumes, nuts, and whole grains) with their nutrient density, as reported in the Global Expanded Nutrient Supply dataset. It then compares the resulting nutrient profiles of dietary scenarios with World Health Organization (WHO) recommendations. To calculate population-level average nutrient values, the DIA uses age- and sex-specific demographic data from the Global Burden of Disease (GBD) project for the given year of analysis. It also considers the energy requirements of a moderately active population, using average US height as an upper bound.

Furthermore, linking the MAFSEU model to the DIA model will enable some of the health impacts of dietary changes to be estimated. The DIA model calculates Population Impact Fractions (PIF) to estimate mortality and morbidity linked to dietary risk factors. These represent the proportion of disease cases that could be prevented by shifting risk exposure from the baseline level to an alternative scenario. The model uses dose-response functions based on the relative risks associated with each food product. The model will thus enable the assessment of the just dimension linked to diets of the SJOS for EU livestock.

3.2. AGMEMOD

The primary objective of AGMEMOD is to provide projections that can be used to analyse the economic impact of policy measures or other structural changes on the agri-food sector of EU Member States and the EU as a whole. The modelling approach is rooted in a bottom-up principle, wherein country-specific models are derived from a standard model template. These models are then merged into a consistent aggregated EU model. The maintenance, updating and utilisation of these models is primarily conducted by economic modellers within each country's respective context, which is a distinctive trait of AGMEMOD. The AGMEMOD Partnership collaborates with expert committees at the country level. These committees regularly review and comment on the model outputs. The purpose of this process is to improve the quality and relevance of the projections for the purpose of political decision-making. Consequently, the model has emerged as a key instrument in the analysis of agricultural policies and markets within the EU, thereby providing a robust partial equilibrium model for evidence-based policy decision-making.

The AGMEMOD model was originally developed to provide a detailed representation of the agri-food markets in the member states of the European Union. Over time, the model has been expanded to include other countries outside the EU. Today it includes the EU-27, United Kingdom, Norway, Iceland, Macedonia, Turkey, Belarus, Russia, Ukraine, Kazakhstan, some African Countries and Argentina. Furthermore, a stylised model for the Rest of the World (ROW) was integrated, although it does not contain a detailed political or structural representation of these countries. The model facilitates medium-term annual projections (baseline projections) for the included countries and the EU as a whole. These projections encompass a range of economic variables, including supply, demand, price and trade developments. The econometrically estimated parameters of each model reflect the behaviour of economic agents (e.g. farmers, consumers). In instances where estimation is not feasible, calibration of parameters is employed. The modelling incorporates a range of political instruments, including coupled and decoupled direct payments, taxes, and tariff rate quotas (TRQ).

3.2.1. Model description

AGMEMOD (**AG**ricultural **ME**mber states **MOD**elling) is an econometric, dynamic, multi-country, multi-market, partial equilibrium model. Here is the justification for these characteristics:

- **econometric**, while **e**quation parameters are estimated based on annual time series data;
- **dynamic**, because of recursive structure: lagged endogenous variables become exogenous in subsequent periods (e.g., prices and quantities);
- **multi-country**, as individual countries are modelled;
- **multi-markets,** as a number of commodity markets modelled individually**;**
- **partial equilibrium model,** as it models only agri-food sector, information about macroeconomic developments enter the model exogenously (via assumptions).

Figure 3 presents a schematic representation of the AGMEMOD model's fundamental structure. Each 'country-market box' is a representative of a distinct agricultural commodity market in one specific country, modelled individually. The system of functional equations and identities captures interlinkages between variables in the same commodity markets in one country as well as impact of relevant variables from other agricultural markets and countries. The parametrisation of functional equations is done based on annual time series data and is also used for historical trend estimation. Supply and demand (use) equations are estimated separately, but the price mechanism ensures market closure by adjusting import and export quantities to achieve equilibrium between supply and demand. Prices in AGMEMOD are formed in three main ways. For the majority of commodities and Member States, domestic prices are determined by price transmission equations. These link the national price to an external reference price, which is typically defined in a key-price country (e.g. Germany for beef, pork, poultry and butter) or in the ROW region. The domestic price is determined by the key price and a vector of exogenous variables, including self-sufficiency rates at national and EU level. Key-price equations also incorporate relevant policy instruments (e.g. coupled payments, TRQs), ensuring that such measures indirectly influence all linked country prices. In this way, the model connects domestic markets to the world market, allowing external shocks to disseminate through the EU price system. The EU's net trade position, in conjunction with other modelled countries, impacts demand in the ROW, and consequently influences global price formation. The ROW is captured via a stylised regional module without internal policies, and its production and consumption respond directly to world market prices.

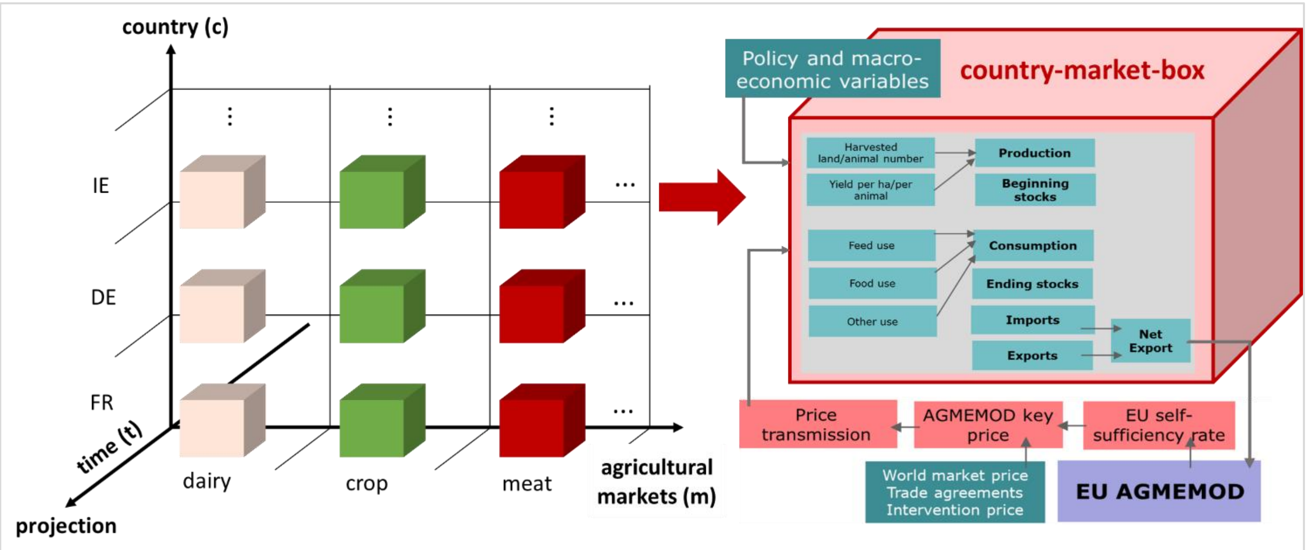

Figure 3: Schematic overview of agricultural market modelling in AGMEMOD
Source: Own elaboration based on Chantreuil et al. (2012) and Salamon et al. (2017)

In line with the model structure presented in Figure 3, future projections along timeline (t) for each country (c) and agricultural market (m) can be generated. These so-called baseline results are driven by several underlying assumptions and exogenous variables, which are determined outside the model (Salomon 2017). At the end of each time period, the following market identity is solved within each country-market-box to ensure consistency and balance.

$$\underbrace{Production + Import + beginning\ stocks}_{Supply} \equiv \underbrace{Domestic\ use + export + ending\ stocks}_{Demand}$$

AGMEMOD covers, for each country, the markets for **a) crop products** and **b) livestock products**, whereby the latter is further split into the markets dairy and meat products (Chantreuil et al. 2012; Salamon et al. 2017).

a) Crop products

The initial step in this process is the allocation of available land in each country. The distribution of available land across different crop types follows a top-down approach. The utilised agricultural area is the main land variable, and is divided into permanent grassland, permanent crops, and arable land, with the latter serving as a residual category. The arable land is further categorised into fodder and non-fodder use (crops and vegetables). While the exact quantity of green fodder produced for livestock feeding is not explicitly modelled, nevertheless it can be calculated.

The models' primary crops comprise eight different cereals (soft wheat, durum wheat, maize, barley, rye, rice, oats, and triticale), with all except rice being linked to the livestock sector via feed use. Additionally, rapeseed, sunflower, and soybeans, along with their processed products (oil and meal), are partially allocated to the livestock sector. Other crops, such as industrial crops (potatoes and sugar beet) and protein crops, have only an indirect impact on the livestock sector within the model. For each of these crops, the model annually determines the cultivated area, yield, and derived production, as well as usage (food, feed, industrial use, etc.), imports and exports, stocks, and domestic prices.

Finally, the decisions on which crops to grow are influenced by expected gross margins, expected prices (including policy-related cash transfers), and expected yields. The model incorporates additional explanatory variables, including lagged area shares, trend variables, and competing crops

b) Livestock products

The AGMEMOD models stocks of individual animals, as well as related markets for animal-based products (meats and dairy products) on the level of individual countries. As a starting point, the representation of livestock numbers is described in more detail below, as the general approach of each livestock commodity model builds on the ending stock of the previous period, which serves as the beginning stock of the following period. The ending stock of live animals is determined by economic factors (e.g. prices) as well as by productivity indicators (e.g. offsprings per animal and year, milk yield per cow and year).

For each meat market (*m*) in country *(c)*, the herd size of animal type *(i)* in year *(t)* represents the breeding stock, which constitutes the key endogenous function of the meat model. This breeding stock is defined species-specifically. In the cattle sector, it is modelled as the weighted sum of dairy and suckler cows; in the pig sector, as the weighted number of sows; and in the sheep and goat sectors, as the weighted number of ewes.

The breeding stock is determined endogenously as a function of the previous year's herd size, a set of exogenous variables (e.g. policy instruments such as coupled payments), a derived average feed cost component, and the product's output price. This relationship is formalized as:

$$HerdSize_t^i = f(HerdSize_{t-1}^i, KeyPrice_t^i, FeedCost_t^i, ExogenousVariables)$$

Here, the key price, which is defined as either the relevant world market price or the price in the EU market leader country, is employed in the price transmission mechanism. The price formation mechanism for the key price country is modelled as a function of the corresponding world market price, the EU self-sufficiency rate (SSR), the lagged domestic price, and additional exogenous variables (e.g. trade policy measures, exchange rates). This function is expressed as:

$$KeyPrice_t^i = f(WorldPrice_t^i, SSR_t^i, KeyPrice_{t-1}^i, ExogenousVariables)$$

Based on the endogenously determined breeding stock, the animal crop (i.e. number of animals produced) is calculated. This is modelled as a function of the previous year's breeding stock and an exogenous yield per breeding animal (e.g. birth rate), which reflects reproductive efficiency. The resulting total animal stock includes both breeding and non-breeding animals. In addition to this herd growth, adjustments are made for live animal imports and exports, as well as for death losses.

Subsequently, the number of slaughtered animals in category (j) of animal type (i) (e.g. for cattle: cows, calves, and other bovines) is derived. Total slaughtering is modelled as a function of current and lagged herd sizes, the output price, feed costs (which incorporate global prices), and lagged slaughter volumes:

$$TotalSlaughtering_t^i = f(HerdSize_{t-0,1}^i, KeyPrice_t^i, FeedCost_t^i, TotalSlaughtering\ _{t-1}^i,)$$

In the cattle model, the volume of cows' milk collected is explicitly incorporated. Higher milk yields tend to extend the productive lifespan of cows within the herd, which subsequently delays slaughter and reduces the number of animals available for meat production in the short run.

Based on the number of slaughtered animals, meat production is subsequently derived by taking into account additional biological/technical parameters. Each animal type (cattle, pig, sheep/goat, poultry) comprises specific categories of animals intended for slaughter. For each slaughter category, an average slaughter weight is applied. This weight is either simulated endogenously or can be defined exogenously, depending on data availability and/or modelling structure. These average slaughter weights are used to quantify the species- and category-specific meat supply volumes.

Accordingly, meat production is calculated as:

$$MeatProduction_t^{i,j} = TotalSlaughterings_t^{i,j} * AverageSlaughterWeight_t^{i,j}$$

For modelling the **dairy commodity markets** a two-tier approach is applied. In the first tier, the volume of whole milk available is determined by accounting for milk production, imports, exports, on-farm use, and deliveries to dairies, with the latter closing the raw milk balance. Milk production itself is modelled as a function of output prices, input costs, quota rents (in the pre-quota abolition period), and assumptions on supply elasticities. The second tier focuses on allocating the main milk components, fat and protein, to various processed dairy products. Firstly, the total quantity of milk fat and protein available from the delivered milk to the manufactures is calculated based on exogenous technical parameters of the average fat and protein content of the whole milk. These quantities then serve as the basis for allocation to dairy products.

The way in which milk fat or protein is allocated to a specific dairy product (a) is modelled as a function of the previously allocated amount, the own price of product a, the cross-prices of other dairy products (b), and relevant exogenous variables. This can be expressed as follows:

$$Allocation_t^a = f(Allocation_{t-1}^a, Price_t^a, CrossPrice_t^b, ExogenousVariables) \quad a, b = 1, \ldots, n; a \neq b$$

Finally, the calculated quantities of allocated milk components are converted into physical product volumes using exogenous technical conversion coefficients specific to each product. This step yields the final output levels of dairy products such as butter, cheese, skimmed milk powder, whole milk powder, and cream.

In addition, further variables are projected for each livestock product market, including domestic use, per capita use, trade in animal products (including imports and exports), and domestic prices. These variables capture demand-side dynamics and ensure consistency in the supply–demand balance within the overall market framework.

3.2.2. Main variables

The main output of AGMEMOD model are endogenous projections (year-by-year) of following variables for each country and each commodity market (if applicable):

- Allocation of land,
- Animal stock,
- Yields (crops, animals),
- production quantities,
- demand (uses) quantities,
- import and export quantities,
- prices.

Future projections are made using exogenous information (see also Chapter 5.1), i.e. projections of macro variables, world market prices, policies.

Table 5 provides an overview (1) which activities are covered in AGMEMOD (here ‘activity’), (2) which commodity markets are explicitly modelled (here ‘Outputs’), and (3) which production inputs are explicitly considered by model specification (here ‘Inputs’).

Inputs (physical quantities)	Activity	Outputs (physical quantities)
Land allocation top-down approach for each crop Biomass allocation: seeds	**Crop production** (Producing biomass)	Cereals, oilseeds, root crops, fruits & vegetables, nuts Processed products: Oils & meals from oilseeds Industrial crops Potatoes, sugar beet, protein crops
Biomass allocation Feed crops Processed products Oils & meals from oilseeds Stocks of breeding animals (Producing animal crop)	**Livestock production** **Stocks:** **Cattle** Dairy cows Suckler cows Other cattle **Pig** Sows Other pigs **Sheep and goat** Ewes Other sheep	**Marketable products** Beef and veal meat Cow’s milk collected Processed dairy products: Butter, cheese, drinking milk, WMP, SMP, cream, other fresh Pig meat Sheep and goat meat Other milk collected Poultry meat Broiler meat Eggs

Table 5: Main supply-side variables and activities in AGMEMOD

3.2.3. Derived Indicators

AGMEMOD focuses on market indicators, which primarily can be calculated using projections for main variables. One of the central derived indicators is the **self-sufficiency rate (SSR)**. It is calculated on the level of each individual commodity and country, and additionally also for the total EU.

Per capita consumption of food for individual products is another indicator of interest. Via post calculation derived fat/protein consumption can be calculated and if needed aggregated across multiple commodities. In that form it provides some insights in human diet composition.

Change in **distribution of demand among different uses** (food – feed – seed – energy – materials) over time can illustrate how specific use categories (i.e., material use, energy use) could gain/lose on importance over time.

With respect to environmental indicators, AGMEMOD provides projections for **GHG emissions**, although using quite a simple approach.

If indicators can be linked to main variables projected by AGMEMOD, they can be easily introduced in the model and projected using a post calculation procedure.

3.3. CAPRI

The CAPRI (Common Agricultural Policy Regional Impact) model is a global economic model designed to analyse the impact of agricultural, environmental and trade policies, primarily in the European Union. As a partial equilibrium model, it focuses exclusively on the agricultural sector. CAPRI is also a comparative static model, meaning it compares different policy or market scenarios at distinct points in time, rather than simulating dynamic developments year by year. CAPRI is used to evaluate the impact of policy changes, such as subsidies, tariffs, or environmental regulations, on agricultural outcomes like production, prices, trade flows, land use, and emissions. The core of the model lies in the integration of a European-focused supply module with a global partial equilibrium market module.

The supply model simulates agricultural production using regional programming models for approximately 280 NUTS2 regions across Europe. These models represent farmers' decision-making processes under constraints such as land availability, input costs, and policy regulations, with the objective of maximizing farm income. The modelling approach combines Leontief technology for intermediate inputs—accounting for both low- and high-yield variants across different production activities—with a non-linear cost function that captures the influence of labour and capital on production decisions. CAPRI's market module is a spatial, non-stochastic, global, multi-commodity model covering approximately 60 primary and processed agricultural products. It covers around 80 countries within 40 trading blocs, and uses the Armington assumption to model international trade. This approach treats products from different countries as distinct, providing a more realistic reflection of trade patterns and preferences**.** Due to its modular structure, CAPRI allows, for example, regional supply models for a specific EU Member State to be run independently of the market module, using fixed exogenous prices. Environmental impacts in CAPRI are quantified using a set of environmental indicators that are linked to detailed accounts of nutrient flows in agricultural production enabling region-specific assessment of environmental outcomes.

CAPRI can generate baseline projections based on current policies, which can then be used as a reference point when evaluating the effects of alternative policy scenarios. Implemented in the General Algebraic Modelling System (GAMS) and supported by a Java-based graphical user interface, CAPRI is accessible to users. The CAPRI model is open source and can be downloaded from the following URL: https://www.capri-model.org/dokuwiki_help/doku.php?id=getting_started_with_capri **.**

3.3.1. Supply and market model in CAPRI

The CAPRI model comprises supply and market modules that are interlinked. The supply module covers about 50 crop and animal activities for each of the around 280 regions (at NUTS-2 level covering EU27, Norway, Western Balkans and Turkey), and includes about 50 inputs and outputs. In the supply module, the regional supply of agricultural crops and animal products is modelled using an aggregated profit function approach, subject to a limited number of constraints, including the land supply curve, policy restrictions such as sales quotas and set-aside obligations, and feeding restrictions based on animal requirement functions. The decision variables include crop acreages, total land use, herd sizes, fertilizer application rates and feed mixes. Each independent model maximises regional agricultural income at given prices and subsidies, subject to constraints on land, policy variables as well as feed and plant nutrient requirements in each region.

The underlying methodology assumes a two-stage decision-making process. In the first stage, producers determine the optimal variable input coefficients per hectare or head for given yields. These coefficients cover nutrient needs for crops and animals, as well as other inputs such as seed, plant protection, energy and pharmaceuticals. The yields are determined exogenously by trend analysis and are updated depending on price changes against the baseline. Nutrient requirements enter the supply models as constraints, while all other variable inputs and their respective prices define the accounting cost matrix. In the second stage, the mix of crop and animal activities that maximises profit is determined simultaneously with the minimisation of feed and fertiliser costs in the supply models.

Total feed use can be sourced either from regional production (non-tradable)—such as grass, fodder root crops, silage maize, milk from suckler cows, mother goats and sheep, and other fodder from arable land—or purchased from the market at fixed prices. These prices, however, are updated in each iteration of the market module to reflect changing market conditions. The allocation of feed sources is primarily driven by non-linear terms in the objective function, which are either econometrically estimated (Jansson and Heckelei 2011) or derived from exogenous supply elasticities. The fertiliser needs of crops must be met by either organic nutrients found in manure (an animal by-product), crop residues or purchased fertiliser. The availability of grass and arable land, as well as the presence of quotas and set-aside obligations, imposes restrictions on acreage or production possibilities. A cost function covering the effect of all factors not explicitly handled by restrictions or accounting costs ensures the calibration of activity levels and feeding habits in the base year, as well as the system's plausible reactions.

The market model in CAPRI is defined by a system of behavioural equations that represent agricultural supply, demand for food and feed, demand from processing industries, and multilateral trade relations, all differentiated by commodity and geographical region. National average food consumption is based on food availability data from FAOSTAT and Eurostat. Consumer food demand is modelled using generalised Leontief expenditure functions (Ryan and Wales 1999) where the resulting indirect utility functions depend on prices and changes in income. Bilateral trade flows and associated prices are modelled using the Armington approach, which assumes product differentiation by country of origin.

Equilibrium in CAPRI is achieved by allowing the supply and market modules to iterate with each other. During the initial iteration, the regional aggregate programming models (one for each NUTS 2 region) are solved using exogenous prices. Regional agricultural income is therefore maximised, subject to restrictions such as land and fertiliser allocation and feed requirements. Once solved, the regional results of these models (e.g. crop areas, herd sizes and input/output coefficients) are aggregated and enter a small, non-spatial, multi-commodity module for young animal trade. In the second iteration, the supply and feed demand functions of the market module are calibrated to the feed use and production results obtained from the supply module in the previous iteration. The market module is then solved and the resulting producer prices at the level of the Member State are transmitted to the supply models for the next iteration. This process is repeated until an equilibrium is reached an overview can be seen in Figure 4.

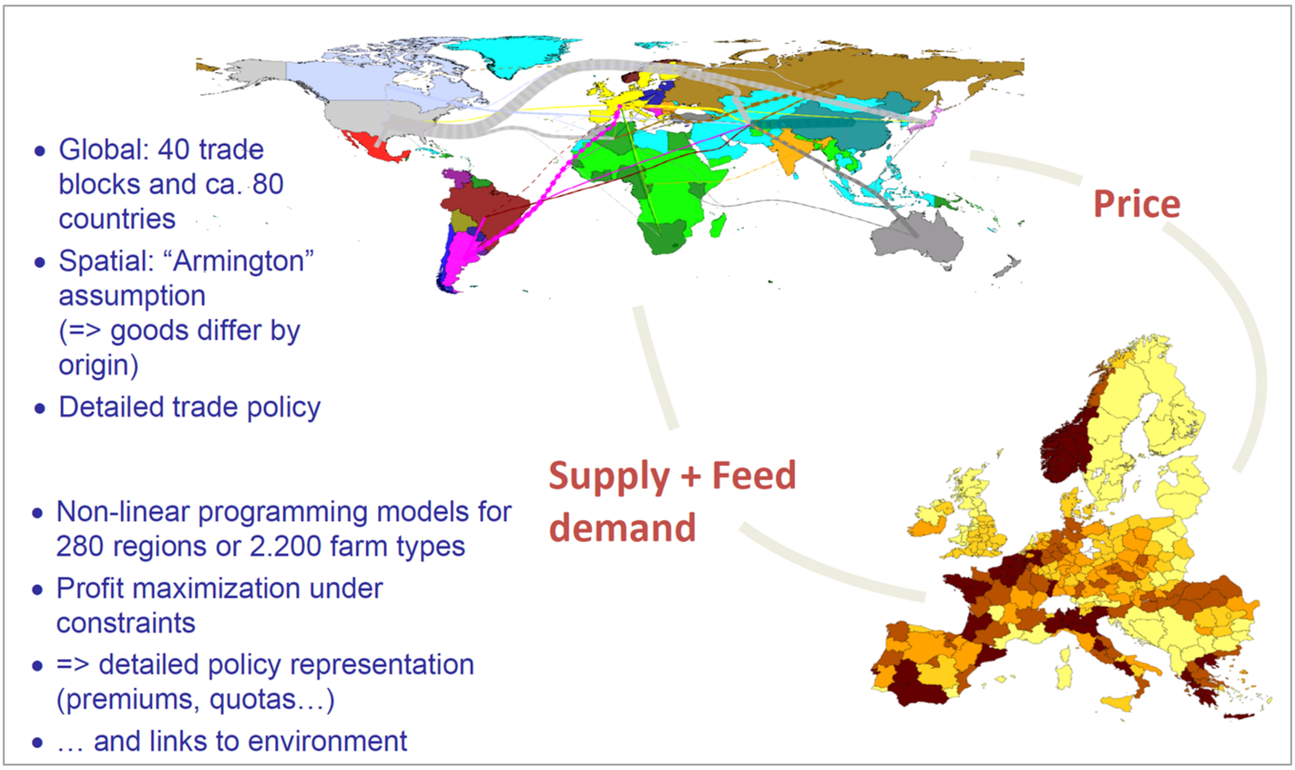

Figure 4: Overview of the CAPRI model

3.3.2. Livestock activities in CAPRI

Table 6 is a detailed representation of the livestock-related activities in the CAPRI model, showing the relationships between inputs, activities and outputs in the livestock production system. Livestock production in the CAPRI model is structured around a flow of inputs that support a variety of animal production activities, ultimately resulting in both intermediate and final outputs. This system starts with three main categories of inputs: feed, animal-specific inputs and general maintenance inputs. Feed inputs include a wide range of materials such as cereals, protein- and energy-rich forages, grass, forage maize, root crops, straw and other forages grown on arable land. These provide the nutritional basis for all livestock production. In parallel, young animals - including calves, piglets, lambs and chicks - and other animal-specific resources such as medicines and veterinary inputs are essential to initiate and sustain production cycles. These inputs are tailored to the type of livestock being reared and are critical for breeding, growth and health management. Supporting both feed and animal-specific needs are general inputs - including maintenance of machinery and buildings, energy sources such as electricity and heating fuels, water, lubricants and services needed to run the farm. These combined inputs flow into a variety of livestock activities, which can be broadly divided into two groups. The first is cattle-related activities, which include dairy cows for milk production and suckler cows for beef production. The cattle segment also includes the fattening of adult cattle and calves and the rearing of heifers and calves, both male and female. The second group includes pigs, poultry, sheep, goats and other animals. Activities here include pig fattening and rearing, poultry fattening, egg production from laying hens and both meat and milk production from sheep and goats. Other animal categories, although less detailed, are grouped under 'other animals'. Several types of outputs result from these activities. Some are intermediate, such as manure (which provides nitrogen, phosphate and potassium for use elsewhere) and young animals, which may be retained or sold for further production. The main marketable outputs are a variety of meats - beef, pork, lamb, poultry - as well as milk from a variety of animals and eggs. These are the main agricultural products destined for the food market. A further processing step transforms raw milk into processed dairy products, including butter, cheese, milk powder (skimmed and whole), creams, whey powder and casein. These are high-value items in the dairy supply chain and are key components of the EU's agricultural output.

<table>
<tr><th>Input</th><th>Activity</th><th colspan="2">Output</th></tr>
<tr><td>Feeding Stuff

Feed cereals
Feed rich protein
Feed rich energy
Feed based on milk products
Gras
Fodder maize
Other Feed from arable land
Fodder root crops
Feed other
Straw</td><td rowspan="3">Cattle
Dairy cows
Suckler cows
Male adult cattle fattening
Heifers fattening
Heifers raising
Fattening of male calves
Fattening of female calves
Raising of male calves
Raising of female calves

Pigs, poultry and other animals
Pig fattening
Pig breeding
Poultry fattening
Laying hens
Sheep and goat fattening
Sheep and goat for milk
Other animals</td><td>Intermediate products from animal production</td><td>Milk from cows for feeding
Milk from sheep and goat for feeding
Young cows
Young bulls
Young heifers
Young male calves
Young female calves
Piglets
Lambs
Chicken

Nitrogen from manure
Phosphate from manure
Potassium from manure</td></tr>
<tr><td>Young animals/other animal specific input

Young cow
Young bull
Young heifer
Young male calf
Young female calf
Piglet
Lamb
Chicken
Pharmaceutical inputs</td><td>Marketable products from animal production</td><td>Milk from cows
Beef
Pork meat
Sheep and goat meat
Sheep and goat milk
Poultry meat
Eggs
Other marketable animal products</td></tr>
<tr><td>General inputs

Maintenance machinery
Maintenance buildings
Electricity
Heating gas and oil
Fuels
Lubricants
Water
Agricultural services input
Other inputs</td><td>Dairy products (processed)</td><td>Butter
Skimmed milk powder
Cheese
Fresh milk products
Creams
Concentrated milk
Whole milk powder
Whey powder
Casein and caseinates</td></tr>
</table>

Table 6: Livestock activities in CAPRI

3.3.3. Derived indicators

CAPRI offers an extensive list of indicators that might be interesting to look at. For the purpose of this deliverable, we focused on income and environmental indicators as they will be the most useful within the project framework.

CAPRI offers several ways to look into farm income. In the CAPRI model in general, income is primarily calculated using the concept of Gross Value Added (GVA) plus premiums. The GVA is the difference between revenues (output quantities valued at farm gate prices) and intermediate input costs (input quantities multiplied by their farm gate prices, excluding the primary factors land, capital, and labour). Income is calculated for individual production activities, such as single crop production or animal husbandry, and then aggregated to groups of activities and over regions. GVA plus premiums is the main indicator of producer (farmer) welfare at this level.

Table 7 provides an overview of the main greenhouse gas (GHG) emissions used in CAPRI. The Model endogenously calculates GHG emissions from agricultural activities in the European Union based on the inputs and outputs of production processes within its supply module. It integrates a detailed, region- and activity-specific nutrient flow model that explicitly accounts for feeding and fertilising practices by balancing nutrient requirements with availability. Crop yields are determined per agricultural activity, forming the basis for the subsequent GHG emission estimates, which are carried out in accordance with the IPCC (2006) guidelines. Emission factors in CAPRI are calculated primarily using the Tier 2 methodology, offering a more detailed approach. However, when necessary, data are unavailable (e.g., in the case of rice cultivation), the model resorts to the Tier 1 method. Methane emissions from enteric fermentation and manure management are estimated using Tier 2 for cattle, while Tier 1 is applied to swine, poultry, sheep, and goats. Feed digestibility, a key determinant of methane emissions, is calculated endogenously based on feed composition. For non-EU regions, emission accounting is conducted on a product basis, following the methodology outlined by (Jansson and SÄLL 2018). In scenario analyses, total emissions per region are computed by multiplying region-specific, commodity-level emission factors with the corresponding production volumes.

Emissions	Sources modelled in CAPRI
CH_4	Enteric fermentation Manure management Rice cultivation
N_2O	Synthetic fertilizer Manure management (application) Excretion on pasture Crop residues Histosols Deposition of ammonia Emissions due to leaching of nitrogen
CO_2	Liming Urea application

Table 7: GHG emission sources accounted for by CAPRI
Source: Own depiction based on Pérez Domínguez et al (2020)

Nitrogen-related emissions (e.g., N_2O) are quantified using a mass flow approach developed for the MITERRA-EUROPE model, incorporating data from the GAINS database. Nutrient surpluses and balances are computed at the NUTS2 level for three macro-nutrients: nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), across distinct crop groups. Plant nutrient demands are met through three fertiliser sources: purchased mineral fertilisers, animal manure, and crop residues. Manure-based fertiliser production is modelled per animal type, factoring in the raising period (in days) and the animal's live weight at both the beginning and end of this period. Nitrogen emission factors from animal production are linked to crude protein intake.

Crop-specific nutrient requirements per hectare are derived from yield levels. CAPRI offers alternative technology options for each cropping activity, enabling producers to choose between high-input/high-yield and low-input/low-yield systems (Gocht and Witzke 2022). In CAPRI, nutrient surpluses and soil-level nutrient surpluses for each NUTS2 region in Europe are calculated by accounting for the relevant sources and sinks of nutrients, as outlined in Table 8.

Source	Sink	Nutrients
+ Mineral fertilizer	− Exports with crops	N, P_2O_5, K_2O
+ Manure		N, P_2O_5, K_2O
+ Crop residues		N, P_2O_5, K_2O
+ Biological fixation		N
+ Atmospheric deposition		N
= Nutrient surplus		N, P_2O_5, K_2O
	− Gaseous losses	N
	− Run off mineral fertilizer	N
	− Run off manure	N
= Nutrient surplus at soil level		N

Table 8: Sources and sinks used in computation of nutrient surplus and nutrient surplus at soil level for Nitrate (N), Phosphate (P2O5) and Potassium (K2O)
Source: Own depiction

For more details of nutrient balance calculations and fertilisation practices in CAPRI, refer to (Jansson et al. 2019). Other relevant environmental indicators in CAPRI related to biodiversity include the Shannon index and the Biodiversity-Friendly Farming Practices (BFP) Index. The BFP Index incorporates factors such as crop richness and crop diversity indices, the nitrogen input index, the share of arable land, grassland, permanent crops, and olive groves within the Utilised Agricultural Area (UAA), as well as pesticide usage (Gocht et al. 2016).

4. Possible Scenarios

WP5 will provide a model-based assessment of the scenarios developed in WP6. For a successful outcome, it is important that we have a common understanding of the types of scenarios that can be analysed using the available models. The separate sub-chapters will provide an overview of the possible scenarios relating to livestock activities that could be analysed using the individual MAFSEU, AGMEMOD and CAPRI models. Additionally, Table 9 provides an overview of a selection of storyline elements that could be considered when defining scenario shocks, as well as the variables that would be affected by their implementation in models.

Topic	Shock variable used for Implementation	Associated storyline elements (narratives in scenario)
Production related shocks	Yield changes (crop, milk, meat)	- general increase due to overall technologies and management improvements
		- general decrease due to overall extensification (less chemical inputs, more organic production etc.) and climate change
		- specific impact of use of chemical inputs (fertilisers, antibiotics etc.)
		- specific impact of technology or management practices (for example, feed composition, practices related to mitigation of GHG emissions)
	Additional changes in livestock number/density	- impact of adjustment of CAP payments (premium for suckler cows etc.)
		- predefined impact of stronger structural change (i.e. due to challenges in generation renewable)
		- Decrease of livestock density due to stronger environmental regulations
		- Decrease of livestock density due to animal welfare issues
Change in food demand	Market-driven change in food demand	- change in income (GDP/ capita)
		- change in prices (due to changes in world market prices, taxes/subsidies for specific products, i.e. for capturing negative or positive external effects)
	'Prescribed' change in demand	- predefined changes in consumer preferences (decrease in consumption of animal-based products, increase in consumption of plant-based products and vice-versa, etc.)
		- Waste reduction
		- Health policies/ Political regulations
Change in other uses	Feed use	- Changes in animal diets (change of composition/ origin of feed)
	Energy use	- Production of biofuels
	Material use	- Production of biochemicals etc. (evolvement of bioeconomy)
Macroeconomic development	Population development	- Total population number (i.e., changes because of migration etc.)
	GDP/capita	- Assumption about GDP developments
Land use	Prescribed changes in land use / allocation	- Policy restriction of land use, i.e. related to conversion of pasture to arable land
		- CAP policy, i.e. set-aside targets
Trade	Trade policy	- Border adjustment measures

Table 9: A selection of storyline elements, along with the ways they could be implemented in models

4.1. Possible scenarios with MAFSU

Due to its characteristics, MAFSEU is well suited to simulating the impacts of substantial changes to the entire EU food system. An initial, simplified version of the model was used to evaluate the effects of key agricultural aspects of the European Green Deal (EGD), including a reduction in chemical inputs and an increase in agricultural land converted for agro-ecological infrastructure (Guyomard et al., 2023). The extended and improved version of the model, developed as part of the STEP UP project, could also simulate the impacts of the aforementioned scenario, as well as more comprehensive EGD scenarios covering supply shocks, food waste and losses throughout the entire chain, and dietary changes. This new model enables the selection of economic policy instruments to either constrain or incentivise changes in practices on the supply and demand sides, as well as with regard to food losses and waste.

In the context of the STEP UP project, MAFSEU can, in particular, be used to assess the market and non-market impacts on the EU livestock sector and the different animal products of scenarios involving **dietary shifts**, such as diets with fewer animal products or reduced red meat consumption. More generally, it could be used to assess the impacts on EU agriculture, specifically EU livestock, of a shift towards healthier diets with less salt, carbohydrates and fat, fewer animal products in a general way or less red meat only, and more healthy goods such as F&V, nuts and dietary fibers.

On the supply side, the model could be used to assess and compare the market and non-market impacts of **intensifying versus extensifying** EU agriculture, more specifically EU livestock. An increase in intensification could be modelled by: increasing the use of concentrated feeds in animal rations (for all or some species only); increasing the use of cultivated forages at the expense of grass (notably permanent grassland) for beef and milk production; and improving animal efficiency coefficients (for all or some species only). Extensification could be modelled by acting on these three levers in the 'opposite direction', that is by: decreasing concentrated feed in animal rations, ii) increasing grass use, particularly permanent pasture, at the expense of cultivated forages and concentrated feed, and iii) reducing animal efficiency due to lower stocking densities or slower-growing breeds and strains. All of these supply-side measures could be implemented with or without accompanying dietary change policies and with or without border measures, the legitimacy of which must also be evaluated for each option. This will enable us to define a set of scenarios whose market and non-market consequences will be assessed to determine their position within the SJOS for EU livestock.

We do not have reliable, comprehensive information that would allow us to distinguish between various farming systems for each type of animal production. However, it is possible to determine whether each production type is organic or not. This would enable us to analyse the market and non-market consequences of an increase in the proportion of organic livestock farming. This analysis would only be meaningful if the two market segments — organic and non-organic — could be differentiated and calibrated at all levels of supply, derived demand, trade and final demand. The available data, particularly with regard to behavioural parameters, makes this work challenging and fraught with significant uncertainty. Furthermore, the conventional agriculture market segment is not homogeneous. Farming intensity levels do not exist as discrete categories, but rather as a continuum. Taking all these factors into account, and bearing in mind the characteristics of the model, we believe it is more appropriate to analyse the impacts of increased intensification versus extensification in European livestock systems in the manner we propose.

4.2. Possible Scenarios with AGMEMOD

AGMEMOD is initially designed to make mid-term baseline projections, i.e. to provide projections of the 'business as usual' scenario. This scenario typically describes expected developments in individual countries over the next ten years, under the current agricultural policy framework and with assumptions about the development of certain external factors (GDP and population growth, world market prices). AGMEMOD is well suited to making such projections. It is based on a comprehensive database of time series data, which in most cases goes back to 1973. This allows equations to be estimated that are based not only on a number of explanatory variables, but also trend variables, which cover some developments that are otherwise difficult to model (e.g. structural changes).

Since 2015 the AGMEMOD has participated in the process through which the European Commission's Directorate General for Agriculture (DG AGRI) has produced its annual medium-term agricultural outlook for the EU. The EC's medium-term outlook is developed at EU level, while AGMEMOD produces linked projections for individual EU member states, which contribute to the report by focusing on selected markets (with the focus changing each year). AGMEMOD is also used for national baselines projections, like Thünen-Baseline which is produced every two years and describe developments expected in the German agricultural sector during the next ten years (as part of the Thünen Modelling Network, which include i.e. also CAPRI).

The baseline scenario may already include a number of policy changes that should be modelled. These could be predefined EU-level policies, such as adjustments to the CAP budget or its allocation, or EU biofuel or some national-specific policies.

In the course of time AGMEMOD is increasingly used to run alternative scenarios that encompass alternative/additional assumptions. Here some chosen elements that were analysed in the scope of different studies and are related to the livestock sector:

- reductions in animal stocks (as a result of welfare and environmental policies),
- productivity of livestock (impact of climate),
- Dietary changes (shift to more plant-based diets),
- Reduction of household food waste (through the reduction of food demand),
- candidate countries' accession to the EU, Implementation of free trade agreement.

The STEP UP project focuses on the impact and externalities of different EU livestock production systems. Important characteristics of current European Livestock Production Systems (ELPS) include the intensity of input use (e.g. feed composition and pasture use) and the level of productivity (yields). In essence, scenarios analysing changes in current ELPS would analyse which effects intensification/extensification of livestock may have. Shocks to feed demand for livestock (linked to herd size) and livestock productivity (through slaughter numbers and weights for meat, milk production per cow, and dairy cow numbers) can be used to simulate changes to the current system. If we implement the enhancement of AGMEMOD with a distinction of different production systems, that will also fine-tune the implementation of scenarios that foresee changes within existing ELPS, as well as changes in terms of the prevalence of specific ELPS in the EU.

4.3. Possible Scenarios in CAPRI

The CAPRI model is designed to support the analysis of a wide range of agricultural, trade, and environmental policies. While CAPRI offers a particularly high level of regional detail within Europe - making it well-suited for evaluating EU policy impacts - it also includes global coverage, allowing for the assessment of international market developments, trade interactions and changes in GHG emissions. Scenario options in CAPRI include both single and combined shocks affecting input and output prices (e.g. fertiliser or milk prices), crop and livestock yields, nutrient needs for crops, feed requirements for livestock, and animal production parameters such as production days. Additionally, the model can simulate constraints like upper limits for nutrient balances, changes in trade policies (e.g. tariffs), and modifications to the Common Agricultural Policy.

The CAPRI model is well-suited for analyzing complex scenarios such as demand-side transitions, including reductions in the consumption of animal-based products as well as increases in the demand for plant-based alternatives. Its detailed representation of agricultural production, market interactions, and environmental outcomes enables the simulation of dietary transition impacts on land use, greenhouse gas emissions, and trade patterns. For example, Rieger et al. (2023) and Himics et al. (2022)used the CAPRI model to evaluate the environmental consequences of EU-wide dietary shifts toward healthier, more sustainable eating patterns based on the recommendations of the EAT-Lancet Commission (Springmann et al., 2019). In addition, Springmann et al. (2023) analysed the implementation of the EAT-Lancet diet on a global scale.

In contrast to the assumption of costless preference shifts, the CAPRI model also allows for the simulation of more policy-relevant instruments to influence consumer behaviour. Specifically, it enables the implementation of measures such as a carbon tax on food products (Gren et al. 2021) and adjustments in value-added tax (VAT) rates (Ricci et al. 2024). These instruments introduce explicit price signals that can influence both production and consumption patterns, providing a more realistic framework for assessing the costs and effectiveness of dietary transitions toward sustainability.

Another option in CAPRI to account for the monetisation of external effects of agricultural production is the implementation of carbon taxes on the producer side (Stepanyan et al. 2023; Jansson et al. 2024; Nordin et al. 2024). In the CAPRI model, a carbon price can be imposed on the CO_2-equivalent emissions from all agricultural sources. It is assumed that farmers hold emission permits equal to their baseline emissions as defined in the reference scenario. The model applies a tax to the deviation between actual emissions and the allocated permits. Consequently, if a region's emissions fall below the baseline level, the mechanism effectively results in a subsidy.

In addition various technological mitigation options for the European agricultural sector are available on CAPRI for the crop and the livestock sector as well as technologies related to ammonia reduction (see Table 10) which have been analysed in various studies (Agora Agriculture 2024; Fellmann et al. 2021; Stepanyan et al. 2023). A detailed description of the available technological options targeting different greenhouse gases can be found in Pérez Domínguez et al. (2020).

Crop Sector	Livestock sector	Ammonia related technologies
- Better timing of fertilisation - Nitrification inhibitors - Precision farming - Variable rate technology - Increasing legume share on temporary grassland - Rice measures - Fallowing histosols - Winter cover crops - No tillage - Conservation tillage	- Low nitrogen feed - Linseed as feed additive - Nitrate as feed additive - Antimethagon vaccination - Farm scale anaerobic digestion - Increasing milk yield via genetic improvements - Increased ruminant feed efficiency via genetic improvements	- Low emission housing - Manure storage with basin in concrete - Storage cover - Low ammonia application - Low emission housing

Table 10: Technological mitigation options available in the CAPRI model
Source: Own depiction

Based on a non-linear mitigation cost function, the implementation share of each mitigation technology is determined endogenously at the regional level, reflecting economic decisions made by farmers. The scope and degree of adoption are represented by an endogenous variable influenced by the technology's costs—including annual investment and operational expenditures—as well as potential revenues (e.g. from anaerobic digestion), cost savings (e.g. reduced mineral fertiliser use through precision farming), and policy incentives such as subsidies or taxes. Within the CAPRI regional programming models, farmers are assumed to be profit maximisers; thus, a mitigation technology is adopted only if it leads to an increase in marginal profit, defined in terms of gross value added. The level of production activities and the adoption of mitigation technologies are subject to multiple constraints, including the availability of land, the nutrient requirements of cropping systems relative to the supply of organic fertilizers, and the feed demands of livestock. These feed requirements are specified in terms of key nutritional components such as dry matter, net energy, protein, and fibre, ensuring that both crop and animal production remain agronomically and nutritionally feasible within the modelled system.

In general, two main types of scenarios for the adoption of technological mitigation options can be diafiltrated. In the *standalone measures approach*, each mitigation technology is assessed individually in separate scenarios, assuming full adoption up to its maximum potential without considering costs or interactions with other measures. This method estimates the theoretical maximum mitigation potential and associated costs of each technology within the CAPRI model. In contrast, the *combined measures approach* makes all technologies simultaneously available, accounts for interactions and competition between them, and allows adoption levels to emerge endogenously based on farmers' profit-maximizing decisions, providing a more realistic assessment of combined mitigation outcomes (Fellmann et al. 2021). Here a subsidy or carbon price can incentivize the adoption of mitigation technologies, as their uptake in the CAPRI model is governed by a profit maximization framework. Farmers will only adopt such technologies if they enhance competitiveness by lowering production costs. Introducing a carbon tax links greenhouse gas emissions to production costs, thereby internalizing the environmental externality (Himics et al., 2018). When emissions become a cost factor, mitigation technologies may become more economically attractive, as the potential savings from reduced emission-related costs can outweigh the investment and operational expenses associated with their implementation (Himics et al. 2022; Stepanyan et al. 2023).

Other potential scenario options in CAPRI for the livestock sector in the EU is the change in livestock production density. The objective is to mitigate the environmental pressures associated with intensive livestock systems, such as nutrient surpluses and greenhouse gas emissions. By adjusting the density limit, the policy encourages a more spatially balanced distribution of livestock production across the EU, potentially shifting production away from regions with high concentrations toward less intensive areas, thereby promoting more sustainable and regionally adapted livestock farming practices (Hristov et al. 2024).

5. Data and Information needs

This chapter describes the basic data and information required for scenario simulation and differentiating between livestock production systems in models. This information is expected to be particularly relevant to the linked tasks of WP6 and WP1.

5.1. For scenario runs

Scenario narratives (also 'storylines') predominantly describe future developments and situations verbally, often focusing on a specific area of interest in detail while sparing other aspects from description. However, to run mid- or long-term scenarios, models require 'translation' of information in quantified form.

The following information in quantified form will be needed to run any future scenario:

- Future projections of macro variables
    - Population per country (million persons)
    - GDP per country (billion euro)
    - Inflation rates (GDP deflator)
    - Exchange rate Euro/USD (USD/euro).
    - Exchange rates national, currency/Euro (if applicable)
- Future projections of world market prices
- Policy related information (in place or agreed)
    - Common Agricultural Policy (CAP) budget distribution
    - Biofuel targets
    - Etc.

By construction of the so called 'Business as usual Scenario' (Baseline scenario), AGMEMOD takes most of this information from DG AGRI Outlook reports (i.e. AGLINK projections). This can also be done in the STEP UP project and then adjusted if needed.

For other elements of storylines or scenario narratives, the translation of information in quantified form will also be needed. This could be based on literature, expert or stakeholder consultations, or an internal project agreement.

5.2. For differentiating between livestock production systems

In 'D1.1: Typology of current European livestock systems', the detailed classification of European Livestock Production Systems is proposed. For modelling activities and estimation of aggregated effects in WP5, a more condensed version of this typology could be applied, with nine main livestock categories (1. dairy cattle, 2. suckler cows, 3. beef/finishing cattle, 4. meet sheep, 5. dairy sheep, 6. goats, 7. pigs, 8. laying hens and 9. broilers) and three main sub-systems with the option to account for 'conventional / organic' in some systems. The three main sub-systems are: (1) Intensive indoor systems, (2) Intensive grazing (i.e. ruminants) or outdoor (i.e., pigs and granivores) systems and (3) semi-extensive.

In order to capture the differences between livestock production systems in models, data on the prevalence of these systems is required, as well as information that characterises them.

In terms of prevalence, information on the decomposition of the total population between the sub-systems is required for each livestock category (absolute numbers or, alternatively, the % share of the total population). For example, for dairy cows:

Total dairy cows = cows in intensive indoor system + cows in intensive grazing (C/O) system

+ cows in semi-extensive grazing (C/O) system

To implement this in the MAFSEU and AGMEMOD models, information is required at the EU27 and EU member state levels, respectively. Ideally, time series data are needed for AGMEMOD (showing evolution over the last 10 years). This would help analyse whether changes in the prevalence of sub-systems have occurred over time and what has driven these changes. This would considerably improve the ability of the models to provide projections on this issue.

With respect to the characteristics of each sub-system, the following information is of particular interest:

- Detailed information on feed rations (composition: cereals, meals, maize silage, green silage etc.),
- Proportion of forage land/pasture devoted to each system,
- differentiated antimicrobial use
- intensity use of other inputs (e. g. labour)
- values of specific impacts/externalities.

It is important to stress that this data is required at the sub-system level. Therefore, if the data in T1.4 will be attributed at a more disaggregated level, an additional step will be needed to aggregate that data to the level of the main sub-systems.

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