



## D9.1 Modelling Sustainability and Nutrition in Long Run Analyses of the EU Agri-Food system: Work plan for the SUSFANS Toolbox

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This paper presents a plan for operationalising a modelling toolbox for the assessment of food and nutrition security and sustainability of the EU food system. The toolbox will be capable of:

- (1) Tracing nutrients in agriculture, fish, food and feed through the EU system;
- (2) Supporting foresight on EU diets and food production systems;
- (3) Capturing dimensions of sustainability by stage of the food supply chain (primary food production, food processing and consuming);
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## Executive summary

This paper presents a plan for operationalising a modelling toolbox for the assessment of food and nutrition security and sustainability of the EU food system. The toolbox will be capable of:

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- (4) Providing entry points for policy and innovation by government, private sector, NGOs and the science community.

The **SUSFANS toolbox** includes both well-established models in the field of agricultural, economic and biophysical modelling, such as MAGNET, CAPRI and GLOBIOM, and purposely developed new European models of optimal diets (SHARP) and short-term price perturbations (AgriPrice4Cast).

The toolbox is developed by enhancing existing long-term models, subsequently linking these models with each other and other mostly novel, short-term models and micro models of consumer behaviour and diets. Outcomes of variables produced by the various models will serve to quantify performance metrics on sustainable food and nutrition security, as developed within SUSFANS.

Existing long-term models are enhanced on the consumption side to better capture behavioural aspects of changing diets and nutrition outcomes, on the primary production side to improve farm supply behaviour, notably that of fisheries and aquaculture, and on the supply chain side by incorporating more completely biomass flows, notably food loss and waste, tracing nutrients, and imperfectly competitive behaviour.

**Model-linking** takes place through input and output data linkages between the various models, i.e. exchanges of information. With respect to the long-term macro models, this is based on existing model mappings (leaning on experience in other projects). With respect to the coupling of macro with micro models, this is achieved by mapping respective model classifications to a common denominator, the FAO classification of agri-food commodities. The models included in the toolbox cover all scale levels, including the global level, EU28, the sub-regional levels of EU4 (the four case study countries), national level and province level (NUTS2), household types (e.g. rural, urban) and the individual level (stratified by socioeconomic and health characteristics) and capture different time horizons (long-term, medium-term and short-term).

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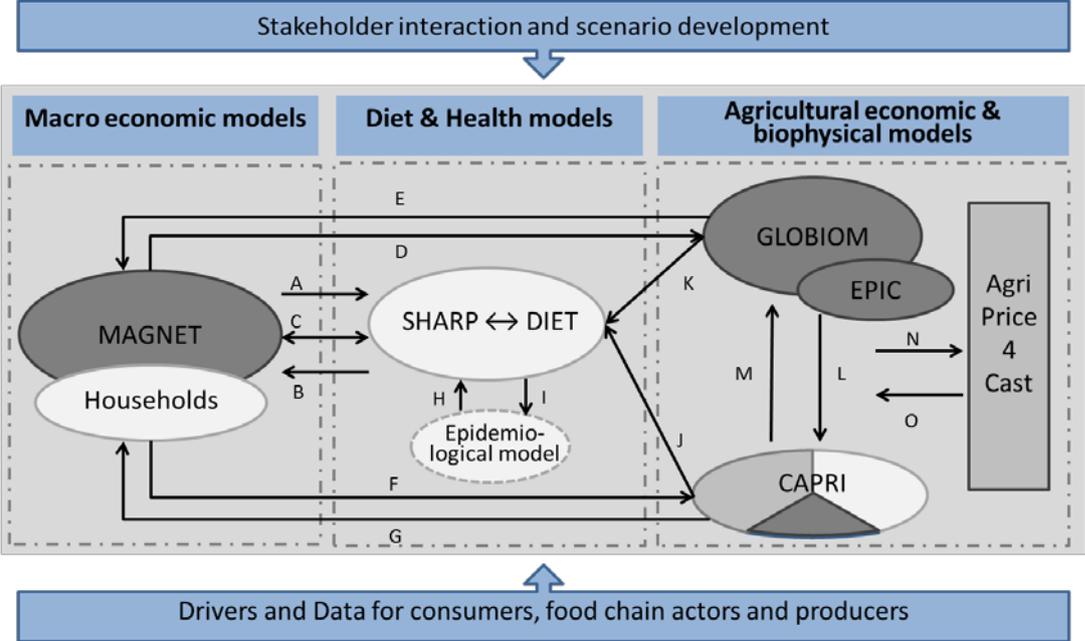
\* Corresponding author: [martine.rutten@wur.nl](mailto:martine.rutten@wur.nl) (Martine Rutten). We are grateful for contributions from the modelling teams at LEI, UBO, IIASA and JRC, and leaders/members from other work packages. The research leading to these results has received funding from the European Union's H2020 Programme under Grant Agreement number 633692 (SUSFANS). See [www.susfans.eu](http://www.susfans.eu) for more information. This paper is work in progress; comments are welcome. The authors only are responsible for any omissions or deficiencies.

The model outputs in the toolbox are mapped to **metrics** by taking into consideration each model’s comparative advantage compared with the other models. The models may nonetheless provide outcomes for variables and indicators which may partially overlap. Where this is the case, the outcomes of the model being strongest in the area under scrutiny are used. Deviations of important outcomes across models will be traced back to the underlying structural or data reasons in discussions across modelling teams. This may lead to model adjustments or differentiated reports with additional explanatory detail and insight.

**Case studies and forward-looking scenario simulations** are two different but complementary ways to use the SUSFANS toolbox. Case studies focus on specific innovations in the agri-food supply chain (e.g. more regional plant-based production, novel sources of vitamin in more healthy diets). Forward-looking scenario applications address single or a multiple drivers of the food system with potential impacts on FNS. Here, targeted application of a subset of SUSFANS models and comprehensive integrated assessments shall demonstrate the flexibility of the toolbox.

**A map of SUSFANS toolbox:**

The left-hand side of the depicted toolbox contains macroeconomic models: specifically the **MAGNET** model for medium- to long-term global analyses, with **household level detail** of effects for a selection of countries. The middle column displays diet and health models, including **SHARP** - a model, which designs optimal diets on the basis of various attributes, **DIET** - a short-term behavioural model for diets in response to various constraints (economic, health, environmental), and an **epidemiological model** to calculate health impacts. The right-hand side shows long-term agricultural economic and biophysical models, the partial equilibrium models **CAPRI** and **GLOBIOM** – a global model coupled to **EPIC**, which on the complete right interact with the short-term model **AgriPrice4Cast**. These models are linked, as indicated via the arrows, and thereby form the SUSFANS toolbox. The toolbox is put to use in scenarios and innovation pathways fed by stakeholder input (top bar), based on drivers and data from pillar I of the SUSFANS project (bottom bar).



- A: Incomes and food prices
- B: Macro and micro nutrient consumption
- C: Dietary composition (optimal diets in an iterative process)
- D: Input prices and macro environment
- E: Agricultural productivity shocks
- F: Input prices
- G: Crop response to climate change, water availability, water demand
- H: Criteria for healthy diets
- I: Diets and nutrient consumption
- J: Food prices, EU environmental impacts of food products, EU farm income
- K: Food prices, global environmental impacts of food products
- L: Yield growth on NUTS 2 level (EPIC), forestry land use
- N: Detailed EU agricultural information (production, prices, policies)
- O: Fundamental market developments (production, prices)

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# 1. Background

## 1.1 Context: WP9 objectives

Strengthening food and nutrition security in the EU requires sustainable food consumption and production, and aligned action from all agents in the food systems. The SUSFANS project aims to build the conceptual framework, the evidence base and analytical tools for underpinning EU-wide food policies with respect to their impact on consumer diet and their implications for nutrition and public health, the environment, the competitiveness of the EU agri-food sectors, and global FNS. A major result of the project is a coherent toolbox for integrating data and modelling European sustainable FNS.

The toolbox is developed in work package 9 (WP9) of the SUSFANS project. The overall objective of WP9 is to provide foresight towards 2050 on Sustainable Food and Nutrition Security (SFNS) in the EU by improving long-term models (see Figure A in the Annex for a presentation of the project's work packages):

1. To develop a work plan for operationalising the framework for assessing EU SFNS (WP1, 2 to 4) in a quantitative toolbox (SUSFANS toolbox), with a focus on two major food supply chains; (WP5), which links enhanced European and global economic and biophysical models, including short-term models (WP8), and micro models of EU balanced diets (WP7);
2. To improve food demand modelling at the household level, building on WP2 and WP7;
3. To develop the modelling of food supply, building on WP4;
4. To enhance the modelling of the food chain, building on WP3;
5. Building on task 1-4, to create the SUSFANS toolbox for assessing EU SFNS. The toolbox enables the consistent monitoring of EU SFNS in the short-, medium- and long-term (up to 50 years) for use by case studies (WP5), foresight (WP10) and policy support (WP11).

## 1.2 Outline of the work plan (D9.1)

The work plan specifies how the enhanced short-term models (WP8), long-term models (WP9), macro and micro models (WP7) in the SUSFANS toolbox 'talk' to one another and how they can be used in the assessment of EU SFNS. Specifically the work plan documents:

- (a) the (input and output) data linkages between the various models (WP7, 8, 9), whether up- and downscaling of information is required and how this will be done;
- (b) a discussion of the model improvements foreseen for each model with a plan on how these will be shared so as to achieve synergy effects across models;
- (c) a first reflection on what outcome indicators on SFNS should be used from what model for use in a consistent and accurate assessment of EU SFNS.

The development of the work plan draws upon experiences in similar projects (FOODSECURE, AGRICISTRADe). Since this deliverable is between an operational strategy and a 'work plan', we specify tasks and results contingent on data we know are available and methodologies that may be implemented. Risks are identified as much as possible, as are ways forward to circumvent bottlenecks on the way. Modelling strategies and resulting outcomes may nonetheless be revised in the face of advances in data availability and the literature.

## 1.3 Relevance of work plan and the SUSFANS toolbox in particular

The work plan for modelling sustainability and nutrition in long run analyses of the EU agro-food system by means of a toolbox (D9.1) has direct scientific relevance, in terms of formulating contributed scientific publications, and indirect societal relevance, through its contributions to shaping research in this area. The toolbox is important as it will improve the evidence-base on SFNS, to the benefit of policy making. Environmental change, diet-related diseases, and globalising food

supply cause major challenges for SFNS of EU citizens. <sup>1</sup> Policies to face these challenges need to build on past and current evidence and need to account for uncertainties and unforeseen developments in the future. Data and models can deliver such a scientific evidence-base. But if we accept SFNS as a policy ambition, it introduces a multi-dimensional concept into the policy cycle. Already there are policies with multi-dimensional goals and effects, such as the CAP and the resource use efficiency strategy. A multi-disciplinary approach is required to assess the performance of such policies across a range of effects and variables, at different scale levels and across different time horizons, looking backwards (ex-post) and looking forward (ex-ante). This is brought about by employing a diverse set of models from the agricultural/economic, environmental/climate, and nutrition/health domain that operate at different scale levels and time frames, and by bringing them together in the SUSFANS toolbox so as to maintain analytical consistency.

#### **1.4 Overview of WP9: Deliverables and Links to other Work Packages**

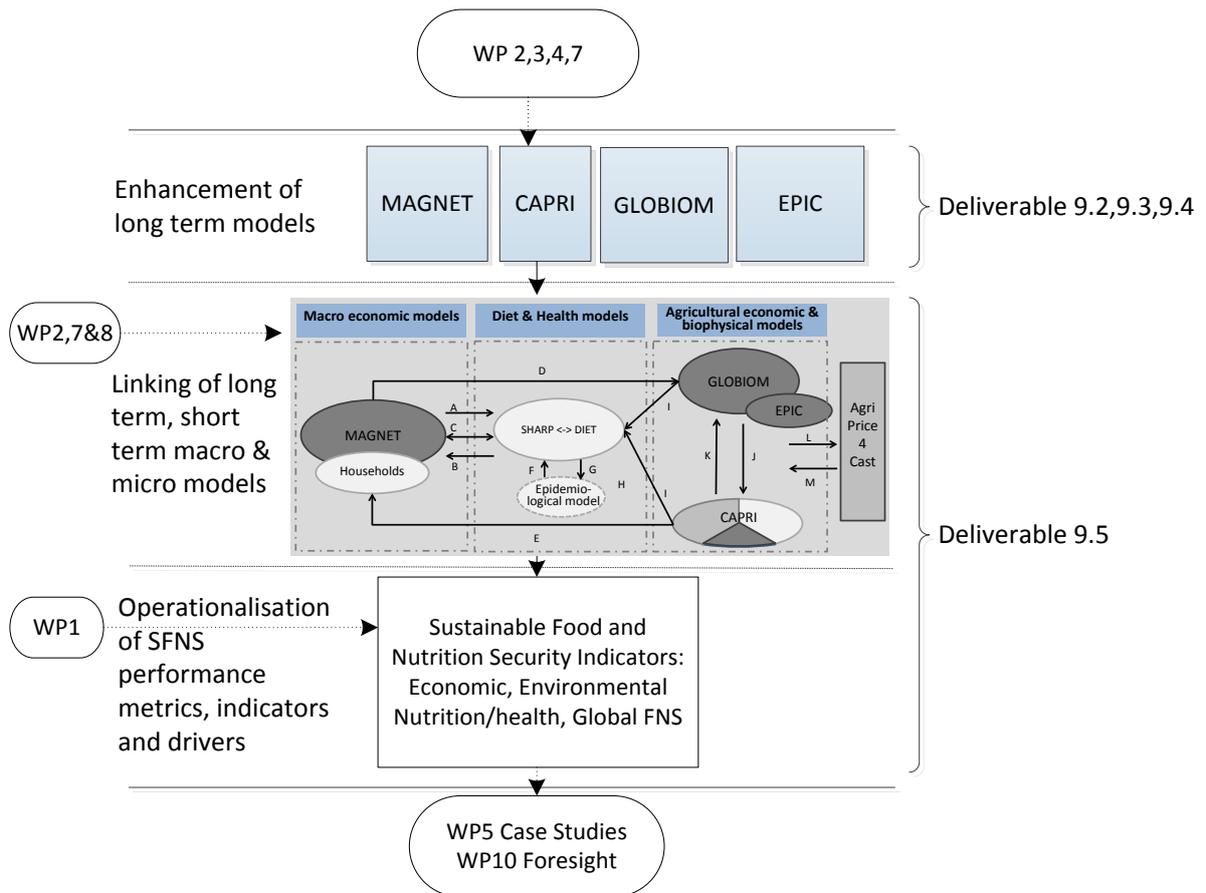
The methodological framework for WP9 comprises three stages (Figure 1):

- Enhancement of long-term models
- Linking of long-term, short-term macro and micro models
- Operationalisation in SFNS indicators

The three stages correspond to the deliverables of WP9 as indicated in Figure 1. The first stage involves the enhancement of the long-term models (MAGNET, CAPRI, GLOBIOM and EPIC) in the SUSFANS toolbox with respect to consumption, food supply chain and production, using data and modelling tools from, respectively, WP2 (Drivers and Data Food Consumption) and WP7 (Modelling Sharp Diets), WP3 (Drivers and Data: Food Supply Chains), and WP4 (Drivers and Data Primary Agriculture and Fisheries). The second stage covers the linking of long-term, short-term, macro and micro models in the SUSFANS toolbox. This includes models from WPs 2 and 7 (DIET model; SHARP model) and WP8 (AgriPrice4Cast). The final stage operationalises the toolbox in terms of a consistent set of Sustainable Food and Nutrition Security (SFNS) indicators, covering economic, environmental, nutrition/health and global dimensions of SFNS. These are based on the conceptual framework and metrics developed in WP1. The toolbox is subsequently used in case studies (WP5), and in creating foresight through scenario and policy analysis (WP10).

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<sup>1</sup> See for more information the SUSFANS position paper on “Metrics, models and foresight for sustainable food and nutrition security in Europe.” (Rutten et al., 2015).



**Figure 1 Methodological framework for the SUSFANS toolbox**  
 The three stages of WP9 are further elaborated in the following sections.

## 2. Enhancement of long-term models

The first section describes the models that are used for the long-term modelling, whereas the second section describes how these models will be improved.

### 2.1 Description of long-term models

The long-term models of the SUSFANS toolbox include MAGNET, CAPRI and GLOBIOM, each of which are described below.

#### 2.1.1 MAGNET

##### Introduction

MAGNET (Modular Applied GeNeral Equilibrium Tool) is a multi-sector, multi-region Computable General Equilibrium model of the world economy (Woltjer et al., 2014), which has been widely used to simulate the impacts of agricultural, trade, land and biofuel policies on the global economy, as well as for long-term projections. MAGNET is based on the GTAP model, which accounts for the behaviour of households, firms, and the government in the global economy and how they interact in markets (Hertel, 1997). The model includes the food supply chain from farm, as represented by agricultural sectors, - via food processing industries and food service sectors - to fork taking into account bilateral trade flows for major countries and regions in the world. MAGNET has been extended from the GTAP model so as to make it suitable for in-depth analyses in the area of agriculture, characterised by competing demands from food, feed and biofuels, and food and nutrition security. The extensions have been added in separate modules to the GTAP core, which can be switched on or off depending on the policy question at hand, making MAGNET particularly flexible for use in applied policy analyses. The model has been developed at LEI Wageningen UR (LEI) and is applied and further extended at LEI, Thünen Institute (TI) and the Joint Research Center Institute for Prospective Technological Studies (JRC/IPTS).

##### Data

GTAP V9 database with 2007 as reference year (Narayanan, Aguiar, and McDougall, 2015) forms the starting point for quantifying the global economy in MAGNET. It distinguishes 140 countries or regions, 57 sectors and 5 factor endowments<sup>2</sup>. It is based on country input-output tables and includes consistent bilateral trade flows, transport and protection data. All monetary values of the data are in millions of US\$. Additional data sources include the International Energy Agency (IEA), the Food and Agriculture Organisation of the United Nations (FAO) and the United States Department of Agriculture (USDA). Regions<sup>3</sup> and sectors<sup>4</sup> can be flexibly aggregated to set-up a model version specific for the problem in question. When it comes to food and nutrition for humans, at its most detailed (GTAP) level, MAGNET can distinguish (N.B. numbers refer to GTAP sectors):

- Eleven primary food and nutrition-related sectors: (1) paddy rice; (2) wheat; (3) other cereal grains; (4) vegetables, fruits, nuts; (5) oil seeds; (6) sugar cane, sugar beet; (8) other crops; (9) bovine cattle, sheep, goats, horses; (10) other animal products (pigs, poultry, eggs,...); (11) raw milk; and (14) fishing.
- Eight processed food sectors, which process commodities from aforementioned sectors into food products: (19) bovine meat products (i.e. red meat); (20) other meat products (i.e. white meat); (21) vegetable oils and fats; (22) dairy products; (23) processed rice; (24) sugar; (25) other food products; and (26) beverages and tobacco.
- Three food-related service sectors, through which a lot of food (primary or processed) is consumed indirectly: (47) trade services, including retail, wholesale, hotels and restaurants; (55) recreational and other services; and (56) public services (admin, defence, health, education).

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<sup>2</sup> In the last GTAP database release additional detail in labour endowments is added, increasing the number of labour endowments from 2 to 5. This additional detail has not yet been incorporated in the MAGNET database.

<sup>3</sup> <https://www.gtap.agecon.purdue.edu/databases/regions.asp?Version=9.211>.

<sup>4</sup> [https://www.gtap.agecon.purdue.edu/databases/v9/v9\\_sectors.asp](https://www.gtap.agecon.purdue.edu/databases/v9/v9_sectors.asp).

Using additional data, mostly from FAOSTAT, the MAGNET model can disaggregate GTAP sectors to arrive at finer detail which enhances the modelling of the interactions between the agricultural and non-agricultural production sectors, such as different types of fertilisers or first and second generation bio-based (by-)products. In terms of human nutrition the following sector splits are worth mentioning:

- Separating crude vegetable oil from (21) vegetable oils and fats, including a separation of oilcake used as animal feed (by-product of producing vegetable oil).
- Separating animal feed from (25) other food products.

Next to distinguishing types of food, the ability to distinguish sources of changes in household income is important for analysing changes in consumption. In addition to the five GTAP production factors (land, unskilled and skilled labour, capital, natural resources), MAGNET can - for a selective number of countries (for which suitable additional national data sources are available) - distinguish more production factors. In combination with the household module (discussed below) this allows for a much more detailed assessment of changes in household income and thus in expenditure patterns.

### GTAP core model

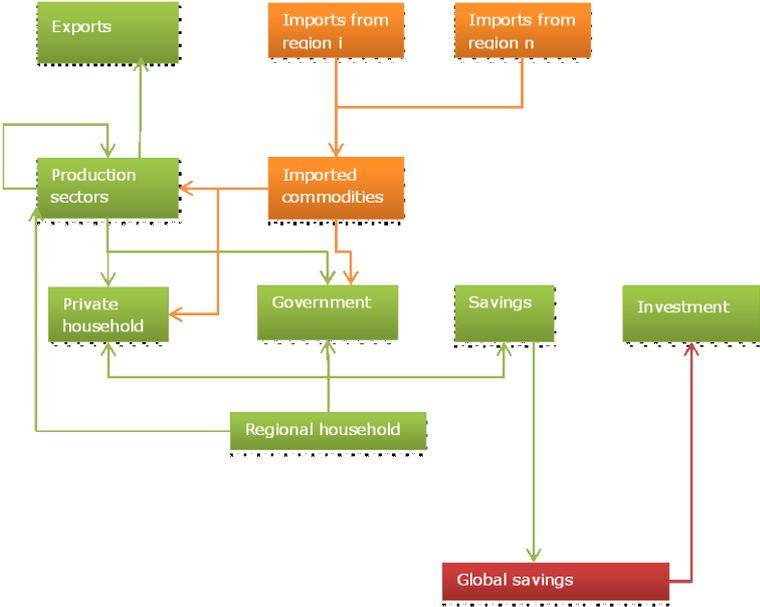
The GTAP core model behaviour can be described as follows (see Brockmeier (2001) for a graphical description of the GTAP model). Household behaviour is captured via a 'representative (regional) household', which in search for maximising its utility, collects all income that is generated in the economy and allocates it, using constant shares, over private household and government expenditures on commodities, and savings for investment goods. Income comes from payments by firms to the regional household for the use of endowments of skilled and unskilled labour, land, capital and natural resources. The regional household also receives income from (net) taxes paid by the private household (on private consumption and income), firms (taxes on intermediate inputs and production) and the government (on its expenditures). Firms, in search of maximising profits, produce commodities by employing the aforementioned endowments and intermediate inputs from other firms using a 'constant returns to scale' production technology<sup>5</sup> so as to sell them to private households, the government and other producers. Regarding trade, domestically produced goods can either be sold on the domestic market or to other regions in the world. Similarly, domestic intermediate, private household and government demand for goods can be satisfied by domestic production or by imports from other regions in the world ('Armington assumption'). These come with their own import and export taxes. Sourcing of imports happens at the border, after which - on the basis of the resulting composite import price - the optimal mix of import and domestic goods is derived.<sup>6</sup> Demand for and supply of commodities and endowments meet in markets, which are perfectly competitive and clear via price adjustments. Natural resources and land are assumed to adjust sluggishly between sectors, whereas capital and labour are perfectly mobile. With all markets in equilibrium, firms earning zero profits and households being on their budget constraint, global savings must equal global investments. Investments are computed on a global basis, via a 'global bank' which assembles savings and disburses investments, so that all savers in the model face a common price for this savings commodity. Global savings determine global investments, i.e. the macro closure is savings driven and essentially neoclassical in nature. Since GTAP is essentially a comparative static model, investments only influence the pattern of production via investments as a demand category and are not installed so as to add to the productive capacity of industries over time. As the CGE model can only determine relative prices, the GDP deflator is set as the 'numéraire' (i.e. the basic unit to represent value) of the model, against which all other prices are benchmarked.

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<sup>5</sup> This means that as firms grow, they do not become more efficient or less efficient.

<sup>6</sup> The Armington assumption implies that an increase in the domestic price relative to imports will lead to an increase in demand for imports relative to domestic goods. Similarly, if imports from one source country become more expensive, there will be substitution towards imports from another, cheaper, source country.

Changes in prices resulting from the model simulations thus constitute real price changes. The model parameters (mainly elasticities) are based on estimations, literature and expert knowledge.



**Figure 2 A simplified representation of the GTAP model**  
 Source: Woltjer et al. (2014)

**MAGNET modular extensions**

The various extensions in MAGNET are modelled in a modular way so that they can be switched on and off by region. This makes MAGNET flexible and applicable to a diverse set of research questions. The extensions offer a more detailed and improved representation of certain parts of the economy and include the following modules:

- The *production module* does justice to the inherent variances in the production process of commodities, notably food, feed and fuel. This results in six distinctly different production structures, including for petrol (substitution between biofuels and fossil fuels), animal products (substitution between pasture land and compound feed), compound feed (substitution among feedstock), chemicals including fertilisers (substitution between land and non-land value added), ethanol (substitution among ethanol feed stock) and crop-producing sectors (substitution between land and fertilisers).
- The *consumption module* allows for a better depiction of changes in diets observed over time away from staple foods, towards vegetables and fruits, meats, dairy and fish. This is achieved by updating the income elasticities in MAGNET as a decreasing function of real – purchasing power parity (PPP) corrected - GDP per capita as economies grow over time. The approach avoids unrealistically high consumption of food items in fast growing economies resulting from the Constant Difference of Elasticities (CDE) consumption function used in GTAP.
- The *labour market module* introduces a relationship between wages and the supply of labour using labour supply functions for skilled and unskilled labour. Reflects changes in the participation rate in the short- and medium-term as a result of changing wage levels.
- The *segmented factor market module* divides the market for capital, skilled and unskilled labour into an agricultural and non-agricultural market. Within each of these markets there is perfect movement, but it is more difficult to move from one to another. This results in, for example, differences in wage levels for labour in agriculture compared with non-agriculture (i.e. industry and services sectors), which is observed in reality.

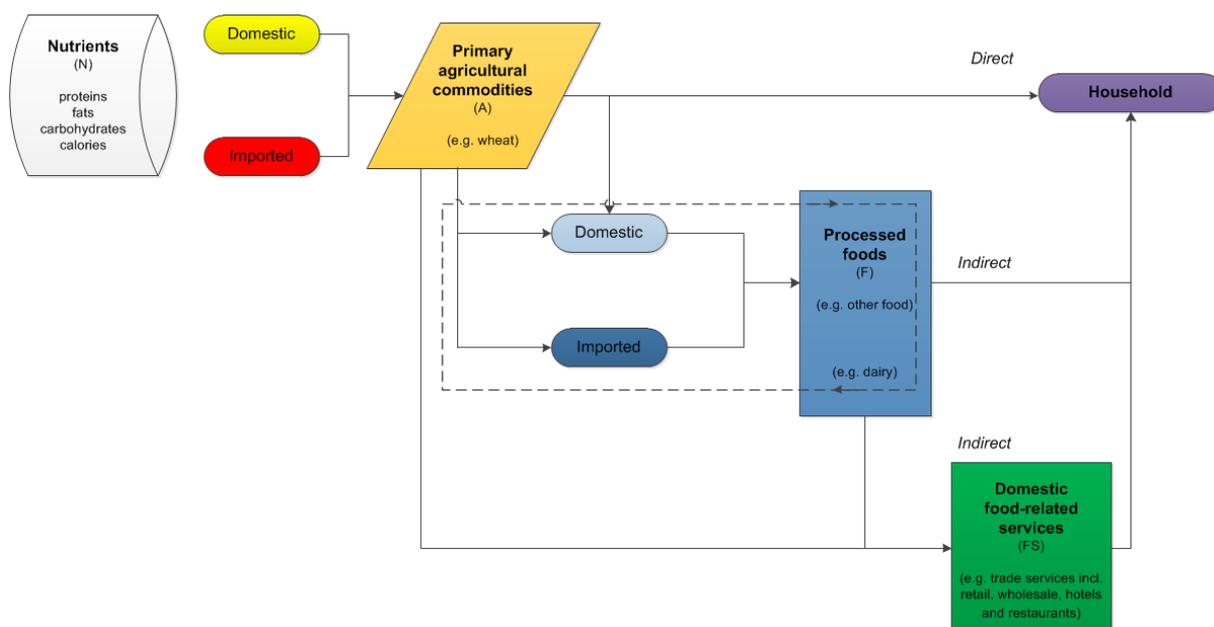
- The *endogenous land supply* and *land allocation modules* govern the land market in MAGNET. By means of the former, land supply endogenously responds to a land rental rate. An increase in demand for agricultural sectors will lead to land conversion into agricultural land and, if enough land is available, a modest increase in rental rates, whereas if almost all agricultural land is in use (land is scarce) increases in demand will lead to strongly rising rental rates. By means of the latter, the allocation of land over sectors takes place according to differing degrees of substitutability.
- The *CAP module* captures key features of the EU Common Agricultural Policy (price and income support to farmers, agricultural market protection measures, agricultural quotas for milk and sugar).
- The *biofuels module* adds biofuel sectors to the model and captures the biofuel directive, which influences agricultural markets and, consequently, food supply and prices.
- The *investment module* forms an alternative investment specification to the standard GTAP investment specification, which at times causes improbable baselines or might even cause the model to fail for certain baseline shocks.
- The *bilateral tariff rate quota* (BTRQ) module allows for the modelling of tariff rate quota on bilateral imports in MAGNET.
- The *welfare module*, which contains a welfare decomposition tool that is consistent with the additional MAGNET modules.

Recent modular extensions of particular relevance for the analysis of sustainability and food and nutrition security are:

- The *emissions module*, which includes CO<sub>2</sub> and Non-CO<sub>2</sub> emission data published by GTAP and calculates emissions for newly introduced biofuel sectors, fertiliser sectors and energy sectors. It allows for the modelling of a CO<sub>2</sub> tax, an emission reduction target, and (in future) emissions trade.
- The *household module*, which enables the analyses of impacts of changes in the economy across different types of households and the modelling of household level policies (consumption taxes or subsidies, income transfers, remittances and aid). The module can be activated by region, resulting in one of three choices: (1) a regional household as in GTAP, (2) a split between a single private household and government with no overarching regional household, or (3) multiple households and a government. In case private household(s) are distinguished, transfers between the government and private households are explicitly included. The module has been applied to Ghana, Kenya, Uganda, India (completed), Indonesia, and Ethiopia (ongoing) and can in principle be applied to other countries in the world, if Social Accounting Matrix data with detailed household level information are available.
- The *nutrition module*, which traces nutrients from farm - via food processing and food-service sectors - to fork, allows for the analysis of nutrition impacts in economy-wide analyses, providing entry points for where, when and how (policy) to act. The module accounts for three channels of consumption (Figure 3), directly via primary commodities and indirectly via processed foods and food-related services (as indicated before), and produces indicators showing content by nutrient, channel, source region and sector. The module has been applied to macronutrients (calories; proteins, fats and carbohydrates), and can in principle be applied to micronutrients, if data at the primary production level are available. This would allow for the modelling of biofortification/supplementation or limiting bad ingredients in foods and modelling healthy diets. The nutrition module has been combined with the household module so as to arrive at household-level nutrition indicators.<sup>7</sup>

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<sup>7</sup> Nutrition indicators at the household level currently have limited applicability for aggregated GTAP commodities covering a wide variety of products.



**Figure 3 Visualisation of the MAGNET nutrition module**

*Source: Rutten et al. (2013, 2014)*

### Dynamics

Projections over time up to 2100 are possible and are mainly driven by exogenously assumed GDP and population growth, technology/productivity changes (including yields) and changing policies.

### (Policy) levers to induce change

(Policy) instruments that are/will be available in the model include:

- domestic/trade taxes and subsidies
- government/inter-household transfers, remittances and aid
- taste shifters (induced by information and marketing campaigns, food labelling)
- yields, productivity changes (from technological change) throughout the chain
- availability of land (or other endowments)
- biofortification/supplementation or reducing bad ingredients in foods (in case micronutrients are incorporated in the model)
- food loss and waste reductions (in case food losses and waste streams are incorporated)
- emission targets.

### Output indicators

Outputs of MAGNET are presented in value terms or in percentage price and quantity changes. Main outputs are production, trade flows, consumption, use of endowments, intermediate input use, income and price changes.

More specifically, useful output indicators from the MAGNET model for the analysis of sustainable diets, food and nutrition security (Figure 4) include (changes in):

- household incomes (decomposable by source) and savings
- prices of agri-food products
- production, consumption and trade in agri-food products
- employment and land use, and associated wages and land rental rates
- emissions
- calories/nutrients (traced back to their country/raw commodity origin) and composite indicators (dietary diversity/quality).

**Figure 4 FNS indicators in MAGNET**

Food and Nutrition Security			
Status		Stability	
<b>Food availability</b> Domestic food production ( <i>qo</i> ) Food producer prices ( <i>ps</i> ) Trade in food ( <i>pcif, pjob,qxs</i> )	<b>Food access</b> Household income ( <i>yph</i> ) decomposable by source Factor income ( <i>pf, qf</i> ) Consumer food prices ( <i>pph</i> ) Government transfers ( <i>realTRNG</i> ) Inter-household transfers ( <i>realTRNH</i> ) Remittances Household tax incidence	<b>Food utilisation</b> Household food basket ( <i>qph</i> ) decomposable by food type and source (imported and domestic) Household nutrient consumption: total ( <i>NQTH</i> ) and per capita ( <i>NQPCH</i> ) and by source <sup>1</sup>	<b>Vulnerability &amp; Resilience</b> Household savings Aid payments

Source: Kuiper and Shutes (2014)

**2.1.2 CAPRI**

Introduction

CAPRI is a comparative static partial equilibrium model for the agricultural sector developed for policy and market impact assessments from global to regional and farm type scale. The core of CAPRI is based on the linkage of a European-focused supply module and a global market module. The following brief description of the Common Agricultural Policy Regionalised Impact Modelling System (CAPRI) is based on the most recent CAPRI documentation (Britz and Witzke, 2014). All available information around the CAPRI modelling system can be found on the CAPRI webpage ([www.capri-model.org](http://www.capri-model.org)).

Supply module

The supply module consists of independent aggregate non-linear programming models which cover the EU27, Norway, Western Balkans and Turkey. They represent all agricultural production activities and related output generation and input use at regional (280 NUTS2, Nomenclature of Units for Territorial Statistics) or farm type level (Gocht and Britz, 2011). The programming models feature a hybrid approach consisting of the combination between a Leontief-technology for variable costs covering a low and high yield variant for the different production activities and a non-linear cost function which captures the effects of labour and capital on farmers’ decisions. The non-linear cost function allows for perfect calibration of the models and a smooth simulation response rooted in observed behaviour. Each programming model (at NUTS2 or farm type level) optimises income under restrictions relating to land balances, including a land supply curve, nutrient balances and nutrient requirements of animals and, if applicable, policy obligations. Decision variables are crop areas and total land use, herd sizes, fertiliser application rates and the feed mix. With respect to policy implementation, the different policy instruments of Pillar I and Pillar II of the Common Agricultural Policy (CAP) are depicted in detail for the EU. Prices are exogenous to the supply module and provided by the market module.

Global market module

The global market module is a spatial, non-stochastic global multi-commodity model for about 50 primary and processed agricultural products, covering about 80 countries/country blocks, which are organised in 40 trading blocks. The market module is defined by a system of behavioural equations representing agricultural supply, human and feed consumption, multilateral trade relations, feed energy and land as inputs and the processing industry; all differentiated by commodity and geographical units. Land is not explicitly allocated to activities when the model is solving. But the land demand elasticities in the system imply certain yield elasticities that may be used to disaggregate the

total supply response into contributions from yields and from areas and to estimate the land allocation in scenarios, starting from the baseline land allocation. On the demand side the Armington approach (Armington, 1969), assumes that the products are differentiated by origin, allowing the simulation of bilateral trade flows and of related bilateral and multilateral trade instruments, including tariff-rate quotas. This sub-module delivers the output prices used in the supply module and allows for market analysis at global, EU and national scale, including a welfare analysis.

### Data

The main databases used in CAPRI are based on EUROSTAT, FAOSTAT, OECD and extractions from the Farm Accounting Data Network (FADN). The supply response of each NUTS2 or farm type in the European-focused supply module is estimated using time series data on land use and corresponding price and cost developments (Jansson and Heckeley, 2011). The parameters of the global market model are synthetic, i.e. to a large extent taken from the literature and other modelling systems.

### Dynamics

Typically, CAPRI is used for simulations starting from a given baseline. For medium-term horizons, the price-quantity structure of the model is calibrated to commodity market outlook of the European Commission. To produce longer-term baselines, trend estimations constrained to account for technology restrictions and external prior information become more important. Some information supporting this process comes, for example, from the GLOBIOM model. This baseline alignment across models ensures a relatively similar starting point for subsequent scenario analyses.

A complete list of products considered in CAPRI is given in Table 1. Main outcome indicators are listed in Table 2.

**Table 1 Outputs, inputs, income indicators, policy variables and processed products in the data base**

Group	Item	Code
<b>Outputs</b>		
Cereals	Soft wheat Durum wheat Rye and Meslin Barley Oats Paddy rice Maize Other cereals	SWHE DWHE RYEM BARL OATS PARI MAIZ OCER
Oilseeds	Rape Sunflower Soya Olives for oil Other oilseeds	RAPE SUNF SOYA OLIV OOIL
Other annual crops	Pulses Potatoes Sugar beet Flax and hemp Tobacco Other industrial crops	PULS POTA SUGB TEXT TOBA OIND
Vegetables Fruits Other perennials	Tomatoes Other vegetables Apples, pear & peaches Citrus fruits Other fruits Table grapes Table olives Table wine	TOMA OVEG APPL CITR OFRU TAGR TABO TWIN

<b>Group</b>	<b>Item</b>	<b>Code</b>
	Nurseries Flowers Other marketable crops	NURS FLOW OCRO
Fodder	Gras Fodder maize Other fodder from arable land Fodder root crops Straw	GRAS MAIF OFAR ROOF STRA
Marketable products from animal product	Milk from cows Beef Pork meat Sheep and goat meat Sheep and goat milk Poultry meat Other marketable animal products	COMI BEEF PORK SGMT SGMI POUM OANI
Intermediate products from animal production	Milk from cows for feeding Milk from sheep and goat cows 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	COMF SGMF YCOW YBUL YHEI YCAM YCAF YPIG YLAM YCHI MANN MANP MANK
Other Output from EAA	Renting of milk quota Agricultural services	RQUO SERO
<b>Inputs</b>		
Mineral and organic fertiliser Seed and plant protection	Nitrogen fertiliser Phosphate fertiliser Potassium fertiliser Calcium fertiliser Seed Plant protection	NITF PHOF POTF CAOF SEED PLAP
Feedings tuff	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	FCER FPRO FENE FMIL FGRA FMAI FOFA FROO FOTH FSTRA
Young animal Other animal specific inputs	Young cow Young bull Young heifer Young male calf Young female calf Piglet Lamb Chicken	ICOW IBUL IHEI ICAM ICAF IPIG ILAM ICHI

Group	Item	Code
	Pharmaceutical inputs	IPHA
General inputs	Maintenance machinery Maintenance buildings Electricity Heating gas and oil Fuels Lubricants Water Agricultural services input Other inputs	REPM REPB ELEC EGAS EFUL ELUB WATR SERI INPO
Income indicators	Production value Total input costs Gross value added at producer prices Gross value added at basic prices Gross value added at market prices plus CAP premiums	TOOU TOIN GVAP GVAB MGVA
Activity level	Cropped area, slaughtered heads or herd size	LEVL
Policy variables Relating to activities	Premium ceiling Historic yield Premium per ton historic yield Set-aside rate Premium declared below base area/herd Premium effectively paid Premium amount in regulation Type of premium application Factor converting PRMR into PRMD Ceiling cut factor	PRMC HSTY PRET SETR PRMD PRME PRMR APPTYPE APFFACT CEILCUT
Processed products	Rice milled Molasse Starch Sugar Rape seed oil Sunflower seed oil Soya oil Olive oil Other oil Rape seed cake Sunflower seed cake Soya cake Olive cakes Other cakes Gluten feed from ethanol production Biodiesel Bioethanol Palm oil Butter Skimmed milk powder Cheese Fresh milk products Creams Concentrated milk Whole milk powder Whey powder Casein and caseinates Feed rich protein imports or byproducts Feed rich energy imports or byproducts	RICE MOLA STAR SUGA RAPO SUNO SOYO OLIO OTHO RAPC SUNC SOYC OLIC OTHC GLUE BIOD BIOE PLMO BUTT SMIP CHES FRMI CREM COCM WMIO WHEP CASE FPRI FENI

**Table 2 Main outcome indicators**

Module	Outcome indicator
European supply module	Supply Feed demand (in bulks) Areas Herds Yields Input demand Gross value added
Global trade module	Supply Final demand Feed Processing Prices (consumer/producer) Trade flows
Post model processing	Support of results analysis Aggregation over scales/products/activities Decomposition: yield response, behavioural functions market model Economics Farm income indicators Welfare analysis CAP budget, CAP instruments Environmental indicators Gaseous emissions N, P, K balances GHG inventories Energy use in European agriculture Diet related Calories Macronutrients Spatial downscaling

### 2.1.3 GLOBIOM

#### Introduction

GLOBIOM (Global Biosphere Management Model) is a global recursive dynamic bottom-up partial equilibrium model integrating the agricultural, bioenergy and forestry sectors. It has been developed at IIASA since 2007 (Havlík et al., 2011; Havlík et al., 2014). GLOBIOM is a linear programming model based on the spatial equilibrium approach developed by Takayama and Judge (1973). In the objective function of the model, a global agricultural and forest market equilibrium is computed by choosing land use and processing activities to maximize welfare (i.e. the sum of producer and consumer surplus) subject to resource, technological, demand and policy constraints. Figure 5 presents the model structure graphically.

The model depicts all world regions aggregated to in between 30 and 57 regions (depending on the model version and research question), which either represent single countries or country aggregates. International trade representation is based on the spatial equilibrium modelling approach, where individual regions trade with each other based purely on cost competitiveness because goods are assumed to be homogenous (Takayama and Judge, 1973; Schneider et al., 2007). GLOBIOM is calibrated to FAOSTAT market data for the year 2000 (average 1998 - 2002) and runs recursively dynamic in 10-year time-steps up to 2050/2100.

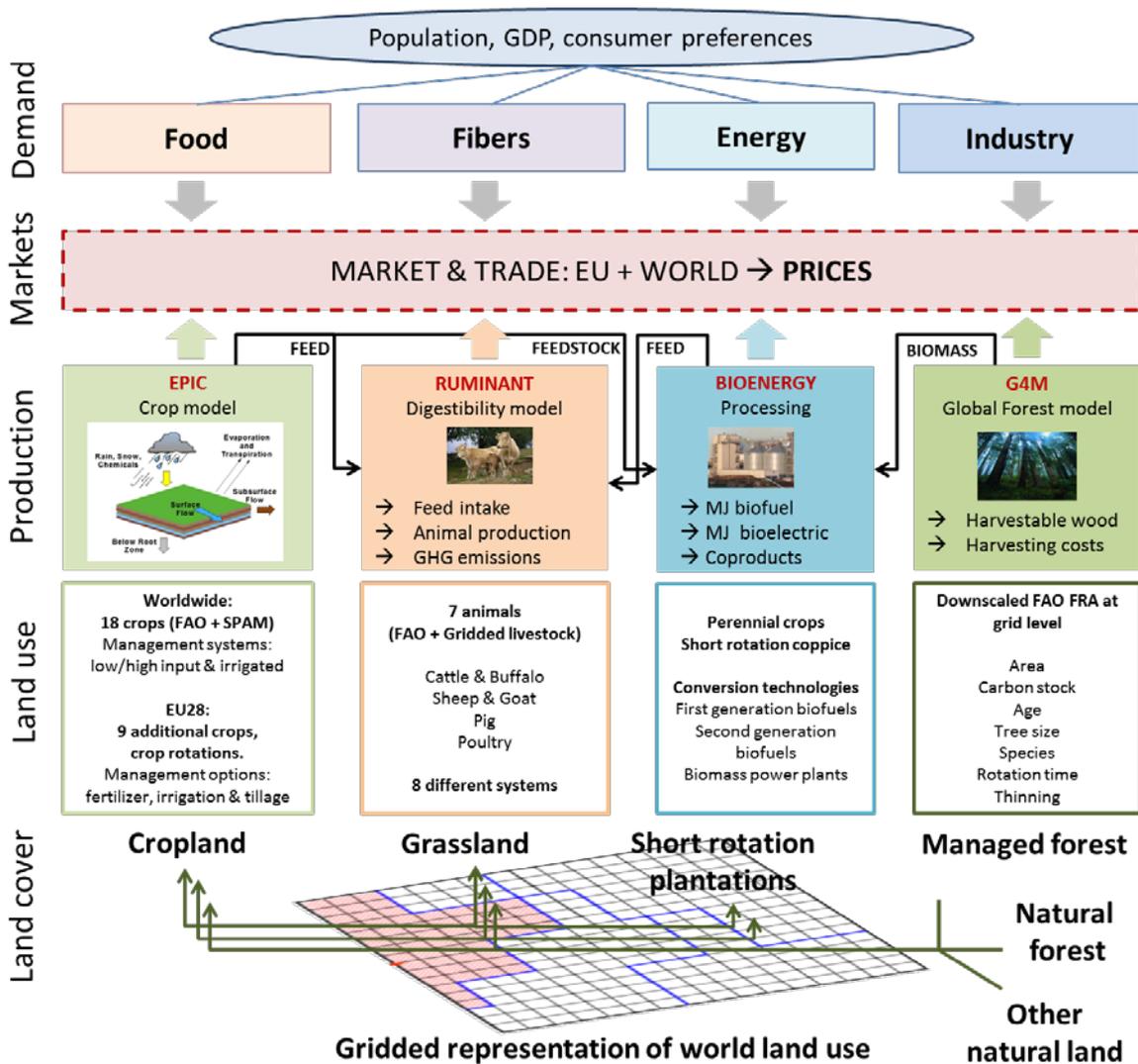


Figure 5 Illustrative GLOBIOM model structure

### Production structure

On the supply side, the model is built on a spatially explicit, bottom-up setting. The basis is a detailed disaggregation of land into Simulation Units – clusters of 5 arcmin pixels belonging to the same country, altitude, slope and soil class and to the same 0.5° x 0.5° pixel (Skalský et al., 2008). This information is then re-aggregated to 2° x 2° degree cells disaggregated by country boundaries and by three agro-ecological zones. In the EU version of GLOBIOM, the EU28 is depicted at the NUTS2 level.

Regarding crop production, GLOBIOM globally represents 18 major crops (barley, beans, cassava, chickpeas, corn, cotton, groundnut, millet, palm oil, potato, rapeseed, rice, soybean, sorghum, sugarcane, sunflower, sweet potato, wheat) and 4 different management systems (irrigated – high input, rainfed – high input, rainfed – low input and subsistence) simulated by the biophysical process based crop model EPIC (Williams, 1995; Izaurralde et al., 2006). In the EU version of GLOBIOM, nine additional commodities are represented: soft wheat, durum wheat, rye, oats, sugar beet, peas, corn silage, other green fodder and fallow.

Within each management system, the input structure is fixed following a Leontief production function. But crop yields can change in reaction to external socio-economic drivers through switching to another management system or reallocation of the production to a more or less productive Supply

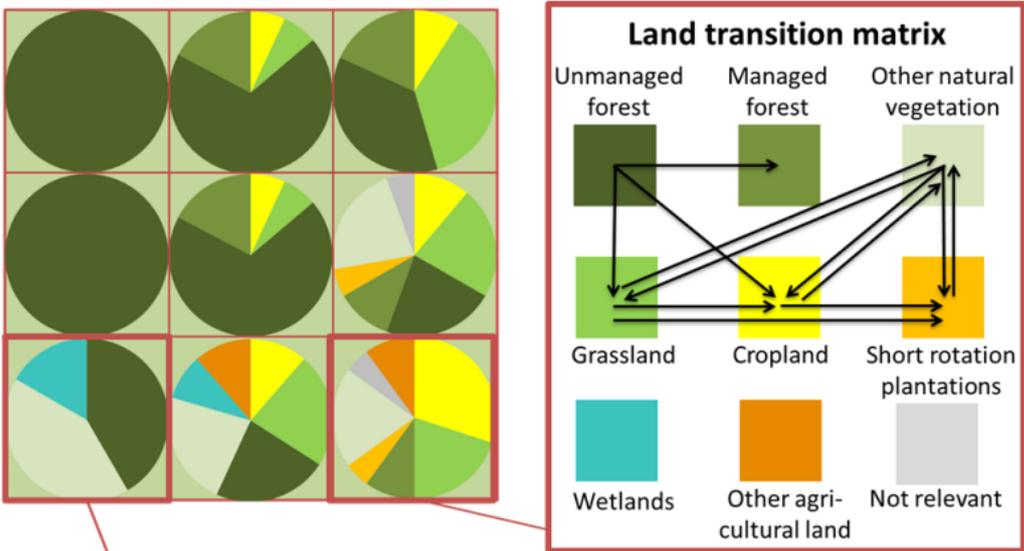
Unit. Besides these endogenous mechanisms, an exogenous component representing long-term technological change is also considered.

The market balances in GLOBIOM rely on EUROSTAT accounts for the EU28 and on FAOSTAT for outside the EU. The land cover description for the EU28 is based on CORINE/PELCOM cover maps, which ensure a great level of detail in land cover. The land cover for the rest of the World is based on Global Land Cover 2000 (GLC, 2000).

The livestock sector component of the model uses the International Livestock Research Institute/FAO production systems classification. Four production systems are considered: grassland based, mixed, urban and other. The first two systems are further differentiated by agro-ecological zones. For our classification we retained three zones arid/semi-arid, humid/subhumid and temperate/tropical highlands. Monogastrics are split into Industrial and Smallholder. Eight different animal groups are considered: bovine dairy and meat herds, sheep and goat dairy and meat herds, poultry broilers, poultry laying hens, mixed poultry, and pigs. Animal numbers are at the country level consistent with FAOSTAT. The livestock production system parameterisation relies on the dataset by Herrero et al. (2013).

For the forest sector, primary forest productivity such as mean annual wood biomass increment, maximum share of saw logs in harvested biomass, and harvesting costs are provided by the G4M model (Kindermann et al., 2006). Five primary forest products are represented in the model (saw logs, pulp logs, other industrial logs, fuel wood and biomass for energy).

Regarding land use change, nine different land cover types are considered in the model: cropland, grassland, managed forest, unmanaged forest, short rotation plantations, other natural vegetation, other agricultural land, wetland and non-relevant land (Figure 6). Transition is modelled between the first six land cover types, while the remaining three are assumed to be constant over time. Economic activities are associated with cropland, grassland, managed forest and short rotation plantations. In principle, each simulation unit can contain all nine land cover types.



Model gridcell land use composition

## Figure 6 Land use change representation in GLOBIOM

Source: Havlík et al. (2014)

Land conversion over the simulation period is endogenously determined for each simulation unit within the available land resources. Such land use change movements imply conversion costs, which are increasing with the area of land that is converted and which are taken into account in the producer optimization behaviour. Land conversion possibilities are further restricted through biophysical land suitability and production potential, as well as through a matrix of potential land cover transitions (Figure 6). The latter defines which land type can be transformed into which other land type. For example, new cropland can be sourced from unmanaged forest, other natural vegetation or managed grassland.

### Demand structure

On the demand side, a representative consumer is modelled for each region. Food demand in GLOBIOM is endogenous and depends on population, gross domestic product (GDP) and own product prices. Population and GDP are exogenous variables while prices are endogenous. The simple demand system is presented in Eq. 1. First, for each product  $i$  in region  $r$  and period  $t$ , the *prior* demand quantity  $\bar{Q}$  is calculated as a function of population  $POP$ , GDP per capita  $GDP^{cap}$  adjusted by the income elasticity  $\varepsilon^{GDP}$ , and the base year consumption level as reported in the Food Balance Sheets of FAOSTAT. If the *prior* demand quantity could be satisfied at the base year price  $\bar{P}$ , this would be also the optimal demand quantity  $Q$ . However, usually the optimal quantity will be different from the *prior* quantity, and will depend on the optimal price  $P$  and the price elasticity  $\varepsilon^{price}$ , the latter calculated from USDA (Seale et al., 2003, updated in Muhammad et al., 2011) for the base year 2000. Because food demand in developed countries is more inelastic than in developing ones, the value of this elasticity is assumed to decrease with the level of GDP per capita. The rule we apply is that the price elasticity of developing countries converges to the price elasticity of the USA in 2000 at the same pace as their GDP per capita reaches the USA GDP per capita value of 2000. This allows us to capture the effect of changes in relative prices on food consumption taking into account heterogeneity of responses across regions, products and over time.

$$\frac{Q_{i,r,t}}{\bar{Q}_{i,r,t}} = \left( \frac{P_{i,r,t}}{\bar{P}_{i,r,2000}} \right)^{\varepsilon_{i,r,t}^{price}} \quad \text{where} \quad \bar{Q}_{i,r,t} = \frac{POP_{r,t}}{POP_{r,2000}} \times \left( \frac{GDP_{r,t}^{cap}}{GDP_{r,2000}^{cap}} \right)^{\varepsilon_{i,r,t}^{GDP}} \times \bar{Q}_{i,r,2000} \quad (\text{Eq. 1})$$

### Dynamics and drivers

Scenarios are driven in GLOBIOM by a set of exogenously changing parameters. The two principal exogenous drivers are changes in population and GDP. As described above, population and GDP determine exogenous demand changes. Furthermore, in GLOBIOM we follow Tilman et al. (2011) who showed that economic income groups are a significant variable when projecting crop yields. Therefore, we estimate yield response functions to GDP per capita for crops using a fixed effects model with panel data, which are the basis for exogenous crop productivity shifters implemented in GLOBIOM to reflect future technological change.

Further potential exogenous drivers taken into account in GLOBIOM are climate change impacts. Specifically, four representative concentration pathways have been developed for the climate modelling community as a basis for long-term and near-term modelling experiments (Van Vuuren et al., 2014). The four RCPs span from 2.6 to 8.5W/m<sup>2</sup> radiative forcing values until 2100 ranging thereby from a <2 degree warming scenario up to a 4 degree scenario. The four RCPs have been quantified by different global climate models (Warszawski et al., 2014) and climate effects have been passed on to global gridded crop models which in turn simulated crop- and grassland specific productivity shifters (Rosenzweig et al., 2014). For implementation of these climate change impacts on crop- and grasslands in GLOBIOM, average yield shifters were calculated per crop, management

system and region from the crop models for the different climate scenarios. These shifters can be applied to shift future yields and costs in the different climate scenarios (Havlík et al., 2015).

In addition, different policy options can be taken into consideration for GLOBIOM scenarios. The detailed representation of different GHG emission sources related to agriculture and land use change offers a simulation of different *climate change mitigation policies* with the model. However, also other *environmental policies* can be simulated with GLOBIOM (for instance taxation of fertilizer use). *Bioenergy policies* are represented via the consideration of projected bioenergy demand. Demand for bioenergy is not calculated endogenously in GLOBIOM, instead projections from external energy models are used to drive the bioenergy supply. Furthermore, *trade policies* can be depicted within GLOBIOM by exogenous changes in tariffs or other transportation costs on a bilateral basis.

Additionally, scenarios are driven by assumptions on waste and loss reductions, exogenous changes in consumer preferences, GDP independent technical developments in crop production (yield growth, input efficiency) and efficiency changes in livestock production, which are all taken into account in the model.

#### **Output indicators**

Each scenario simulated with GLOBIOM will generate a rich set of results variables at the grid cell, regional- and/or global level. The main output indicators are:

- Prices
- Demand and supply quantities
- Bilateral trade flows
- GHG emissions
- Calorie consumption (per person/day/product/region)
- Nitrogen and phosphorous use
- Water use for irrigation
- Land use and land prices

#### **2.1.4 Model comparison**

This section explains how the models CAPRI, GLOBIOM and MAGNET compare in the use of scenario analyses, both in terms of their general characteristics and their application to the research area of food and nutrition security. Table 3 gives an overview of the main model characteristics.

**Table 3 Overview of the main model characteristics, implementation of FNS drivers and output indicators of CAPRI, GLOBIOM and MAGNET**

	<b>CAPRI</b>	<b>GLOBIOM</b>	<b>MAGNET</b>
Institution	Network, coordination: University of Bonn, Germany	IIASA, Austria	LEI Wageningen UR with Thünen Institute (Brunswick), JRC/IPTS (Seville)
Model type	Comparative static, partial equilibrium	Recursive dynamic, partial equilibrium	Recursive dynamic, general equilibrium
Scope and sectors	Global coverage of agricultural and biofuel sectors	Global coverage of agricultural, bioenergy and forestry sectors	Global coverage of the full economy; all sectors (57 GTAP sectors plus additional sector splits (linked to biofuels incl. by-products, fertilisers, feed))
Representation of food related sectors	Agricultural sector; Mainly raw products (30 crops, 7 animal products, 5 fodder); Processing: Sugar, rice, 9 milk products, 6 veg. oil, biofuels, by-products	Agricultural sector; Mainly raw products (18 crops, 7 animal products, grazing, + additional 6 crops and 3 fodder for EU28); Processing: woody biomass, biofuels, by-products	Food supply chain (7 crop sectors, 4 livestock sectors, 8 food processing industries, 3 food service sectors)
Demand	Generalised Leontief expenditure; representative consumer at the region level (i.e, for 77 countries or country aggregates)	Iso-elastic; representative consumer at the region level; 30 – 57 world regions (depending on model version and research question)	CES functions for up to 140 regions (GTAP Nomenclature). Average utilisation: 30-40; Options: (1) a regional household as in GTAP, (2) a split between a single private household and government with no overarching regional household, (3) multiple households and a government. For option 2 and 3 a LES demand system can be used instead of a CES
Agricultural supply	Non-linear programming: EU member states, Norway, Western Balkans and Turkey at NUTS2 or farm type level; Linear supply derived from NQ profit functions for remaining countries or country aggregates in the rest of world	LP approach; Substitution between Leontief technologies at the grid-cell (>200,000 Simulation Units to represent land spatial heterogeneity re-aggregated to 2° x 2° degree cells, disaggregated by country boundaries and 3 AEZs); EU version: EU28 depicted at NUTS2 level	Fully flexible CES sector-specific production structure for up to 140 regions (GTAP Nomenclature). Average utilisation: 30-40
Trade modelling	Armington spatial equilibrium; Bilateral trade among 40 trade blocks	Enke-Samuelson-Takayama-Judge spatial equilibrium; Bilateral trade among 30 – 57 world regions	Bilateral Trade with Armington among up to 140 regions (GTAP Nomenclature); Average utilisation: 30-40

(table 3, continued)

	CAPRI	GLOBIOM	MAGNET
<b>FNS Drivers</b>			
Exogenous national Income	Yes	yes	yes
Endogenous national income	Only for agricultural sector	-	yes
Exogenous technological change	yes	yes	yes
Endogenous food prices	yes	yes	yes
Endogenous non-food prices	Biofuels	Forestry products, biofuels	yes
Exogenous population growth	yes	yes	yes
Change in diets (including preferences, education, ageing)	yes	yes	yes
Land availability	yes	yes	yes
Other farm inputs availability	-	Water	yes
International market access costs	yes	yes	yes
Food loss and waste reductions	yes	yes	yes
Climate Change impacts	Impacts on crop production	4 RCPs; impacts on crop production	Through exogenous shocks on yields
Common Agricultural Policy	Pillar I in great detail; Important payments of pillar II	Tariffs explicitly; rest of Pillar I implicitly	Key features (price and income support to farmers, agricultural market protection measures, agricultural quotas for milk and sugar)
Bioenergy policy	Exogenous demand for biofuels	Exogenous demand for bioenergy	Exogenous demand for biofuels
Climate change mitigation policy	For European agriculture	CO2 tax, emission reduction target	CO2 tax, emission reduction target
Biofortification/s upplementation /reducing bad ingredients in foods	-	-	Planned in SUSFANS

(table 3, continued)

	CAPRI	GLOBIOM	MAGNET
<b>FNS related output Indicators</b>			
Calorie consumption (average per capita)	yes	yes	yes
Nutrition indicators (average per capita)	For raw and processed products as above: Macronutrients (micronutrients planned in SUSFANS)	Macronutrients	Macronutrients (micronutrients planned in SUSFANS); from farm to fork
Food consumption at household level	-	-	yes (for selected countries - Ghana, Uganda, Kenya, India, Indonesia, China; EU countries to be added in SUSFANS)
Income per capita (national average)	exogenous	exogenous	endogenous
Income per capita (household level)	-	-	yes (for selected countries - Ghana, Uganda, Kenya, India, Indonesia, China; EU countries to be added in SUSFANS)
Food prices	yes	yes	yes
Production, consumption and trade in agri-food products	yes	yes	yes
Land use and land rents	yes	yes	yes
Employment and wages	Farm labour in Europe	-	yes
Government/inter-household transfers, remittances and aid	-	-	yes
Share of food in total consumption (country level)	yes	yes	yes
National self-sufficiency ratio	yes	yes	yes

All models have a global coverage, however, with different focuses; MAGNET as a Computable General Equilibrium (CGE) model covers all economic sectors, whereas CAPRI and GLOBIOM as partial models focus on the agricultural and related sectors (bioenergy, forest). For all models agricultural production, food consumption and food prices are endogenously calculated and bilateral trade flows are depicted. While CAPRI and GLOBIOM have a very detailed – spatially explicit – representation of agricultural production, MAGNET facilitates a detailed analysis of food demand and consumption accounting for general equilibrium feedbacks.

Due to the coverage of all sectors and their monetary interrelations, **MAGNET** enables an analysis of endogenous income changes. This may have strong relations to FNS, potentially also via second round effects of certain policy interventions. Furthermore, as the only model among the three, MAGNET includes the entire food supply chain from farm (as represented by agricultural sectors), via food processing and food service sectors, to fork, which allows for a detailed tracing of nutrient flows. MAGNET also offers the possibility to analyse heterogeneous consumer groups as well as governmental demand. Agricultural production in MAGNET is modelled in a top-down manner per agricultural sector at the national level via a constant elasticity of substitution function. CAPRI and GLOBIOM offer a more detailed analysis of agricultural production via a spatially explicit representation of production and a higher disaggregation of the agricultural sector in terms of commodity specification.

The detailed, grid-cell based disaggregation of land and the specification of different Leontief production functions for each production unit in **GLOBIOM** allows for a detailed consideration of bio-physical constraints in agricultural supply (crop and livestock production). This bottom-up structure facilitates a representation of all land-use types and a detailed analyses of all land-use related research questions at the global scale, such as climate change impact, which potentially is an important future driver of global FNS.

While global agricultural sectors and trade are covered in **CAPRI** as well, the focus of the model is on a detailed representation of European agriculture both in terms of regional and product coverage. For EU member states, Norway, the Western Balkans and Turkey, the spatial resolution is at NUTS2 or even farm level. Various farm income indicators can be derived from CAPRI results. A specific strength of the model lies in the sophisticated representation of the European Common Agricultural Policy.

## **2.2 Model improvements**

This section describes the model improvements that are foreseen for each of the models in the toolbox, categorised by element of the food supply chain; the consumer side, the primary production side and the food chain side. For ease of readability, each subsection is structured along the lines of reporting: task involved, method and data used, result, inputs needed from other WPs, outputs given to other WPs, timeline for the work, output (academic/technical/policy report), sharing of model improvements (across other long-term models), team involved and foreseen risks (and coping strategy).

### **2.2.1 Strengthening the consumer side (diet, nutrition and health)**

This subsection lists model improvements on the demand side, incorporated in MAGNET but made available to the other long-term models in this work package, and can be decomposed in four specific subtasks, including: incorporation of micronutrient indicators, household decomposition, household behaviour under financial, environmental and health considerations and health effects (optional). These model improvements are carried out to support better and more detailed analyses of dietary patterns and associated changes in food and nutrition security across households in the EU and the rest of the world.

#### Micronutrient indicators

by LEI Wageningen UR

**Task:** MAGNET currently includes macronutrients related to food consumption for the average consumer at the aggregated level of MAGNET agri-food commodities for all countries and regions in the world. To enhance the analysis, these data will be expanded with data for micronutrients. Where available, underlying detailed data on agri-food commodities supplying the nutrients as well as information on the type of household buying these commodities will be preserved to support the translation of the aggregate MAGNET results to more detailed nutritional assessments (see subtask on household behaviour).

**Method and data:** the procedure of implementing micronutrients will follow that of macronutrients in MAGNET, which traces nutrients from farm (primary production) to fork (consumers) via direct and indirect channels of consumption (directly via consuming fresh produce from agriculture or indirectly via consuming processed foods and food-services), taking into account trade (Rutten et al., 2014, 2013). This implies that micronutrients related to primary products in MAGNET should be compiled from underlying commodities, using more detailed datasets.

In this project we will use food consumption survey data for four countries (Czech Republic, Denmark, France, and Italy) plus rest of EU if available (see below, from WP7). These food

consumption surveys, will be linked to national composition tables to calculate the nutrient content of country-specific diets. To be able to compare food consumption data between countries, we will use the FoodEx2 classification system (EFSA). The release of this data is scheduled for WP7 (T7.1). For MAGNET we need a link between FAO and the FoodEx2 system, which is also necessary for mapping with the CAPRI model. This mapping is scheduled in WP7 (T7.3)

Additional data which can be used in case of missing or incomplete data (e.g. for rest of the EU and non-EU countries/regions) or for other reasons, can be obtained from

- FAO nutrient composition tables for African countries (<http://www.fao.org/docrep/003/x6877e/X6877E08.htm#ch5.4>)
- USDA nutrient database for American countries containing nutrient contents for raw and processed food. A complete downloaded version is available at LEI. ([http://www.ars.usda.gov/main/site\\_main.htm?modecode=80-40-05-25](http://www.ars.usda.gov/main/site_main.htm?modecode=80-40-05-25))
- The Genus model (Smith et al., 2016) and underlying data (Planetary Health Alliance: <http://projects.iq.harvard.edu/pha/genus>) containing edible food and food products per person in a country.
- For the Netherlands there are RVO-tables which are also available at LEI

**Result:** once implemented, the task will result in micronutrient consumption for the average household of all countries and regions of the world (including for the specified EU countries), which can be decomposed by channel of consumption, primary sector and region of origin. Particular micro nutrients that will be focused on (from WP7) include most likely vitamin D, folate, iron, iodine, SFA, salt and fibre.

**Inputs needed from other WPs:** this task needs data on micronutrients (see list before) from WP7 (WP7.1) by primary food group at least for the four selected countries, but also other EU and non-EU countries if available so as to support worldwide coverage and tracing of nutrients from farm to fork taking into account trade (procedure indicated above).

**Outputs given to other WPs:** household level income and commodity price developments (at the GTAP level of detail available in the MAGNET model) will be provided to the SHARP model (WP7), as part of the case studies and scenario work (WP5, WP10). The micronutrient indicators related to household consumption in MAGNET will become available for the other long-term models in this WP to use (CAPRI, GLOBIOM).

**Risks:** This task will use the nutrition surveillance data for 4 EU countries from Task 2.2 and WP7. Taking the timeline of WP7 into account, a risk for this task is the availability of nutrition data derived from the FoodEx2 system. As a back-up we may use data from sources as specified under method and data (bullet points).

#### Household decomposition by LEI Wageningen UR

Given that consumption patterns vary greatly across households there's a need to model consumption for representative household types to support more detailed nutritional analyses. MAGNET includes procedures and modules to expand the standard GTAP database with multiple household types by region applied to a selected number of developing countries (Kuiper and Shutes, 2014). These data processing modules and model code can be employed to incorporate household types for European countries. The procedures rely on the availability of national SAMs with two or more household types which provide the consistent description of income and expenditures required by a CGE model. Based on the availability of such national SAMs the MAGNET database will be expanded with multiple household types for Czech Republic, France, Italy and Denmark. Anticipating

the planned developments in the modelling of consumption demand, data availability on the income, educational characteristics and detailed consumption pattern of each household type will be explored. Availability of such data will facilitate the linking of MAGNET results to more detailed nutrition assessments.

**Task involved:** split households in national SAMS for Czech Republic, France, Italy and Denmark.

**Method and data used:** data contain the national SAM for the four countries with a decomposition of the households. These SAMS are implemented in MAGNET following the procedure as described in Kuiper and Shutes (2014). Data for the Czech Republic SAM are available from Křístková (2010). The availability of data for other countries will be explored via national statistical offices and contacts with researchers within and outside of the project.

**Result:** adapted MAGNET model with decomposed household types for selected EU countries

**Sharing of model improvements:** - . MAGNET is the only long-term model that can incorporate household level detail. See also output for sharing of results.

**Risks:** The primary risk to this task is the unavailability of the SAMs with decomposed households. At this moment a SAM with decomposed households is available for Czech Republic. It's expected that there's also one available in Denmark and possibly in France, Italy and the Netherlands. These countries are not yet approached.

**Household behaviour under financial, environmental and nutrition/health constraints in MAGNET**  
by LEI Wageningen UR

**Task:** the existing version of the MAGNET model contains a nutrition module, which traces macronutrients (energy, proteins, fats and carbohydrates) available in primary agricultural products from production to final consumption. It uses FAO food balances as a source of food data. It takes into account different users of agricultural products by tracings nutrient flows through the (global) food accounting system described by food production technology, trade flows and a final demand system. Building on the current MAGNET nutrition module structure, the nutrition module of MAGNET will be enhanced and updated. It includes an extension of the nutrition module on multiple households taking into account differences across them as well as an investigation of consumers' responses to different constraints affecting their behaviour.

**Method and data:** as a global CGE model, the key strength of MAGNET is its modelling of economic decisions in a consistent framework tracing the flows of income and commodities through the world's economy. Covering all economy-wide transactions comes at the cost of detail in terms of sectors and households. The level of detail in nutritional analyses focussing on individual consumption of thousands of products is computationally infeasible in a global CGE model. Furthermore, given that the strength of CGE model is in linking production and consumption decisions in a single framework, the computational burden of a vast increase in the number of products is only warranted if these differ substantially both in production and consumption characteristics. Data on the production technologies of the numerous goods in nutrition models are not available and therefore the MAGNET model developments focus on improving the analyses of nutritional implications of changes in consumption within the boundaries of producing a limited number of commodities.

The only exceptions to not adding detail to the number of sectors are two livestock-related sectors: other animal products (oap) and its associated processed food sectors, other meat products (omt). Currently MAGNET combines pig and poultry production and thus consumption of the associated

processed meat in a single sector. This yields large variations in nutrient contents of the same commodity across regions, depending on the relative shares of pig and poultry in a specific region. To split these commodities data on production technologies and consumption levels are necessary. As potential sources of such data, FAOSTAT data, national statistics and data available from more detailed partial equilibrium models will be considered. These data will be used to model pig and poultry production and their associated processed meat sectors separately. Incorporating these splits in the model expands the possibilities to analyse the nutritional and environmental implications of a change in diets towards poultry meat.

The processed food sector in MAGNET can differ strongly in terms of nutrient content across regions especially for those at opposite ends of the income spectrum. Generally with rising incomes the consumption shifts towards more processed/branded products of higher quality. Thus higher income regions will have a smaller amount of calories per dollar spent on processed food. However, due to lack of data currently all dollars spent on processed food are treated equal. The result is an overestimation of the calories per capita consumed by rich households, balanced by an underestimation of the calories consumed by low-income households. So, while the national average calorie consumption from processed food will remain correct, the allocation of these calories over household types as computed by the model will be incorrect if it is not adjusted for the income-calorie relationship. High-income households may be incorrectly qualified as obese while low-income households are incorrectly qualified as undernourished.

To improve the modelling of the nutritional implications of consumption decisions in MAGNET and to make possible to model correctly consumption for household types, we will either develop a new consumption function or get better estimates for price and income elasticities which in turn can better handle the consumption projections in case of households differentiated strongly by income level. We would explore various alternatives to get these estimates – either re-estimate it or get outside information on food expenditure share ceilings. This would help us capture the decisions made between main consumption categories, like food, industrial commodities and services. Within these main categories, decisions are then made between the commodities produced by MAGNET sectors. This level provides the link to the production side of the model, linking environmental indicators such as land use and GHG emissions to household consumption. To improve the consumption model for household types, we may use household data to recover a relationship between nutrient content of MAGNET commodities on the one side and nutrient content of broad range of products and households' incomes on the other side.

The environmental and nutrition/health restricted consumption calculation can be implemented by changing the nutrient consumption and related environmental indicators (calculated ex-post) into model variable, that can then be targeted through policies. It is also possible to do this with an alternative approach where MAGNET and the micro-model DIET is linked (See section on linking macro and micro models)

**Result:** the task will result in improved consumption and nutrition modules of MAGNET. The product variations in nutrient contents will be improved by splitting pig and poultry commodities. The nutrient consumption calculation will be improved by implementing a more adequate consumption function. The new consumption function will also allow us to calculate consumption and nutrition by household types. The possibility to calculate environmental and nutrition/health constrained consumption patterns next to only income dependent patterns will be included.

**Inputs needed from other WPs:** to split pork and poultry sectors, data on production technologies and consumption levels are necessary. As potential sources of such data, FAOSTAT data, national statistics and data available from more detailed partial equilibrium models (CAPRI) will be considered.

To calibrate the consumption function, we may need data on nutrient consumption for broad range of commodities and household types, which differ by income levels from very rich to very poor households. Partly, these data can be delivered by WP7 (T7.1: To collate individual-level food and nutrient intake data from national surveillance studies representing the EU diversity in food patterns), partly by WP2 (T2.4: Modelling diet changes induced by the adoption of nutritional and environmental recommendations), but most probably, additional household consumption data needs to be collected for low-income countries. Also, data concerning consumption and price elasticities needs to be collected for the consumption function calibration.

**Outputs given to other WPs:** consumption pattern, incomes and prices development calculated by MAGNET will be provided to the Diet model in WP2 (T2.4) when both models are linked. Linking the models will be done in WP9 (T9.5: Creation of the SUSFANS Toolbox for assessing EU SFNS).

**Sharing of model improvements:** the improvements of the MAGNET nutrition module will be made available to GLOBIOM and CAPRI.

**Risks:**

1. Availability of data. In particular,

- Data concerning production technologies for pork and poultry sectors necessary to split these sectors.
- Data concerning households' consumption for different types of households in respect of income level. Rich and poor households should be represented.
- Consistency of household and national data.

2. Possibility to recover from statistical data strong and plausible relationship between nutrient contents of food products and incomes for wide spectrum of income levels.

**Health and feedback effects (optional)**

by LEI Wageningen UR

Given the diet and epidemiological models available from WP2 (DIET – a behavioural model of whole diet adjustment under dietary constraint(s); DIETRON – epidemiological model which estimates the number of deaths avoided due to the dietary change), no direct model improvements that incorporate health and feedback effects in the long-term MAGNET model are foreseen. Instead, health impacts will be looked into using these models, with applications in the scenario work of WP10 and case studies of WP5 (see also section on model-linking). Another avenue that will be looked into is to put forward some MAGNET scenario results to the recently developed Global Health Model (Springmann et al., 2015), a link that has not previously been made. .

**2.2.2 Strengthening the primary production side**

This task has three subtasks: (1) A revision of farm supply responses in CAPRI, (2) the improvement of the link between GLOBIOM and EPIC and (3) the augmentation of GLOBIOM to represent fisheries and aquaculture. The subtasks are described below.

**Revision of farm supply responses in CAPRI**

by University of Bonn

**Task:** the global agricultural sector model CAPRI is a suitable tool to analyse the effects of supply side drivers on agricultural production, land use, environmental externalities, farms and trade. Though global agricultural sectors and trade are represented, CAPRI focuses on the detailed representation of European agriculture both in terms of regional and product coverage. However, supply modelling lacks to some extent the linkage to biophysical parameters. As in many partial equilibrium models

production technologies are poorly represented and supply reactions are based on an artificial cost function, which is criticised frequently (e.g. Heckeley et al., 2012). We wish to overcome this problem by investing into a methodological overhaul of the CAPRI supply side. More specifically, we aim to re-specify the supply setup of the CAPRI model in order to provide a (1) theoretically sounder and (2) more intuitive approach, which at the same time (3) significantly eases the integration with biophysical models. At the core of the methodological innovation, the supply will be based on econometrically estimated production functions from WP4. Therefore, this subtask heavily draws on econometric work from WP4. The coefficients estimated in WP4 will be used to refine supply model reactions at NUTS2 level in the EU in the CAPRI model. Conceptual work on this subtask has already started and a technical working paper is available.

**Method and data:** data from CAPRI database from various sources (e.g. EUROSTAT, FAOSTAT), coefficients from WP4 based on farm-level data (FADN). Artificial cost function steering supply side reaction to be replaced by production functions to explicitly represent farm supply response.

**Result:** revised supply side of the CAPRI model, more detailed supply side response, better integration with crop models

**Inputs needed from other WPs:** econometrically estimated production function coefficients from WP4

**Risks:** input from WP4 could be delayed (e.g. due to delays in data access or problems in estimation), input from WP4 could turn out to be not as suitable as expected (in this case workarounds would be developed).

**Improvement of the link between GLOBIOM and EPIC**  
by IIASA

**Task:** this subtask aims at improving the representation of cropland intensification and its environmental externalities in the GLOBIOM model, via coupling to a new EPIC dataset. The EPIC model (Environmental Policy Integrated Climate, current version EPIC0810) will provide spatially explicit (0.5 arcminute grid) crop yields, input needs and environmental externalities from 18 major crops globally, for 15 different levels of intensification (5 fertilization rates x 3 irrigation intensities). This crop data will be used to improve the process of cropland intensification (i.e. increased fertilization and irrigation) and crop expansion (i.e. cropland and crop area change) in GLOBIOM.

**Method and data:** the initial base year distribution of production technologies will build upon available high spatial resolution datasets such as the SPAM dataset, informing on irrigation and fertilization intensity by crop. The dynamics of production technology change will be calibrated upon cost curves along intensification gradients, which will be determined in a two-step approach: first technology-specific options costs will be initialized based upon an engineering cost accounting approach, then a calibration cost will be added to reproduce observed trends at the regional level. The latter will be determined jointly with the calibration of cropland expansion through a series of econometric studies observing past values of national cropland expansion, irrigation and fertilization increases, as well as their spatially explicit dynamics, over the past. Finally, the EPIC data will be used to inform the nutrient (nitrogen and phosphorus) balance at high resolution, in particular losses to the atmosphere and to the surface waters (N<sub>2</sub>O & NH<sub>3</sub> emissions, nitrate leaching), as directly available at high-resolution for each crop and technology option.

**Result:** improved link between GLOBIOM and EPIC

**Inputs needed from other WPs:** not relevant

**Outputs given to other WPs:** not relevant

**Sharing of model improvements:** scientific exchange with CAPRI foreseen

**Risks:** technical difficulties could delay the work (e.g. in calibration, econometric pre-work)

#### Represent fisheries and aquaculture in GLOBIOM

by IIASA

**Task:** a new module representing fisheries and aquaculture will be developed for the GLOBIOM model.

**Method and data:** this subtask will use several separate datasets from FAOSTAT and the Fisheries branch of the FAO as well as technical coefficients from the literature and trade groups. The first task is to balance supply, demand, and trade in order to make the separate datasets consistent with each other and also with known economic and biophysical relationships. The second task is creating a reasonable set of assumptions for baseline as well as scenario projections, using input from fisheries and aquaculture experts, as well as the literature.

**Result:** new fish module in GLOBIOM. The envisioned outputs are journal articles documenting the partial tasks involved in the construction of the complete model (review of existing work and demand projections; feed markets and production system representation; environmental effects and efficiency of aquaculture production) with scenario analysis

**Risks:** specific data could be missing or data collection could be delayed

### **2.2.3 Strengthening the food chain side**

This subsection lists model improvements foreseen on the food chain side, which can be decomposed in two subtasks, namely incorporating food loss and waste (in MAGNET, CAPRI) and imperfect competition (in MAGNET) for improved modelling of the food chain (biomass flows, behavioural patterns).

#### Food loss and waste/biomass flows

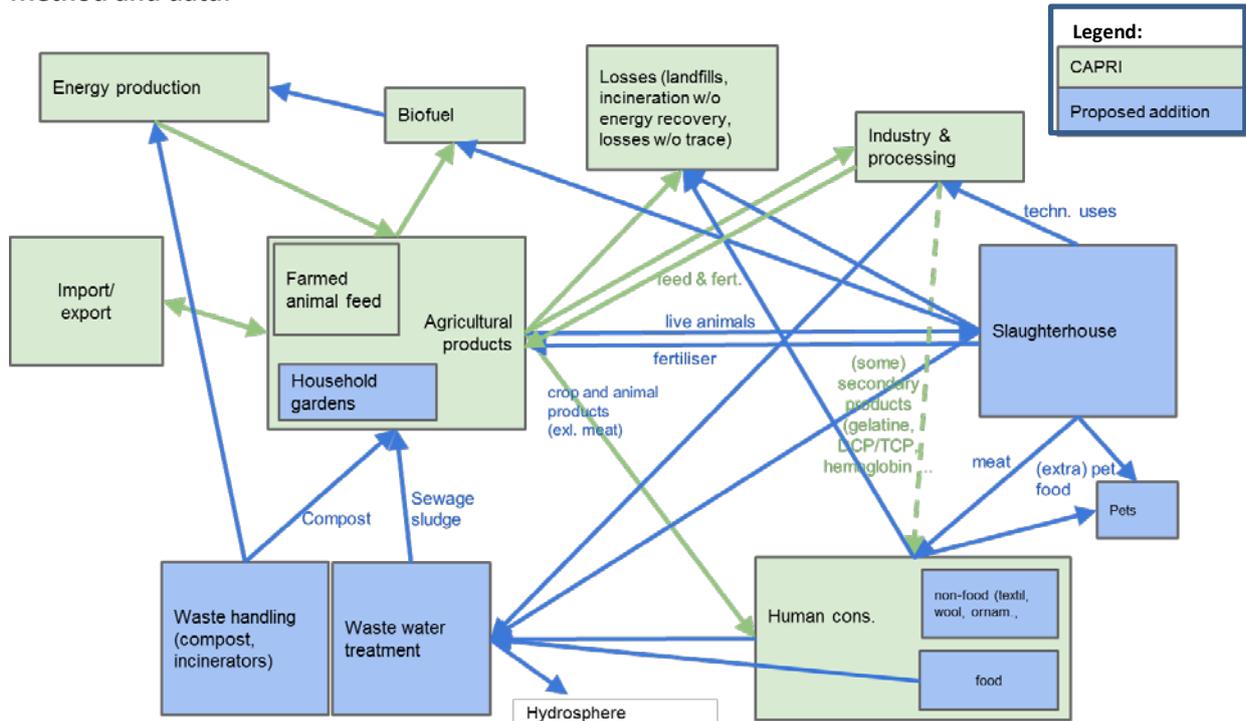
By JRC and LEI Wageningen UR

**Task:** incorporation of food losses and waste along the food supply chain (data from WP3) to fill in the missing links of the food system in CAPRI and MAGNET. This allows for a more accurate projection of food and nutrients consumed and an improved quantification of sustainability indicators. It also allows for the possibility to assess the effect of resource-efficiency (waste reduction) and demand-side options (diet changes) on environmental sustainability and feedbacks to the agriculture sector in Europe.

*Data permitting*, this could extend to accounting for

- a. Nutrient flows embodied in commodities, products and services not destined for human consumption (such as from slaughterhouses), including for example biofuel production and feed, giving additional insights into to the competing claims debate. This task leans on data on biomass streams, reuse and recycling from WP3.
- b. Modelling the food loss and waste phenomenon at a higher resolution (households).

## Method and data:



**Figure 7 Existing and new biomass streams in CAPRI**

Figure 7 shows a draft assessment of biomass flows considered already in CAPRI (green boxes and arrows) and not yet included in the CAPRI model (blue boxes and arrows). The goal of the task is to quantify all missing flows (shown as 'proposed addition' arrows) in a CAPRI post-run model and evaluate possibilities of incorporating them into the CAPRI supply module. The data will be obtained from WP3 (D3.3: The role of the post-farm food chain for sustainability indices). According to data availability, CAPRI will be extended (definition of new 'products' and 'activities' as well as including calculation modules for each of the missing biomass streams).

Existing work on addressing food loss and waste in MAGNET relied on a technical change parameter. Data on household food waste are difficult to obtain. Inclusion of the data in the model may indicate additional information needed which is hard to anticipate. Therefore, a stepwise approach is taken for the modelling of food waste in MAGNET. This will assure model results are available early on and can guide and focus data-collection and cooperation with other teams in SUSFANS. A theoretical model on food waste is developed and implemented in a stylised fashion in MAGNET. Experimenting with these (exogenous) food waste parameters provides a first assessment of the sensitivity of model results to including food waste. It will also highlight the most relevant commodities in terms of model outcomes as well as the detail needed for a realistic assessment (for example accounting for variability within aggregated commodities as with nutrition).

Guided by both the theoretical model and results of the stylised application data will be collected on food waste by country commodity, and possibly household types if available. Starting point are Eurostat, OECD and FAO datasets and the work done in CAPRI to better capture the biomass flows. If necessary targeted additional efforts (for example collecting expert information) will be made for sectors identified as critical in the model runs with exogenous parameters.

The collected data provide the empirical basis for further developing the food waste behaviour of households in MAGNET; food waste will be modelled as governed by prices and income, which are endogenous in the model.

**Results:** the improved CAPRI model will be applied to SUSFANS scenarios providing additional details of relevant nutrient flows in the agro-food chain and improving the quantification of sustainability indicators and metrics. The addition of food waste in MAGNET will help study the economy-wide impact on challenges of feeding an ever growing population and if and how much, reducing food waste can help achieve the goal. The addition would also contribute to refining consumption and calorie projections using MAGNET.

**Inputs needed from other WPs:** data requirements include:

- Data on slaughterhouse by-products and their destiny in various sectors and market value (for allocation of emissions).
- Data on agricultural products/wastes used for the generation of energy
- Data on waste streams such as compost production/use in agriculture; production of sewage sludge/use in agriculture; industrial wastes of agricultural products; wastages in household and in catering services.
- Data on agricultural (by)products for pets
- Food waste percentages at country and product detail, if possible by household type for the selected countries (Denmark, France, Italy and Czech Republic).

**Outputs given to other WPs:** CAPRI results will be cross-checked with model output of the SHARP model; sustainability indicators will be provided to the SHARP model.

**Sharing of model improvements:**

The CAPRI-post-farm-gate module will be shared with the CAPRI network.

**Risks:**

Missing data from deliverable D3.3 might imply that some biomass streams might not be possible to be represented, or represented only with high uncertainty. If detailed data on food waste is not found, either inside or outside the project, expert knowledge or sensitivity analysis will be needed for parameterisation of the food waste development in MAGNET.

### Imperfect competition

by LEI Wageningen UR

There is evidence of imperfect competition and imperfect price transmissions in food chains due to, for example, market power in the concentrated EU and global food supply chains. Incorporating imperfect competition in a CGE model requires data on the magnitude of market power and/or the degree of heterogeneity between firms, neither of which is easily obtained.

**Task:** incorporating imperfect competition in the MAGNET model

**Method and data:** it is envisaged that the imperfect competition module will employ a 'large group' monopolistic competition representation. It is assumed that each firm produces a single variety of the good, whilst a representative firm treatment is employed to characterise how all (symmetric) firms behave in terms of their price setting behaviour. The mark-up of the price over the marginal cost is calibrated to GTAP estimates of the elasticity of substitution whilst welfare effects in the model now account for scale effects (movements along the average total cost curve due to changes in the scale of production) and variety effects (changes in the number of firms/varieties in the industry to satisfy long run zero economic profit conditions). Further work will look to build on this to include a Melitz (2003) treatment of firm heterogeneity. In this version, a parameterised probability density function is used to characterise the degree of homogeneity/heterogeneity of productivity of firms by bilateral route, which determines whether firms in domestic region 'r' are efficient enough to compete in export market 's'.

**Result:** 'large group' monopolistic competition representation in MAGNET

**Inputs needed from other WPs:** for large group monopolistic competition, market power given by the markup (i.e.,  $P > MC$ ) is a function of the own-price elasticity of demand. Notwithstanding, for the EU regions, industry data (using NACE classifications) from colleagues at the University of Leuven involved in WP3 could plausibly be used to radically improve the estimates of industry mark-ups in the food processing sectors (and possibly some non-food sectors), which in turn would enhance the parameterisation of the CGE model specification (from D3.5, due in Month 28, July 2017). On the other hand, to capture firm heterogeneity by sectors/regions in the Melitz representation, there is currently a paucity of reliable estimates from the literature.

**Risks:** it remains unclear at the current time whether a credible alternative source of data and/or estimation technique can be employed to reliably estimate the degree of heterogeneity between firms along different bilateral routes. Nevertheless, the experience of current work with CoPS (University of Melbourne), will provide useful insights to subsequent initiatives of this model representation within MAGNET.

### **3. SUSFANS toolbox of interlinked models**

The enhanced long-term macroeconomic, agricultural economic and biophysical models of WP9 are linked up with more micro oriented diet and health models of WP2/7 and a short-term model of WP8. The first section describes the general approach to model-linking; section 3.2 describes the other models in the toolbox, i.e. models other than the long-term models discussed before. Section 3.3.1 looks into the various linkages in more detail. The final section goes into more detail regarding risks and ways to go about these.

#### **3.1 General approach of model-linking in SUSFANS**

The general approach to link assessment models within the SUSFANS toolbox is a “soft” one, i.e. one which does not aim at a (software-) technical integration but rather at linkages between the various components of the toolbox. This decision is based on the experience gathered by SUSFANS partners from previous EU research projects with a strong modelling focus (e.g. FoodSecure, AGRICISTRADe, SEAMLESS). Soft-linking models within a common conceptual framework allows researchers and decision-makers to fully exploit the complementarities and flexibilities in a modelling system while minimising risks in terms of conceptual dis-alignment, a large software and ICT burden, and compromised transparency. This is supported by the following three arguments:

- (1) The long-term models described above are already very complex modelling systems by themselves. They have been and are currently applied to a multitude of different policy issues related to the future of the global and European agri-food sector. Each system has its own proprietary software infrastructure and is developed and applied by a team or network of modellers. Any attempt to “hard-link” these models in a newly developed, overarching software framework would involve a technical and communication effort far beyond the budget and time horizon of SUSFANS;
- (2) The long-term models in SUSFANS are not only complex already, but they are also continuously adapted in structure to accommodate new policy issues and scientific developments. Other models in the SUSFANS toolbox described below are to be developed and implemented for the first time within the project. Their final structure and scope is not set in detail and will be an outcome of the research process. The uncertainty and dynamics of such single model development itself prohibits the development of a joint technical infrastructure in parallel without stifling conceptual progress;
- (3) Beyond scientific soundness and relevance, the sustainability of the toolbox developed in research projects depends on the institutional setting in which the toolbox will be maintained

and further developed afterwards. A hard-linked system comprising all the involved disciplines and “sub-model-systems” would not find such an institutional home. Collaboration between different institutions to keep it up would be far too costly in monetary terms, but even more so in terms of inflexibilities it creates for the development of the single elements and the lack of identification.

Consequently, SUSFANS opts for a soft-linking approach relying on flexible protocols of data and parameter exchange to achieve a consistent application of the SUSFANS toolbox to FNS policy issues and providing added value to the separate application of single tools.

In delineation to WP10, this work plan for WP9 discusses general issues of model-linking which are independent of specific scenarios. They refer to the preparation of the exchange of data and the harmonisation of parameters and scenario variables in order to make a targeted joint application of models in the toolbox feasible in short time.

We distinguish three types of model soft-linkages:

1. Harmonisation of scenario definitions. This will most often refer to relative changes of drivers between scenarios as definitions and data sources of model inputs differ;
2. Transfer of output data from one model to be used as input data in another model. This is likely the most important type of model-linkage as it allows exploiting the model complementarities
3. Alignment of model behaviour in overlapping model domains. Here, one either harmonises structural model parameters that are comparable across models or – more involved – one sequentially calibrates one model based on the response behaviour of another model (Britz and Hertel, 2011; Jansson et al., 2009).

## **3.2 Description of the other models in the toolbox**

### **3.2.1 AgriPrice4Cast summary**

Unlike most of the other models in the toolbox, AgriPrice4Cast is to be entirely developed within SUSFANS to respond to the need to better understand short-term dynamics on EU agricultural markets, in order to support market surveillance and crises management. Development of this new model is the main focus of WP8. In a first step, WP8 will use a battery of econometric models to identify determinants of agricultural commodity markets behavior based on historical market information and hind-casted predictions from long-term equilibrium models. The forecast averaging procedures will be developed using Bayesian methods from standard time-series econometric specifications resulting from a large set of combinations of variables and lag structures. Both linear and nonlinear specifications will be used, so as to ensure that models with asymmetric reactions to short-term shocks are also considered. In particular, models where shocks can have persistent effects on commodity prices will also be included in the space of specifications considered. Particular attention will be paid to the role of yield forecasts in influencing market volatility. In a second step, short-run predictive econometric model averages using predictions on the market fundamentals from the long-term models (from GLOBIOM, CAPRI or MAGNET) will be constructed using both Bayesian and frequentist approaches. Finally, this meta-model will be linked to crop yield projections with the MARS-Crop Yield Forecasting System by JRC/MARS/AGRI4CAST and those by the USDA to forecast commodity prices on the European market on a horizon spanning from three months to one year.

### **3.2.2 Epic model summary**

The Environmental Policy Integrated Climate (EPIC) model is a biophysical cropping systems model (<http://epicapex.tamu.edu/epic>). It contains routines for simulating crop growth and yield, hydrological, nutrient and carbon cycles, soil erosion and a wide range of crop management options. EPIC operates on a daily time step and can be used for long-term assessments. Potential plant growth is calculated based on intercepted solar radiation, conversion of CO<sub>2</sub> to biomass and vapour

pressure deficit. Actual plant growth accounts for multiple stresses in addition, including temperature stress or nutrient (N and P) and water deficit stress. Nutrient and water stress result in a decrease of the potential daily plant growth if soil water or plant available N & P supply is insufficient compared to the optimal supply. Phenological development is based on daily heat unit accumulation that determines leaf area growth, canopy height, nutrient uptake, harvest index and, optionally, date of harvest. Crop yield is calculated from above-ground biomass and harvest index. EPIC incorporates equations that adjust radiation use efficiency and evapotranspiration for elevated atmospheric CO<sub>2</sub> concentration.

EPIC provides tools to simulate multiple management decisions, including crop rotations, intercropping, crop mechanisation, pesticide treatments and a variety of fertilization and irrigation strategies to analyse cropland utilisation pathways and environmental externalities. In addition, EPIC provides a comprehensive representation of nitrogen and phosphorus cycling, including leaching, losses with erosion, uptake, N fixation, (de)nitrification, volatilisation, organic N,P transformation, immobilisation, and P (de)sorption processes in soils. It also includes a complex soil carbon routine which makes it a powerful tool for analyses of sustainable crop nutrition.

EPIC was up-scaled for global assessments at IIASA. The global EPIC model (Balkovič et al. 2014) was constructed at a 5 arc-min grid by combining GIS-based information on soils, relief, administrative units and daily weather using the approach by Skalský et al. (2008). It uses daily climate inputs on maximum temperature, minimum temperature, precipitation, relative humidity, solar radiation, and wind speed. Terrain properties were derived from globally available digital elevation models (SRTM, GTOPO). Soil data, including organic carbon, pH, cation exchange capacity, sum of bases, bulk density, texture, depth, stoniness, and hydro-physical and hydraulic properties, are based on the ISRIC-WISE database (Batjes, 2006) and the Digital Soil Map of the World (<http://www.fao.org/geonetwork>). Business as usual crop management around year 2000 (baseline) was constructed from multiple globally available datasets, such as crop calendar by Sacks et al. (2010), crop-specific fertilisation rates and attainable yields by Mueller et al. (2012), crop harvested areas by Monfreda et al. (2008), irrigated and rainfed area distribution by Portmann et al. (2010), and land cover maps by GLC2000 and SPAM.

### 3.2.3 SHARP model summary

The SHARP model aims to design Sustainable, Healthy, Affordable, Reliable and Preferred (SHARP) diets for EU consumers. The composition of the diets of representative individual(s) of different consumer groups is optimised based on different SHARP indicators taking into account important nutritional and preference-related constraints.

The method used to develop SHARP diets is Mixed Integer Linear Programming (MILP). This method enables us to select the set of questions in such a way that the amount of information on multiple nutrients is maximised while the food list is as short as possible. This supports the design of diets that are optimal with respect to a chosen objective while satisfying a set of constraints. The objectives reflect the goals of the decision maker, e.g.

- sustainability: “minimize carbon footprint of the diet”,
- health: “maximize intake of dietary fibre”,
- affordability: “minimize diet cost”.

The constraints ensure that the diet satisfies nutritional guidelines and is palatable, for example

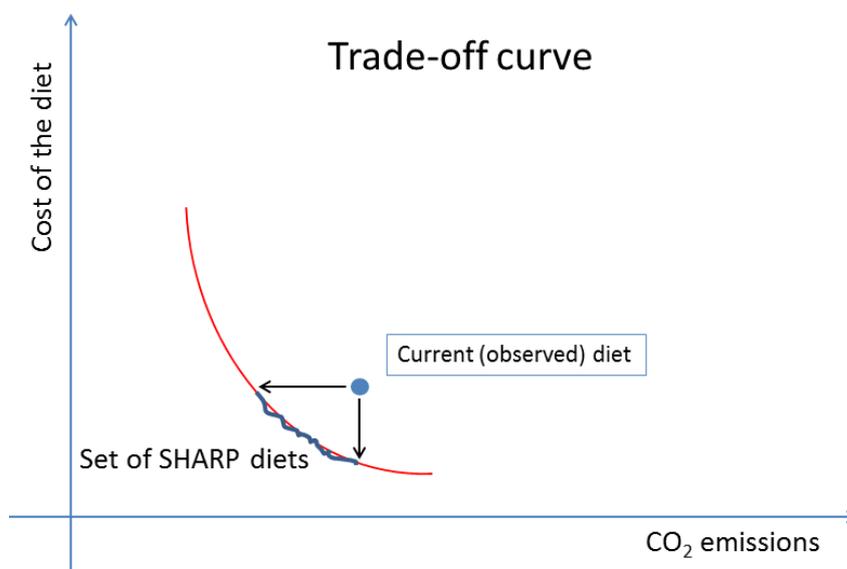
- energy intake should be 10 MJ/dag,
- the diet should contain between four and six slices of bread.

Why develop a new model while diet optimizations models already exist in the literature (Mertens, 2016)? The SHARP model will be developed in interaction and exchange with other models in the SUSFANS toolbox, in order to respond to research challenges at the interface of whole diet and food

system analysis. SHARP will be fed with information on price/income from the CGE/household models, product prices info from the CGE/PE models and environmental indicators of PE models. To account for actual consumer preferences in the analysis of choices for a more adequate diet, the method is elaborated with additional econometric analysis based on the microeconomic theory of the consumer under rationing (Irz et al., 2014).

MILP-models with one objective generate diets that are optimal with respect to that single objective, e.g. diets that have the lowest carbon footprint of all diets, or diets that have the lowest costs of all diets. In many cases these objectives will be conflicting: the diet with the lowest carbon footprint will not have the lowest costs, and vice versa. In case of multiple (conflicting) objectives multi criteria decision making (MCDM) MILP-models are used to obtain so-called Pareto-optimal diets, i.e. diets in which it is not possible to improve one objective without harming another objective. For example, starting from a Pareto-optimal diet it is not possible to find another diet (within the set of constraints) that has a lower carbon footprint as well as a lower price; every change to lower the footprint will increase the price, and vice versa.

The model enables the calculation of trade-offs between SHARP indicators. The distance of current diets from the trade-off provides information about current inefficiencies and can be used to identify a set of SHARP diets that are potentially more efficient alternatives of the current dietary choices.



**Figure 8 Trade-off curve between costs (affordability) and CO<sub>2</sub> emissions.**

The SHARP model requires information on:

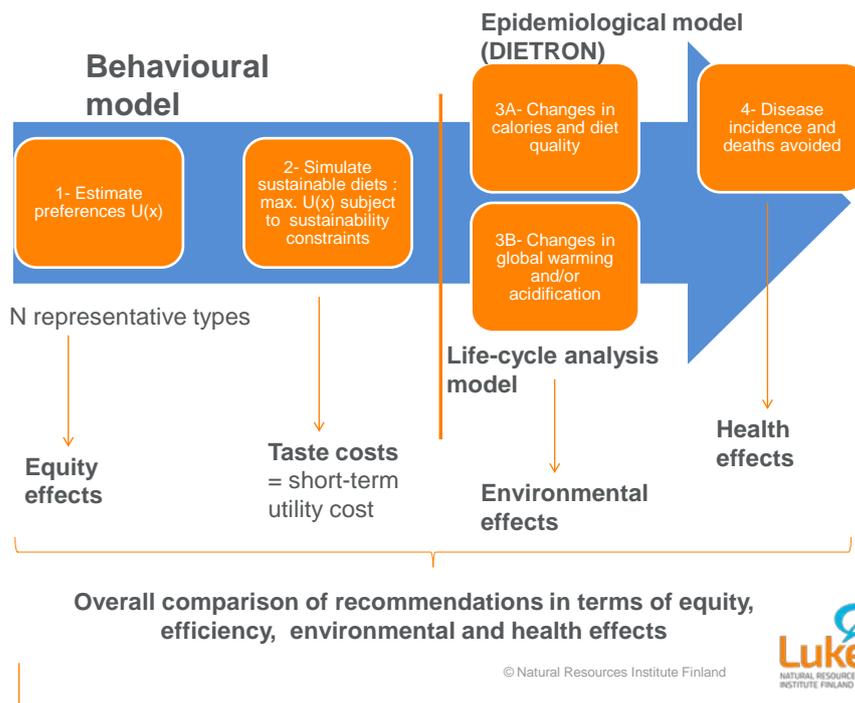
- Available food items and corresponding nutrient composition per region and season.
- Performance of each food item on all selected SHARP indicators.
- Nutrient requirements of representative individuals of each consumer group
- Current dietary choices (composition of food items in current diets) of representative individuals

The applicability of the model will be demonstrated in four different case regions, Czech Republic, Denmark, France and Italy. The availability of information on sustainability indicators will determine the aggregation level of food items. We aim to identify appropriate consumer groups based on for example age, sex, educational level and possibly BMI. The focus of the initial application will be on the calculation of trade-offs between economic, environmental and preference-related criteria.

The versatility of MILP models allows for the comparison, trade off and optimisation of diets on indicators for sustainability, health and affordability, given the norms for nutrient requirements and preferability. Depending on the data and requirements chosen, the optimal diets can be composed e.g. for specific customer groups (such as elderly), various culinary practices (such as vegetarian), or local availability of foods. The SHARP model lacks an explicit time dimension. It will be driven by a dataset of current food products, diets and intake patterns and a set of dietary reference values. By projecting – in interaction with medium-term or long-run models - the SHARP database into the future, and possibly introducing hypothetical data for possible novel components of a future diet, the comparison, trade-off and optimisation of diets can also be replicated for years or decades ahead. In this way the SHARP model can contribute development of long-term, future scenarios regarding sustainable food production and intake within Europe.

#### **3.2.4 DIET model summary**

DIET is a model simulating the dietary adjustments of a rational consumer in response to the imposition of one or multiple dietary constraints. It measures the substitutions that take place when one dimension of the diet is modified exogenously, perhaps in response to social marketing campaigns and/or other healthy-eating policies that modify subjective probabilities of negative health outcomes. Consumer preferences being held constant, the model is best thought of as describing short-term dietary adjustments. DIET can be applied, for instance, to analyse the dietary changes resulting from compliance with the message to consume five portions of fruits and vegetables daily, or to diminish meat consumption. The whole-diet adjustments are inferred from empirically estimated preferences, which gives some realism to the approach, but also implies that the model is best suited to analyse relatively small changes. Further, the micro-economic foundations of the model make it possible to carry a normative analysis of dietary changes (i.e., its impact on social welfare). In particular, the model estimates the “taste” cost of dietary recommendations, which is important in cost-benefit analysis but also to understand why consumers may not comply with official sustainable diet recommendations. Further, the model can easily be linked to food composition tables to estimate the impact of dietary recommendations on diet quality, or to epidemiological models in order to measure health impacts. Similarly, rough environmental effects can be estimated by placing life-cycle analysis coefficients on each of the product aggregates of the model. However, the economy-wide effects of dietary adjustments are not estimated by DIET, which provides the main motivation for linking it to MAGNET. For instance, the linkage would make it possible to assess the employment and sectoral effects of an increase in the relative share of plant-based foods in the diet. A French model with 22 product categories is fully operational, while calibration of the model to Finland and Denmark is ongoing. The technical details of the model are presented in full in Irz et al. (2015).



DIET model output: short-term behavioural responses to sustainable diet constraints, whether motivated by economic, health or environmental considerations; welfare cost, or taste cost, of this adjustment; ranking of sustainable diet recommendations in terms of their relative cost-effectiveness (at the margin); reduced mortality due the dietary adjustments; environmental impact; equity effects of sustainable diet recommendations (i.e. effects on different types of consumers, as distinguished by relevant socio-economic characteristics).

**Figure 9 A schematic representation of the DIET model**

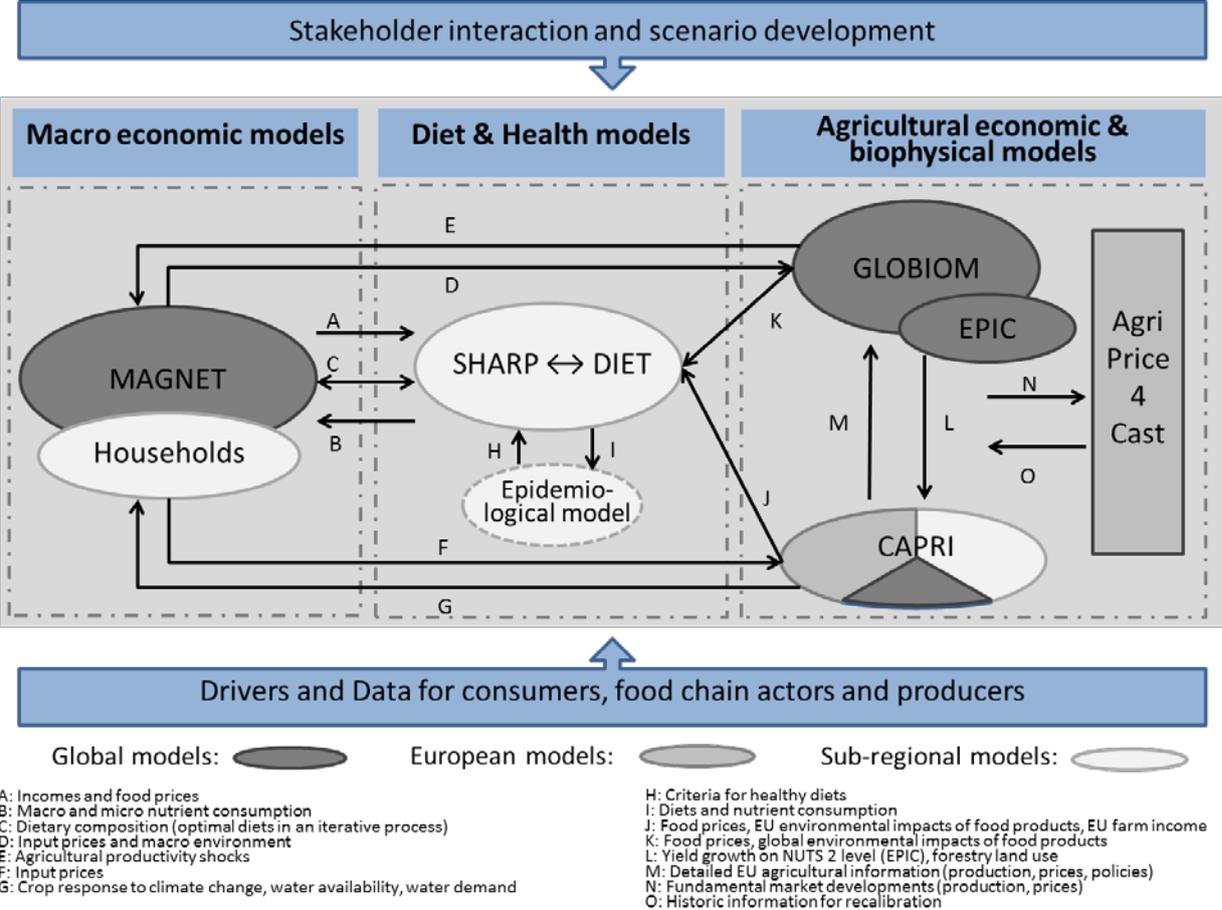
### 3.2.5 Epidemiological model

In its current form the DIET model is linked to the DIETRON epidemiological model, which estimates the impact on chronic disease mortality of counterfactual population dietary scenarios, as explained in detail in Scarborough et al. (2012a, 2012b). The dietary adjustments simulated in DIET are fed into DIETRON as changes in intakes of the following foods and nutrient: fruits, vegetables, fibers, total fat, monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), saturated fatty acids (SFA), cholesterol, salt, and energy. Importantly, the parameters of the DIETRON model are derived from world-wide meta-analyses of dietary risk factors and are not country specific, so that calibrating the model to a new country only requires data on initial mortality levels, by relevant causes. The uncertainty surrounding the estimates of mortality reductions associated with a change in diet can be estimated through Monte-Carlo procedures.

## 3.3 Model-linking in SUSFANS

The approach to model-linking in the SUSFANS toolbox is summarised in Figure 10. It can be summarised as follows. The left-hand side of the figure contains macroeconomic models: specifically the **MAGNET** model for medium- to long-term global analyses, with **household level detail** of effects for a selection of countries. The middle column displays diet and health models, including **SHARP** - a model, which designs optimal diets on the basis of various attributes, **DIET** - a short-term behavioural model for diets in response to various constraints (economic, health, environmental), and an **epidemiological model** to calculate health impacts. The right-hand side shows long-term agricultural economic and biophysical models, the partial equilibrium model **CAPRI** and **GLOBIOM** - a global model coupled to **EPIC**, which on the complete right interact with the short-term model

**AgriPrice4Cast.** These models are linked, as indicated via the arrows, and thereby form the SUSFANS toolbox. The toolbox is put to use in scenarios and innovation pathways fed by stakeholder input (top bar), based on drivers and data from pillar I of the SUSFANS project (bottom bar). The following subsections explain the various model-linkages (the arrows) in more detail for: (1) the long-term models (MAGNET, GLOBIOM, CAPRI); (2) the long-term and short-term models (GLOBIOM, AgriPrice4Cast), (3) the macro and micro models (MAGNET, CAPRI, GLOBIOM and DIET/SHARP) and (4) the micro models (SHARP, DIET and the epidemiological model).



**Figure 10 SUSFANS toolbox of interlinked assessment models**

**3.3.1 Linking of long-term macro models**

This section deals with the linkages between CAPRI, GLOBIOM and MAGNET (WP9 models), as visualised by arrows D, E, F, G, L, and M (Figure 10).

Linking of CAPRI-GLOBIOM (arrow L and M)

CAPRI and GLOBIOM have already been linked in a series of service contracts for DG-CLIMA as well as in the AgMIP/MACSUR projects (e.g. Frank et al., 2014). For SUSFANS, the linking is foreseen in terms of (1) Baseline alignment, (2) Harmonisation of scenarios (3) and transfer of productivity.

The following describes the process of aligning the CAPRI with the GLOBIOM baseline. Aligning the baselines is important for ensuring a reference scenario for both models that is as close as possible to each other. Figure 11 shows the process of generating the CAPRI baseline in general and already indicates where GLOBIOM input is used in the process when CAPRI and GLOBIOM are used in joined scenario simulations.

Generally, CAPRI does not generate a baseline on its own, but it aligns its baseline with several different data sources in order to capture the complex interrelations between technological, structural and preference changes for agricultural products world-wide in combination with changes in policies, population and non-agricultural markets. Thus, the CAPRI baseline is usually based on both external (“expert”) forecasts as well as trend forecasts using the CAPRI database. The purpose of these trend estimates is, on the one hand, to compare expert forecasts with a purely technical extrapolation of time series and, on the other hand, to provide a safeguard in case no information from external sources is available. The CAPRI module providing projections for European regions operates in several steps:

1. Step 1 involves independent trend estimations on all series, providing initial forecasts and statistics on the goodness of fit or indirectly on the variability of the series.
2. Step 2 imposes constraints like identities (e.g. production = area \* yield) or technical bounds (e.g. maximum yields) and introduces specific expert information given at the Member State level or for specific sectors.
3. Step 3 includes expert information on aggregate EU markets.
4. Step 4 creates “constrained trends” by merging the information in the ex-post time series with external information (for example from other models such as AGLINK, PRIMES, GLOBIOM or national expert information). The result of this step is a first projection for the key variables in the agricultural sector (activity levels and market balances) of Europe.
5. The “technical baseline” calibrates missing parameters and calculates missing variables that are related to the key variables, in particular complete nutrient balances in the crop and livestock sectors and all non EU market balances and the bilateral trade matrix.
6. An optional last step may be applied to arrive at the final reference run (the baseline) if some assumptions made in steps one or two need to be revised to obtain the desired starting point for further analysis (Britz and Witzke, 2012).

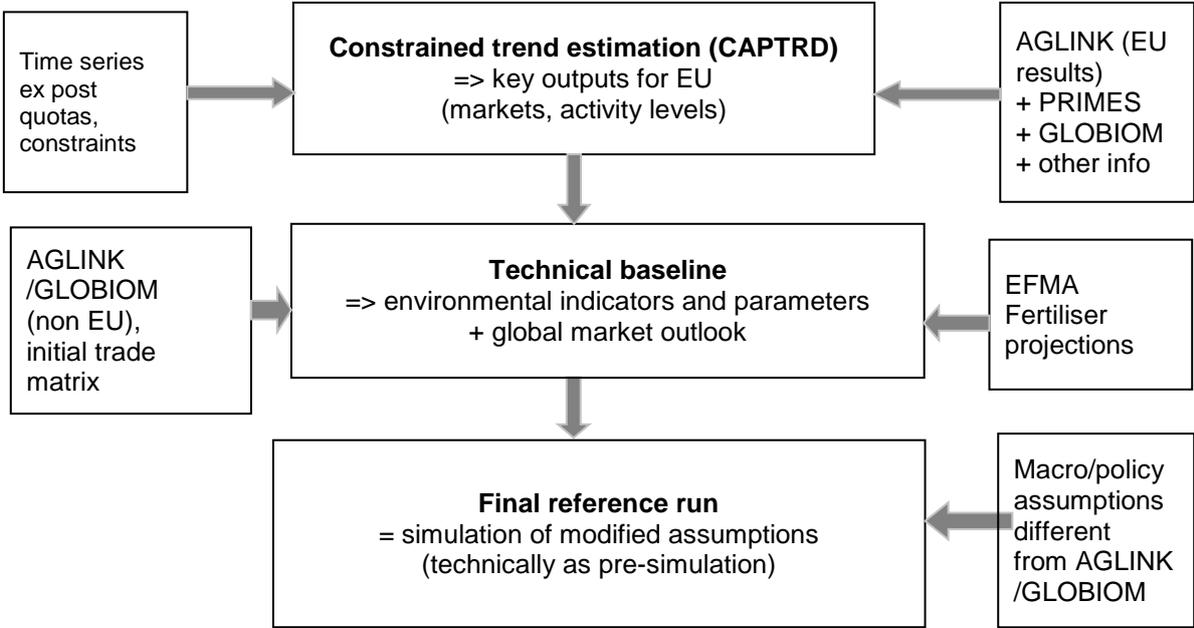


Figure 11 CAPRI baseline process with GLOBIOM input

Input from GLOBIOM in this CAPRI baseline process occurs in step 4 and 5 where GLOBIOM provides some EU but mainly non-EU technical information on primary agricultural production.

The application of both systems to scenarios then requires a harmonised scenario formulation with matching macroeconomic assumptions and comparable implementations of policy changes relative to the baseline. A sequential link in scenario runs is the transfer of productivity shocks in climate change scenarios using crop yield changes from EPIC via GLOBIOM to CAPRI for crops and livestock in the different regions.

#### Linking of CAPRI-MAGNET (arrow F and G)

Parameters from MAGNET will be used in a similar way for creating the CAPRI baseline. Ensuring consistent baselines of both MAGNET and GLOBIOM in CAPRI is accomplished by using information from GLOBIOM as described above and taking other missing information, for example on energy prices from MAGNET.

Consistency between the scenarios across all three models can be achieved by aligning scenario assumptions on key drivers included in all three models (for example population projections). Additionally, productivity shocks due to climate change will be aligned with GLOBIOM by using the same EPIC results. Equivalently, scenarios results from MAGNET on some macro economic factors (e.g. energy prices) could be used in CAPRI.

Apart from transferring these variable changes that are endogeneous in MAGNET but exogeneous in CAPRI, one could also envisage a more involved process of aligning key output variables that are endogeneous in both models, for example agricultural output in EU member states. A recent prominent example of this sort is Britz and Hertel (2011). The key idea behind this type of model link is that agricultural production and related policies in the EU are represented more detailed in CAPRI than MAGNET. If the results of a scenario application is likely to depend on such detailed modelling, then it might be useful to “replace” the EU agricultural supply response in MAGNET by the one in CAPRI. This can be achieved by a process of calibration where parameters in MAGNET are calibrated to match the supply response in CAPRI. In order to do so, a conceptual basis for the matching of behaviour is necessary that allows to define in what sense supply responses shall be similar, because in most cases the actual model equations are not conceptually aligned. Britz and Hertel (2011) used the concept of a revenue function. Apart from this calibration of endogeneous responses, such linking can also be connected with the transfer of, for example, primary factor price changes that are endogeneous in MAGNET and exogeneous in CAPRI. The SEAMLESS project developed an idea with similar objectives which relied on an iterative process (Jansson et al., 2009).

Currently, the type of linking described in the last paragraph is explored in another project context related to the analysis of the EU Common Agricultural Policy. The progress of this exercise will be closely observed by the involved partners in SUSFANS (LEI and UBO) and if the result is promising for SUSFANS purposes, a potential implementation will be discussed.

#### Linking of MAGNET-GLOBIOM (arrow D and E)

GLOBIOM models besides agricultural and timber markets also land use based on bio-physical properties such as soil, slope, altitude, climate but also several management types which differ in low or high input use and irrigated or rain-fed production (Havlík et al., 2011). GLOBIOM has a spatial resolution of 0.5° x 0.5° grid which can be aggregated to countries or regions. This detailed representation of land and agricultural production allows drawing conclusions on possible land expansion and yield potential but also identifying limits of them. Furthermore, GHG emissions from land using sectors and land use changes are included in the model.

MAGNET simulates bilateral trade including specific tariffs and hence is able to explicitly show effects of trade agreements between two countries or country groups. Furthermore, all economic sectors compete for endowments, e.g. if labour is used in the textile industry, it cannot be used in agriculture. Compared with GLOBIOM, it covers a full economy.

The different characteristics of the two models lead to complementarities which have been exploited already in previous FP7 projects such as FoodSecure or AGRICISTRADe. In FoodSecure, the models have been linked through harmonisation of scenario drivers such as GDP, population, or crop productivity growth. SUSFANS will build on this experience and on existing regional and activities mappings, and will further harmonise with the focus on consistent implementation of agro and non-agro-food policy drivers.

In AGRICISTRADe, two approaches to improve the link between GLOBIOM and MAGNET are being explored. 1. Automised iterative linking, where GLOBIOM provides primary production relevant variables (areas and yields) and MAGNET provides information on bilateral trade flows. 2. Alignment of model parameters, where GLOBIOM tries to mimic MAGNET international trade behaviour, and MAGNET uses GLOBIOM output to parameterise its land supply and crop production functions. Outcomes of the linking through alignment of model parameters will be made available for the SUSFANS project and further refined.

### **3.3.2 Linking of long-term macro models with short-term macro models**

This section deals with the linkages between GLOBIOM/EPIC (WP9) and AgriPrice4Cast (WP8), as visualised by arrows N and O (Figure 10). The linkage is an integral part of WP8, therefore here we provide only a brief summary.

WP8 will use a large battery of econometric models to identify determinants of agricultural commodity markets behaviour based on historical market information. AgriPrice4Cast will allow developing forecast averaging procedures using Bayesian methods from standard time-series econometric specifications resulting from a large set of combinations of variables and lag structures. WP8 will use historical weather information (ECMWF, CRU) in combination with a global crop model (EPIC) to assess historical global crop yield variability. This information will allow for extensive analysis of lead and lag structures of variables explaining market behaviour including price volatility.

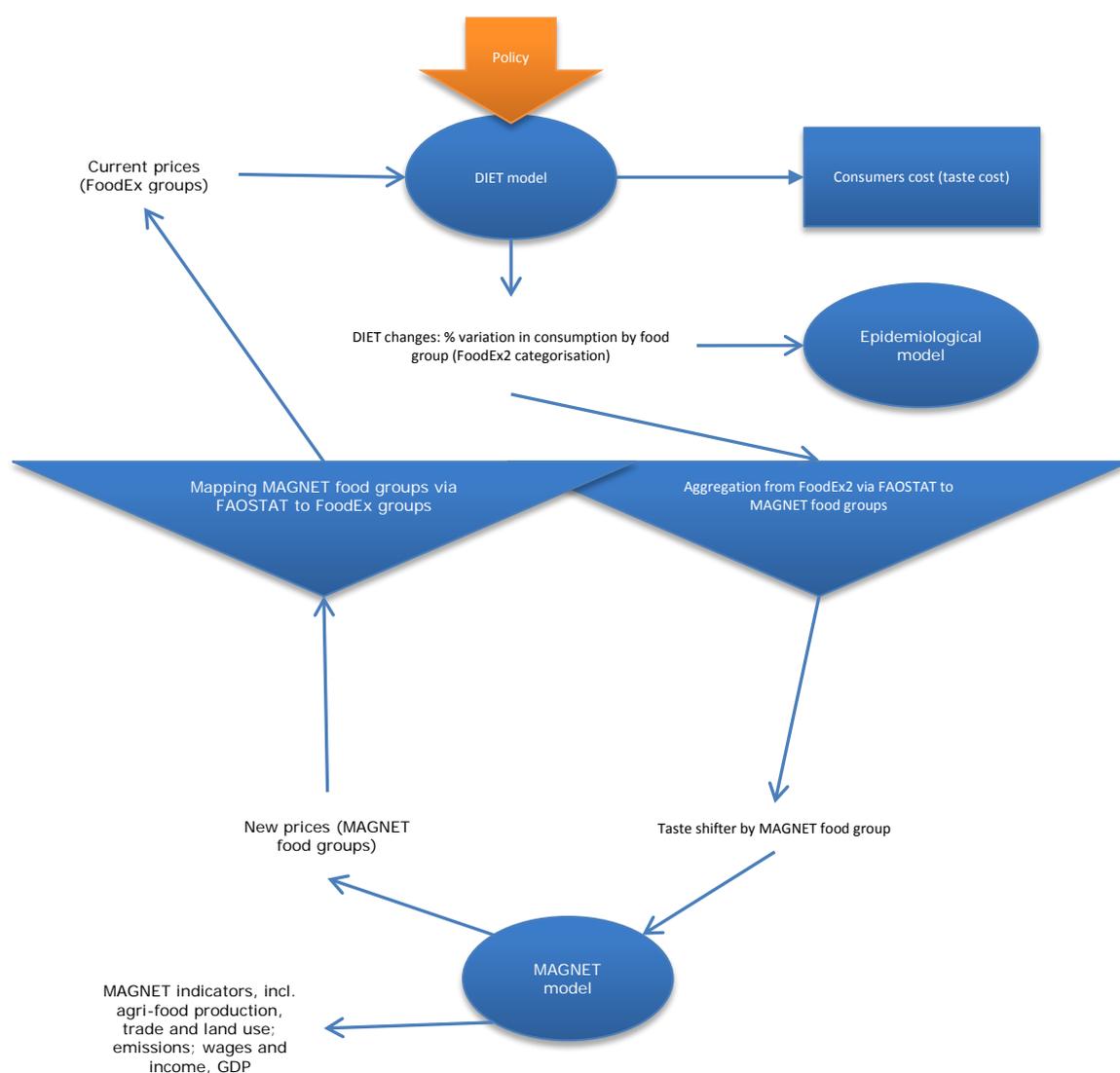
GLOBIOM will be recalibrated and adapted to perform projections at higher time resolution in order to provide fundamental market variables to AgriPrice4Cast which better fit to the time resolution of the high frequency market data (arrow L). The new version of GLOBIOM will solve in yearly steps based on price expectations from the previous period and their alternatives. In a next step, GLOBIOM will be calibrated based on the outputs from the market volatility decomposition in WP8 to represent the full amplitude of the price shocks resulting from extreme events related to whether, pest and disease outbreaks or food safety issues (arrow M).

Short-term perturbations induce important changes in producer behaviour that have long-term consequences. This is in particular the case in sectors with multi-annual production cycles such as milk and beef production. Linked with the livestock case study, the annualised version of the GLOBIOM model will be enhanced to represent explicitly herd dynamics, and hence to take into account the multi-annual character of ruminant production and adaptation possibilities like destocking. This case study will be used to test the ability of the model to capture the long-term effects of short-term perturbations.

### 3.3.3 Linking of long-term macro models with micro models

This section deals with the linkages between MAGNET/GLOBIOM/CAPRI (WP9), SHARP (WP7) and DIET (WP2), as visualised by arrows A, B, C, J, K (Figure 10). Note that the link between SHARP and DIET is discussed in more detail in section 3.3.4.

As shown in Figure 10, the link between GLOBIOM and CAPRI on the one hand and SHARP/DIET on the other is one way in the sense that the former transfer information on agricultural prices and environmental impacts at detailed agricultural product level to the SHARP model (arrows J and K) so that the latter can optimise the diet taking into account economic and environmental attributes, next to nutritional attributes. The link between MAGNET and SHARP/DIET goes both ways in that MAGNET shares information on household incomes and prices (arrow A), and uses micro and micro nutrient information from the SHARP model (arrow B) to acquire more detail into the quality of the consumption basket across households. Moreover, an iteration between the models takes place to align diets resulting from the various models (two-way arrow C).

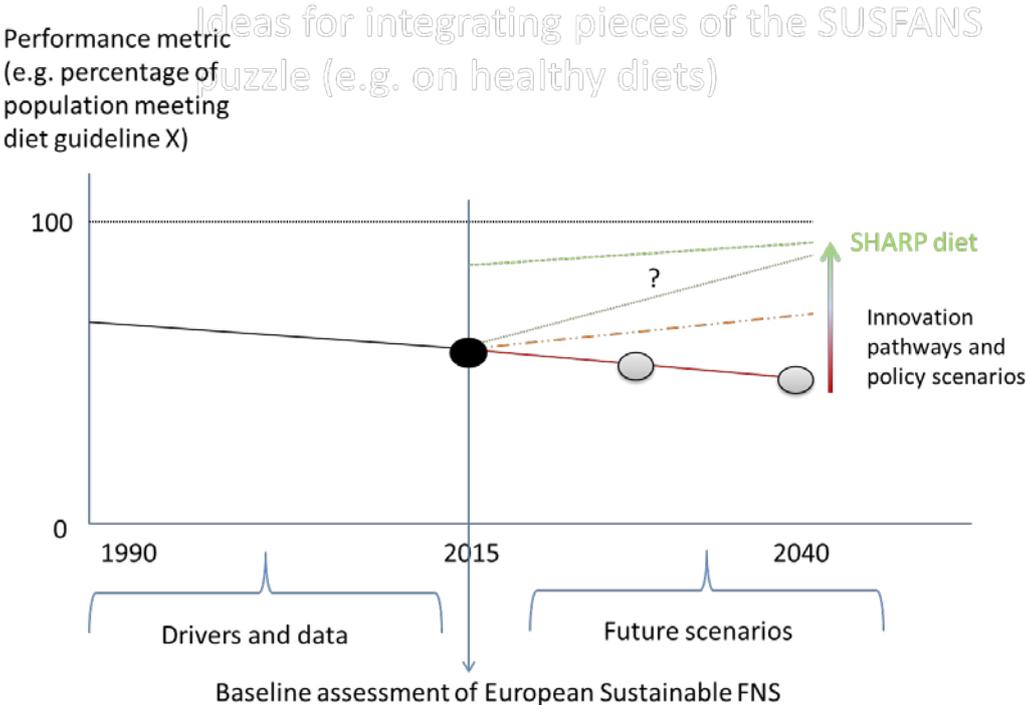


**Figure 12 Linking the DIET model with MAGNET: example**

How the alignment of diets would work between MAGNET and the DIET model is explained in Figure 12, for a hypothetical scenario, e.g. an information campaign that leads to a five percent increase in fruit and vegetable consumption. From the scenario, the DIET model computes dietary changes, i.e. the percentage change in food consumption at the level of detail of FoodEx2 at given prices, and

computes the taste cost to consumers. The dietary changes can subsequently be mapped with and fed into the MAGNET model as a taste shifter in favour of fruit and vegetables (corresponding to arrow B in Figure 10). MAGNET then computes changes in various macro-economic variables, as well as changes in consumer prices, which can be fed into the DIET model (corresponding to arrow A in Figure 10). This most likely leads to a new equilibrium in DIET, which would alter the taste shifter for MAGNET, and the exchange of data can be repeated, and a question to investigate is whether this iterative process converges (i.e. whether or not the two-way arrow C in Figure 10 can be made operational).

To enable this exchange of diets and prices a mapping is needed between FoodEx2 and MAGNET. This mapping is obtained via mapping FoodEx2 to FAO, which is part of T7.3 (all long-term models are mapped to FAO, the most frequently used data source for modelling in the area of agriculture and food at the (inter)national level).



**Figure 13 SHARP diets in a long-term perspective**

This process of alignment between MAGNET and SHARP is depicted in Figure 13, considering a hypothetical performance metric modelled on the percentage of the population meeting a certain dietary guideline. In the example, less and less people meet this guideline, and this process in the future continues (indicated by the bright red baseline). SHARP models an optimal diet on the basis of attributes associated with food groups at a given point in time as SHARP does not have an explicit time dimension. This is illustrated by the bright green line at the top of the figure, which assumes that the optimal diet - modelled on current and future attributes – in part obtained from the long-term economic and biophysical models - ensures that closer to 100 percent of the population meets the guideline and that this percentage increases over time. The pathway from the red lines to the green line (current and optimal dietary patterns) is given by the MAGNET model, which by means of innovation and policy scenarios points the way to how to arrive at such a diet. Specifically such policies and innovations induce changes in levels of production and trade, underlying levels of resource use, and changes in incomes and prices that result in a more optimal diet and puts a time frame to it.

An interesting question to investigate is whether a SHARP diet, modelled on given attributes and in part obtained from the MAGNET model, can feasibly be reached by the food system, as incorporated in MAGNET (in which diets and underlying drivers, i.e. attributes, are endogenously resulting from the food system and the broader macroeconomic context), or equivalently whether optimal diets in MAGNET and SHARP converge. To achieve the linking of MAGNET with SHARP, a mapping is again required from FoodEx2 to FAO (T7.3). It is operationalised by an exchange of information on household level incomes and commodity prices, resulting from the MAGNET model, used as an input into SHARP, with SHARP returning optimal diets at the consumer group level (envisaged information at the level of age, sex, educational level and possibly BMI). This is where a second mapping needs to be obtained.

### **3.3.4 Linking of micro models**

This section deals with the linkages between SHARP (WP7 model), the DIET model and the epidemiological model (both from WP2), as visualised by arrows H and I, and the white oval shape around SHARP and DIET (Figure 10).

In its current form the DIET model is linked to the DIETRON epidemiological model, which estimates the impact on chronic disease mortality of counterfactual population dietary scenarios, as explained in detail in Scarborough et al. (2012a, 2012b). The dietary adjustments simulated in DIET are fed into DIETRON as changes in intakes of the following foods and nutrient: fruits, vegetables, fibres, total fat, monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), saturated fatty acids (SFA), cholesterol, salt, and energy.

The DIET and SHARP models complement each other. The SHARP model is less restrictive than DIET in its characterisation of consumer preferences and can therefore be used to identify sustainable diets while allowing for some level of adjustment in tastes in the medium to long run. The SHARP model also allows for a high level of product disaggregation, which is a condition for the precise nutritional assessment of dietary scenarios. By contrast, DIET assumes the constancy of consumer tastes and therefore simulates relatively short-term dietary changes occurring at the margin. Thus, SHARP is best suited to characterise sustainable diet targets, while DIET provides a tool to assess the relative cost-effectiveness, at the margin, of various sustainable diet recommendations and other policies that could be used to drive consumers towards those targets. For instance, SHARP may identify a diet richer in fish, fruits, vegetables and whole-grain products and containing less meat, cheese and refined-grain products as optimal. However, this would not answer the short-term policy question of which simple healthy-eating message (e.g., five-a-day, six-grams-a-day) should be promoted to consumers first, recognizing the limited amount of resources typically available for this type of public health interventions. DIET, by producing a clear ranking of alternative recommendations, including recommendations suggested by SHARP simulations, provides a prioritization tool to select specific policies in order to influence dietary behaviours in the short run.

Given the foregoing, it is possible to connect SHARP and DIET models as follows:

- SHARP will be used to identify optimal diets (in the long run), for instance based on an increase in fruit, vegetable and pulse consumption and a decrease in red meat consumption.
- Then DIET will be used to estimate the taste cost (in the short run) faced by the consumers when complying with the recommendation for an optimal diet. This allows for the comparison of the cost-efficiency of these recommendations and helps to identify the best ones to promote.

## **3.4 Risks of model-linking and ways forward**

The soft approach of model-linking favoured in SUSFANS has the general advantage that the functioning of each model individually does not depend on the development of a joint software architecture (see section 3.1). This substantially limits risk.

The remaining risk is related to the pursuit of the more ambitious model-linking. This requires significant resources for detailed conceptualisation, mapping of model variables foreseen for exchange, and the iterative adjustment processes induced by inspection of first results. The largest challenges will relate mostly to those links that involve models to be developed during SUSFANS (SHARP, AgriPrice4Cast) and to links not having been implemented in previous projects (e.g. long-term macro with micro models). Consequently, the long-term model linkages that are in the focus of this work package are mainly threatened by a late agreement on the specific scenarios that shall be analysed in the context of SUSFANS. This risk is addressed in the project time-planning. The early focus in the project should be a better joint understanding of the linkages to the newly developed and short-term models as these linkages have little precedence in previous projects. A common understanding of purpose, scope and architecture of the toolbox models is required and this deliverable is an important basis for this.

Should the linking strategy fail, a fall-back position in the project is to have individual model applications under a general harmonised scenario framework. The fall-back option is threatened only by the failure to complete individual models and by a poor alignment through the scenario framework. The latter risk is an important motivation to pursue a more ambitious linking exercise described above because a collection of model results that contradict each other with respect to overlapping model areas or with differences that cannot be explained is detrimental for the stakeholder communication process. Moreover, some of the linkages foreseen are clearly targeted at improving individual modelling responses and making them more scientifically defensible.

Further activities to support the linking process and to reduce late risks for the project should be related to clearly defined paper writing exercises. Partly based on this deliverable, a first conceptual SUSFANS modelling paper is envisaged under the project's pillar II which shall be completed by the end of the second project year. Based on this conceptual paper process and this deliverable, a discussion on further methodological papers focused more on specific links shall be initiated. However, the technical details of model links that shall become operational within the SUSFANS project require the development of appropriate protocols of model-linking. This needs to be reflected in targeted and general project meetings and related deliverables.

#### **4. Operationalisation of SUSFANS toolbox in SFNS indicators**

The SUSFANS toolbox of enhanced models will be tested by means of the case studies of innovation pathways in the livestock-fish supply chain and in the fruit-vegetable chain and will subsequently be documented in deliverable D9.5. During this phase of the project the scenario work will also start.

For the innovation pathways and scenarios, metrics and underlying indicators identified in WP1 will be reported on as far as they can be quantified. The first section documents metrics and indicators that have been identified so far (part of WP1 process). The second section identifies which of these can be provided by what model and at what level of detail. The final section reports on how the toolbox may be used by case studies and scenarios.

## 4.1 Preliminary overview of SFNS metrics and indicators of conceptual framework (WP1)

**Table 4 Conceptual Framework metrics, indicators and variables to assess SFNS**

Policy goals	Performance metrics	Individual variable	Other indicators/variables of interest	
Balanced and sufficient diet for EU citizens	% people that fulfil threshold diversity score			
	% of people fulfill (partly) food-based dietary guidelines	Dietary intake of food group level based on common set of food based dietary guidelines (20-30 food groups) linked to FoodEx2		
	% of people fulfill nutrient-based Dietary Reference Values (DRVs)	BMI (body mass index of EU population)  Protein, fat, carbohydrates, alcohol  Intake of added sugar Intake of SFA (saturated fatty acids) Intake of sodium Intake of dietary fibre Intake of folate/ folic acid Vitamin D Iron Calcium Iodine		
Reduction of environmental impacts	Climate stabilisation	CO2		
		CH4		
		N2O		
		Use/emissions of cooling agents in fish production (CFCs, ...)		
		Land Cover (e.g. albedo)		
	Clean air and water	N input (fertiliser, manure, atmospheric deposition, biological fixation, feed) and N output (yield), change of soil stocks. Maybe split of N surplus into emissions to the atmosphere: air pollution and emissions to the hydrosphere: water pollution)		
		P input and output		
		Use of toxic substances (pesticides, ...)		
Biodiversity conservation	Land use			
		Emissions of GHGs, Nr		
		Land use (Shannon)		
		seafloor area impacted (m <sup>2</sup> )		
	IUCN threatened species affected (terrestrial and marine)			
Preservation of Natural Resources		Irrigation water use		
		Water use in livestock production		
		Water use in the food chain		
		Water supply		
		Fishing mortality (F)		
	primary production required (PPR)			
	Erosion			
	Soil carbon contents			

**Table 4 continued**

Policy goals	Performance metrics	Individual variable	Other indicators/variables of interest
Economic performance of EU agri-food business	Overall competitiveness index (Benchmark: world average of a variable over time (MAGNET); Normalisation to a scale of 0-100, method tbd)	Export value (by sector, agri-food sector; country, EU total, world total; 5 year time intervals)	Number of farms/firms; Employment; Average farm/firm income; Turn-over; Price/Mark-up (all by sector, agri-food sector; country, EU total)
		Export and import values (by sector, agri-food sector, in total; country, EU total, world total; 5 year time intervals)	
		Labour productivity (by sector, agri-food sector; country, EU total, world total; 5 year time intervals) calculated as value added divided by number of employees	
		Value added (by sector, agri-food sector, in total; country, EU total, world total; 5 year time intervals)	
	Market power for the entire supply chain (0-1)	Sales (turnover), cost of employment, cost of capital, cost of material (by sector, total supply chain, country (some), EU average based on the countries; 10 years time	
Food and nutrition security	Global food availability	Production of commodities (value, quantity)	Domestic food production, food imports and exports, average dietary energy supply adequacy, average value of food production, share of dietary energy supply derived from cereals, roots and tubers, Food balance sheet at national level, demographic composition, and per capita energy needs average protein supply of animal origin
	Global food access (either use range from scenarios or distance from reference calcs/capita/day - both under and over consumption)	Consumer prices, producer prices (as proxy for income), household income (general vs. specific contexts e.g. coffee farmers in West Africa)	Ratio of rural wage to cereal price (food access measure), domestic food price index, prevalence of undernourishment, share of food expenditure of the poor, depth of food deficit, prevalence of food inadequacy. Household income relative to consumption price of food; share of household budget spent on food.
	Utilisation not covered by the models but rather by first dimension on Balanced and Sufficient Diets in the EU	Balanced and sufficient intake of key macro and micro nutrients	Household food basket by food type and source. Household nutrient intake per capita relative to healthy diet guidelines so as to calculate FGT type nutrition/undernourishment indicators; Diet diversity score from food items available in the models.
	Stability of FNS		Household savings, dependency on remittances and international aid. Cereal import dependency ratio, value of food imports over total merchandise exports.

Metrics, indicators and variables developed from within the conceptual framework for assessing SFNS (from WP1) are displayed in the Table 4. They have been structured using a hierarchical approach. Specifically, the first column specifies the EU policy goal that is being served (balanced and sufficient diets, reduced environmental impacts, economic performance, global food and nutrition security). The second column contains the performance metric, which combines various indicators and helps to assess the achievement against a specific EU target (e.g. competitive EU agri-food business). These can be shown on a spider diagram on a scale from 0 to 100, where an outcome closer to 100 represents a better score. The third column gives underlying individual variables which can be counted and or quantified against a universally agreed upon standard (e.g. export value in

euros). These will be used to construct derived variables and aggregate indicators to calculate the performance metric. Finally a column has been added to show other variables of interest that could be provided for by the toolbox and using existing data from ex-post analyses (e.g. the number of farms/firms, employment), which could be helpful in providing more contextual information to explain outcomes of innovation pathways and scenarios. To go from individual variables to performance metrics does not only require aggregation but also some sort of weighing. The method to do so is yet to be determined and will build on experience in other projects. The table is the result of extensive consultations with stakeholders and is still work in progress (part of WP1). What is relevant for this work plan is how the toolbox of interlinked models will take up the metrics, indicators and variables. In the next section we give a first reflection on what outcome indicators on SFNS could be used from what model for use in a consistent and accurate assessment of EU SFNS. The assessment and analysis of performance metrics will presumably involve some model-linking beyond those that are described in the current plan. For example, an assessment of the degree of climate stabilisation under a future diet and food system will, by necessity, call upon a modelling framework that is able to integrate the various variables from the SUSFANS toolbox in an earth system model.

#### **4.2 Matching of SFNS metrics and indicators with models**

The SHARP and DIET models will provide information to construct the metrics for sufficient and balanced diets for EU citizens. Information on reduced environmental impacts will be provided by GLOBIOM, CAPRI and MAGNET. Economic performance indicators will be provided by MAGNET, GLOBIOM and CAPRI (for the EU, at more sectoral detail). Global FNS indicators will be provided for predominantly by MAGNET, GLOBIOM and CAPRI (EU, at a higher level of sectoral detail).

#### **4.3 Envisaged use of toolbox by case studies and scenarios for policy support to EU SFNS and further strengthening of the toolbox**

The toolbox will be put to use in forward-looking scenarios (WP10) and in innovation pathways (WP5).

Possible innovations that are currently considered as case studies (final choice to be made in dialogue with stakeholders) include:

- Encourage human health and reduce the environmental impact by replacing animal-source food products with plant-based products or fish in human diets;
- Avoid feed-food competition by feeding biomass to livestock that does not compete with human food production e.g. food waste, co-products or biomass from marginal land;
- Reduce the environmental impact by increasing consumption of locally produced plant-sourced food;
- Adjust diets to improve human health by reducing consumption of processed food (high level of salt and sugar), increase proportion of digestible fibre, and increase fruit and vegetable intake.

Generally, innovations can be taken up by the toolbox via a supply side / food chain side or a demand side route. In the former, a change in the use of inputs through for example a change in technology, affects supply of, trade and consumption of agri-food products. In the latter, the innovation is sparked by changes in taste of the wider public, which alters dietary choices and so production and trade of agri-food products. The innovations come about because of changing behaviour by producers (for example because of Corporate Social Responsibility considerations) or consumers (for example by being better informed on issues of health and environmental sustainability), and/or may

originate from government intervention including changes in regulation or financial policy instruments (taxes, subsidies).

The case studies themselves are also set up so as to test the approach of the toolbox, enabling further improvements of the toolbox. We envisage that the case studies will enhance the toolbox in two ways. First, given the focus on detailed sectors in the case studies, various long-term models can use the data gathered for the case studies to improve their sector and product specification (e.g. fish and aquaculture in CAPRI, MAGNET and GLOBIOM, but also distinguishing pork from poultry in MAGNET). Second, the innovation pathways themselves imply improved technologies, which may be incorporated in the various models of the toolbox. Taking the case studies that are foreseen now this may relate to improved biomass flows (food-feed-fuel), novel foods, and supplementation/reformulation/biofortification.

The forward-looking scenarios will be constructed along two elements: future challenges and agri-food policies for SFNS. Currently considered future challenges can be grouped in four categories: demographic, dietary and income trends, climatic change, technological change, and non-agri-food policies. Agri-food policies considered include health and nutrition policies, the Common Agricultural Policy (CAP), the Common Fisheries Policy (CFP), and market stabilisation policies. While a restricted set of plausible combinations of future challenges and policies will be implemented by the whole SUSFANS toolbox to provide a comprehensive assessment of the whole FNS sustainability matrix covering the supply chain from producers to consumers, and considering social, economic, and environmental criteria, as conceptualised in WP1, only the most relevant components of the toolbox will be used to provide an in-depth assessment of the individual challenges and policies. Hence, for example MAGNET together with SHARP will be used for analysis of the socio-economic challenges and the health and nutrition policies, CAPRI for the technological change and CAP assessment, and GLOBIOM for climate change and market stabilisation policies assessment. This dual approach will allow to demonstrate the flexibility of the toolbox providing the possibility to implement its individual parts for quick and focused assessments, as well as implementing the toolbox as whole for comprehensive integrated assessments.

## **5. Discussion of SUSFANS modelling strategy**

This paper, which takes the form of a work plan, serves the general reader on three purposes. First, it creates awareness on the modelling concepts prior to application stage; second, it provides insight into the foreseen model integration in assessing SFNS; third, it identifies model complementarity in assessing SFNS. The paper has a number of limitations, some of which will be addressed in future research under this work stream while others point to limitations of the SUSFANS toolbox design, and call for exploration under related and future research agendas.

First, the extent to which the paper streamlines and details the model complementarity and integration in assessing SFNS is unequal across the models in the toolbox. It is more explicit for the interaction between four established long-run models (MAGNET, CAPRI, GLOBIOM, EPIC) than for the interplay between the new to be developed European models (SHARP and AgriPrice4Cast) or between the long-term models and these models. During the project, as the development of these models advances, the linkages with the other models will be more explicitly described. In fact, a challenge will be to develop these models in a way that they are intrinsically part of a larger toolbox. The paper is also less comprehensive in describing the interaction between both the models for analysing a more healthy and sustainable EU diet: DIET and SHARP. The current paper suggests both models provide complementary information, respectively for policy analysis on desirable (DIET) and most likely (SHARP) changes to a diet in the short to medium run (in DIET with prices, preferences and production methods constant) and medium to long run (in SHARP with changes in these variables coming from the long-run economic models.) These shortcomings will anyhow be addressed

in later reports on the SUSFANS toolbox, as we record advances in the development of the new methods and the improvement of the established methods.

Second, while the paper explores complementarities across the assessment models, it does not provide for a detailed conceptual analysis of the various components of the toolbox. There are several challenges in integrating the various models within a single toolbox for assessing EU's performance on sustainable FNS that need to be addressed at a conceptual level before they can actually be addressed in an operational framework. Many such challenges can be thought of, including the following:

- How insights from the consumer behaviour model DIET can be scaled up in EU-wide economy and agricultural models, especially as the use of the latter models for long-term projections involves changing consumer preferences;
- How the SHARP model, which optimises on a particular range of desirable diet outcomes, can be interpreted in conjunction with economic models, in which diets are endogenous.
- How a combination of models that analyse short and long term price variability, could help answer the question whether there is a connection between diets and short term variability in food prices.

Such conceptual challenges on modelling sustainable food and nutrition security for monitoring and foresight, will be analysed in a dedicated SUSFANS paper. This paper will respond to the modelling challenges that follow from directions and stakeholder input in the first phases of the project, in particular in terms of Europe's FNS and sustainability challenges, case studies and innovation pathways.

Third, there are numerous research questions on European sustainable FNS that go well beyond the scope of the SUSFANS toolbox as it is proposed in this paper. Examples relate, for example, to a more comprehensive representation of bounded rationality of consumers and of heterogeneous behaviour amongst supply chains agents. The conceptual paper, as announced above, will evaluate limitations, extensions and alternatives for the approach taken in SUSFANS to model EU sustainable FNS.

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# Annex A. Overview of the SUSFANS project

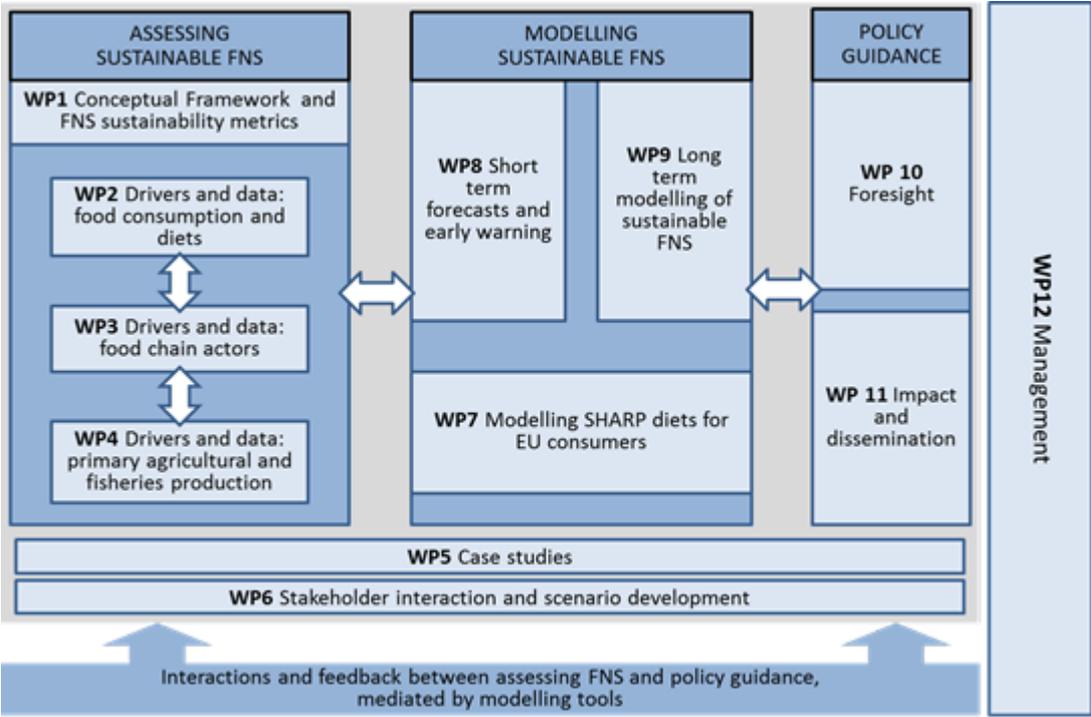


Figure A Structure of the SUSFANS project