A modelling strategy for quantifying the sustainability of food and nutrition security in the EU

Deliverable No. 1.4

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SUSFANS DELIVERABLES

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Food systems for health - environment - enterprise

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This deliverable outlines a modelling strategy for quantifying metrics and methods for quantifying the sustainability of EU FNS. SUSFANS models are assessed in terms of data needs, their limitations and the questions they can address related to sustainable FNS in the short term and the long term. This assessment sets the scene for operationalization of the SUSFANS Toolbox.

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DELIVERABLE SHORT SUMMARY FOR USE IN MEDIA

The SUSFANS project aims to contribute to food systems change by providing policy and decision makers across Europe with the tools to get a holistic understanding of the EU food system and how it relates to Sustainable Food and Nutrition Security. While earlier deliverables have focussed on the building of an aggregated set of metrics that allow for the assessment of the policy goals set by the EU (D1.2 and D1.3), this deliverable describes the strategy to model these performance metrics with the SUSFANS model toolbox. Together these will lead up to the final product, a spider-diagram inspired interactive tool that gives insights into the effects of policy changes on the European food system.

Based on the models constituting the SUSFANS toolbox, we have developed an approach that allows us to explore various aspects of the EU food system in relation to the EU's policy goals. These policy goals are: balanced and sufficient diets for EU citizens, reduced environmental impacts of the EU food system, competitiveness of EU agri-food businesses, and equitable outcomes and conditions of the EU food system. Each of the five modelling approaches (MAGNET, CAPRI, DIET, GLOBIOM/AgriPrice, and SHARP) is explored in detail in the Annexes of this deliverable. Here we describe what aspects of the model relate to SFNS and in what way they can contribute to the SUSFANS aim of assessing the EU food system.

This paper starts with the exploration of drivers of change of the key actors in the food system, namely primary producers, food chain actors and consumers (D1.1). The second section explores which variables that determine the performance metrics can be captured by the models in the SUSFANS toolbox. The complete overview of the SUSFANS modelling approach is presented in table 8, in section 3.5 of this deliverable. This assessment shows that most of the SUSFANS performance metrics can be quantified using the tool box models. The main exception are some of the variables describing the goal of 'Equitable conditions and outcomes of the EU food system', for which the team is currently devising an approach to deriving these qualitatively.

TEASER FOR SOCIAL MEDIA

Connecting existing modelling approaches in the SUSFANS toolbox for a holistic assessment of the European food system; Deliverable 1.4 gives insight into the coverage of the Sustainability metrics (D1.3) by combining models designed for macro-economy, diet and health, and agricultural production. Together, these varied modelling approaches cover the EU's food system related policy goals almost fully.

Twitter

SUSFANS integrated modelling approach to assess #SFNS in #foodsystems: combining existing modelling approaches to cover quantitative & qualitative metrics

ABSTRACT

The EU food system produces a wide range of outcomes, which are assessed by different scientific communities, and various policy goals for specific parts of the system as well as for the whole food system have been formulated by EU and national policy makers. One of the main objectives of the SUSFANS project is to develop a set of concepts, metrics and tools that can help policy and decision makers across Europe make sense of the various trends and outcomes we see associated with the EU food system and to assess if the system as whole is making progress towards any of set policy goals and sustainable food and nutrition security (SFNS). The metrics and tools can then also be used to evaluate various policy measures and their unintended impacts across the whole EU food system, thus allowing for an assessment of synergies and trade-offs between and across goals.

This paper describes the approach using the five models in the SUSFANS tool box to assess the selected metrics (D1.3), based on the SUSFANS conceptual framework (D1.1). As in the past years there has been an increasing amount of research dedicated to the food system, we propose the use of complementary models in order to cover the different metrics selected in D1.3. The novelty of the SUSFANS approach is bringing these models together and as such give a holistic insight into the food system and the four key goals related to food system change. The models in question, are specialised in certain food system domains; MAGNET focusses on the macro-economy, while SHARP and DIET are both designed for the exploration of issues related to diet and health at consumer level. GLOBIOM and CAPRI were developed to assess agricultural production. Through the use of these diverse models, SUSFANS is able to build a modelling approach covering the majority of the selected metrics. In this we have paid specific attention to how the drivers of change for European Sustainable Food and Nutrition Security are captured by the models. These drivers of change are consumer behaviour, primary producer behaviour and drivers of food chain actors. A complete overview showing in detail which models cover the metrics is provided in table 8. The model assessment shows that most of the SUSFANS performance metrics can be quantified using the tool box models. The main exception are some of the variables describing the goal of ‘Equitable conditions and outcomes of the EU food system’, for which the team is currently devising an approach to deriving these qualitatively.

INTRODUCTION

Over the past decades the EU food systems delivered on the main goals formulated by EU and member state policy makers. These foremost included the supply of sufficient and affordable food for EU member country citizens and a decent income for primary producers as well as an internationally competitive agro-food industry. Growing evidence on environmentally unstainable outcomes had reducing negative environmental impacts added to the mix of policy goals for the EU food system. In the face of a growing obesity crisis and other health issues related to EU citizens' dietary habits, more decision makers are worrying about more balanced dietary patterns and the health outcomes of the EU food system. Alongside the growing concern for the health impacts of the current diet on European consumers, attention is also increasingly drawn to the actors in the supply chain delivering this food. Equity and social justice issues both within the EU food system, such as fair wages and power relationships between food system actors, as well as the impact of the EU on global food security move beyond the traditional focus on the income of the agricultural producers towards a focus on the entire supply chain. How to address these various and possibly conflicting goals in a coherent manner is a key question decision makers at EU and national scale as well as in industry will face in the coming decades.

One of the main objectives of the SUSFANS project is to develop a set of concepts, metrics and tools to help policy and decision makers across Europe make sense of the various trends and outcomes we see associated with the EU food system, and to assess if the system as whole is making progress towards the goals that have been formulated for it by different communities. Thus the project aims at improving the tools for decision-makers, stakeholders, and analysts for navigating towards more sustainable European food and nutrition security (SFNS). A food systems approach drives the SUSFANS analyses - while focussing on the diets of European consumers, sight of the functioning of the global and EU food systems delivering this diet is not lost. Public health, environmental protection and thriving enterprises are all key to long term nutritious and sustainable diets (Rutten et al. 2017).

Tools developed by SUSFANS are also aiming to evaluate various policy measures and innovations to the food system and their unintended impacts across the whole system, thus allowing for an assessment of synergies and trade-offs between and across goals. Here the project took a two-step approach (also see Rutten et al. 2017): first a conceptual framework was developed that maps out the EU food system, its actors, driving forces, goals and outcomes and shows a number of feedback loops within the system (see report on deliverable

D1.1). This framework serves as a roadmap for the selection of metrics and lays out what needs to be assessed. In the second step, an approach to metrics selection was developed and used to define metrics for assessing the EU food system described in deliverable D1.3. The metrics cover diets of EU consumers alongside impacts of the food system on equity inside the EU as well as globally, environmental impacts while not losing sight of the competitiveness of EU agri-food businesses.

As outlined in the conceptual framework the outcomes of the EU food system result from activities by food system actors, grouped under the headings of consumers, primary producers and food chain actors. To be able to project future European SFNS the (direct and indirect) driving forces of these actors and their interactions need to be accounted for. The tools used within SUSFANS thus need to cover, to the extent possible, the metrics for measuring food system outcomes in terms of SFNS. But SUSFANS aims to move beyond the status-quo by navigating different innovation pathways towards a more sustainable and healthy future European diet. This requires an understanding of the behaviour of the actors shaping future food system outcomes and possibly leverage points for interventions towards a more desirable outcome as captured by changes in the metrics.

The SUSFANS modelling toolbox provides such a forward-looking description of the behaviour of key actors in response to each other, allowing an assessment of potential interventions aiming at a more healthy sustainable European diet. Figure 1 summarizes key features of the models inside the SUSFANS toolbox. Using a combination of these models allows integrated assessments of specific innovations in the agri-food chain (as explored in SUSFANS case-studies in WP5) or of one or more drivers of the food system (as in the SUSFANS forward-looking scenario simulations in WP 6 and 10) as outlined in D9.1 *Operationalizing the assessment framework in the SUSFANS toolbox*.

The aim of this deliverable is to assess the SUSFANS models in terms of their dual role: capturing the key drivers of actors and quantifying the SUSFANS performance metrics. The driving forces are key in determining the model outcomes which then feed the SUSFANS metrics summarizing the changes in the EU sustainable food and nutrition security. Specifically the models provide the individual variables from which the SUSFANS metrics are derived through an aggregation procedure. The SUSFANS metrics and aggregation procedure are discussed in detail in D1.3 *Sustainability metrics for the whole food system: a review across economic, environmental and social/cultural/health considerations*.

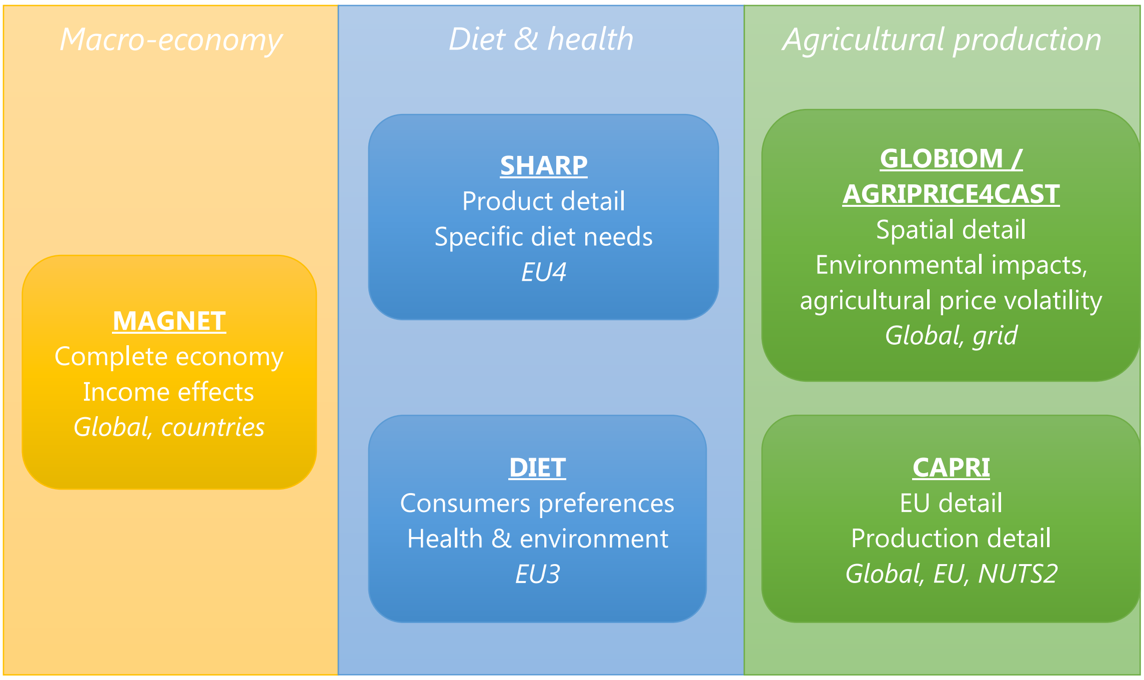

Figure 1 SUSFANS modelling tools

Focussing on the ability of the model toolbox to assess SFNS in the EU we limit the discussion here to the model outputs used in the assessment, the individual variables at the base of the metric hierarchy and the forces driving a change in these variables as captured by the models. In deliverable D4.7 the CAPRI modelling team already ran an experimental aggregation from the individual variables up to the performance metrics for the policy goal of reduced environmental impacts of the food system. This work provides a first quantitative assessment of how this aggregation can be done and where the difficulties lie in operationalizing the metrics.

The current model assessment focusses on two specific parts: drivers of food system actors as defined in the SUSFANS conceptual framework (D1.1) as this provides and understanding of how the models work and the individual variables upon which the SUSFANS metrics are build (D1.2 and D1.3). The deliverable is structured accordingly. Part 1 focuses on the drivers, both direct and indirect, of food system actors looking across the different models. Part 2 then turns to the food systems performance metrics as described in deliverable D1.3 to assess which model in the SUSFANS toolbox can be used to quantify these. The final part takes stock, identifying the need for complementary approaches and ways in which the models can be used in SUSFANS. The annex to this deliverable provides a more detailed description of each model in terms of key behavioural assumptions and metrics.

DRIVERS OF CHANGE IN EUROPEAN SFNS

Our discussion of the drivers of change in European SFNS is organized around the three key groups of decision-makers or actors in the conceptual framework: consumers, primary producers and food chain actors. From a focus on European consumers deciding on their diet, we broaden the scope to the wider food system delivering food from the farm to the fork. The farm where European food originates is not necessarily located in Europe, nor is the consumer of European produced food always located in Europe - this broadening to the food system thus also expands the geographical focus from Europe to the global food system.

SUSFANS' transdisciplinary approach results in a combination of modelling tools from different disciplines. This variety in backgrounds is reflected in the different definitions of actors, which in turn will affect the questions each model can address, as well as the ease with which links to the other models can be established. The disciplinary background is also reflected in different levels of detail or focus, resulting in a complementary set of model tools.

3.4 Drivers of consumer behaviour

The consumer takes central stage in SUSFANS by taking the ultimate decision on what food to buy and eat. The way in which the consumer and its decisions are conceptualized, however, varies across the SUSFANS models. Differences in the drivers of consumption across the SUSFANS models originate from different definitions of consumers, food and (to a lesser extent) consumer behaviour.

3.4.1 Defining the consumer

SHARP has its origins in human nutrition and operations research. Detail in terms of individual consumers as well as products consumed is needed to assess the health implications of a specific combination of foods for a specific type of individual. SHARP uses individual level data capturing differences in age, sex, educational level and overweight/obesity status. While based on individual data, assessments are made for relevant population subgroups.

DIET, while focussing on the scope and implications of diet changes, originates in economics. It defines representative households as consumers, distinguished by income level and region. When the model is coupled with a health impact assessment model (DIETRON), the purchasing decisions by household types are translated into individual intakes using average adult intakes by sex to allow an assessment of the health implications of a specific diet.

MAGNET, a global general equilibrium model, also originates in economics. It defines consumers as representative household types (for regions where data for the household module are available) or a single national representative household (supranational for regions consisting of multiple countries). For most regions only data on the total population, without further details on age or sex, are used when modelling consumer demand. For the multiple household regions household population sizes are used, in some cases with access to detail household composition survey data underlying the totals but these are not used in the model itself.

Both CAPRI and GLOBIOM are partial equilibrium models taking their cues for the consumer from economics while focusing their main modelling efforts and drawing on a broader disciplinary background in modelling primary production. They both include total demand, but similar to most regions in MAGNET modelled as the total demand of a national or supranational representative household.

The way in which consumers are defined reflects the origins of each of the models. GLOBIOM and CAPRI are built for detailed analyses of primary production, from an environmental or CAP perspective. MAGNET originates from the GTAP model and database designed to analyse economy-wide effects of international trade agreements. These three models need total consumer demand to capture price responses resulting from the interplay between production and consumption, but have no intrinsic need for further details on consumers (like age or sex). SHARP and DIET come from the opposite side, zooming in on consumer details to be able to assess health implications of diet choices. A consequence of its nutritional background, also in terms of data sources, the SHARP consumer characteristics are linked to health assessments not captured by the economic definitions of consumers in the other models.

3.4.2 Defining food

A second important component in assessing diets is the amount of detail in products purchased by the households. Again there is quite some variation across the models linked to their origins and main purpose.

SHARP reflects its roots in nutrition by having the largest level of detail in products, capturing the food products as consumed at individual level using food records or 24-hour recalls. It uses the FoodEx2 Exposure hierarchy from the European Food Safety Authority (EFSA) which groups 4311 products into a six level hierarchy towards 21 food groups.

DIET bases it assessment on a survey of supermarket purchases aggregated to 22 food groups used by the model. These groups are defined “taking into account similarities in the nutritional content of the products, consumer preferences, and consumer willingness to substitute one product for another" (Allais, Bertail, and Nichèle 2010, 230).

Where SHARP and DIET focus on the products as consumed by individuals or purchased by households, the other three models define food from a production perspective. In MAGNET the entire economy is covered, ranging from primary production, mining and manufacturing to services. This breadth of scope comes at the expense of detail of individual products. The GTAP database (Narayanan, Aguiar, and McDougall 2015) forms the core of the MAGNET database. It is derived from national accounts expressed in value (dollar) terms. To be able to assess nutrition these data are combined with FAOSTAT data on primary production in quantity terms to trace the flows of primary commodities when they find their way from the farm through processing industries, retail and other services to the consumer. This tracing relies on cost structures and does not account for losses in nutrition (due to losses or transformations along the supply chain nor waste by the consumers) and thus provides an upper bound on the nutritional content of purchased food.

The two partial equilibrium models, CAPRI and GLOBIOM, have a clearly defined focus on primary production with limited detail in processed goods mostly related to biofuel production and to some extent to oil seed markets in addition to CAP regulated commodities. Consumer demand, which to a large extent consists of processed food products, is translated into demand for primary equivalents. This allows both models to account for changes in final demand without explicit modelling of the food supply chain from primary to processed food and services.

As with the consumer definitions, the definitions of food are directly linked to the origins of each model. With a focus on production activities and a global scope CAPRI, GLOBIOM and MAGNET source their consumption quantities (and nutritional values) from the FAOSTAT Food Balance Sheets, which calculate consumption as a residual after accounting for all other uses of produced primary commodities (trade, stocks, industrial use, feed and seeding, losses in industrial processing). Food Balance Sheet data thus describe the amount of (mostly primary) products potentially available for human consumption but not the actual purchase nor consumption of foods. SHARP and DIET again come from the other side, defining food as the products consumed by individuals or purchased by households without accounting for their production or processing.

These different approaches to defining food pose two important challenges when combining the SUSFANS models for an integrated assessment. First of all the assessments of the nutritional value of consumers' diets coming from the producers versus consumers focussed models are not directly comparable, being either per capita potentially available nutrients from primary products (i.e. an upper limit on the available nutrients) versus the nutritional value of household purchased (DIET) or actually consumed products by individuals (SHARP). Secondly, sustainability indicators associated with a limited set of primary production activities are not straightforwardly linked to the large variety of (processed) food products purchased and consumed, even more so in ex-ante projections where both the composition of the diet and the sourcing of commodities from regions or the primary product content of processed foods is likely to change.

CONSUMPTION DECISIONS

So far we have identified differences across the models in defining who takes decisions (i.e. the consumer) and about what kind of products (i.e. the food products) finding quite some variability. If we now turn to the way in which consumers decide between foods there is almost no variance in terms of the theoretical model used: all models but SHARP apply a standard neoclassical framework of utility maximization under a budget constraint with perfect information.

The utility function captures all attributes of the commodities purchased by the households, not only prices but also taste, convenience, environmental impacts and so forth. Utility, however, cannot be observed directly. It is therefore deduced from observable expenditure patterns, i.e. changes in purchasing decisions when income and/or relative prices change (which can both be observed), by assuming rational behaviour: the consumption choices are assumed to be in line with consumers maximizing their utility given their available income.

CAPRI, GLOBOIM and MAGNET all search for a market equilibrium where supply equals demand. To assure convergence (or a feasible solution) regularity constraints on the utility function need to be imposed and data need to be available to calibrate the functions for each region (all three models have a global scope). This amounts in practice to selecting a functional form which balances (conflicting) demands of capturing observed behaviour, mathematical properties supporting convergence and having a limited number of parameters for which empirical estimates are available for a wide range of countries.

Recovering a utility function from observed expenditures allows an assessment of changes in terms of welfare losses and gains expressed in monetary terms. For example, parameterization of the utility function allows the DIET model to calculate of the costs of imposing a specific diet in terms of lowering consumers' utility. This cost can then be compared to the benefits for society of reducing health costs from a changed diet. In the long run simulation models specifying a utility function allows assessment of policy options in terms of their welfare implications, which can differ from GDP-based assessments, providing useful policy guidance.

Strong assumptions about the rationality of consumer behaviour are made in the utility maximization approach, which are not supported by insights from behavioural economics nor cognitive science. A key question is whether irrational (in the economic sense) individual behaviour cancels at the aggregate level where these economic models operate. Depending on the strategic environment a small group of individuals can tilt the aggregate either way, and the conditions under which rational or irrational aggregate responses prevail are not well understood nor researched (Fehr and Tyran 2005). Cases of imperfect competition, where agents' decisions affect market outcomes, are likely candidates for irrational behaviour of individuals affecting the aggregate result and warrant extra thought on the limitation of the rationality assumption.

Despite these valid objections, full rationality remains the workhorse of economic models because of their mathematical convenience, their normative properties (e.g. using welfare computations to guide policy design) and because the models are found to provide relevant insights (Jones 2017).

SHARP is developed in two distinct phases in the course of SUSFANS and can thus only be assessed in terms of its potential contributions. The first phase focuses on Sustainability and Health, comparing current diets in terms of planetary boundaries and nutritional adequacy, both taken as given. Consumer behaviour or choice comes into play in the second phase focussing on developing the ARP dimensions (affordability, reliability and preferability) further constraining the search for an optimal diet. Here as in the other models a utility function is used to describe the relationship between different factors determining consumption choices. In contrast to the other models, however, a-priori constraints on the shape of the utility function are less stringent. SHARP does not include interactions with supply and thus has no need for constraints assuring convergence of demand and supply sides of the model. Furthermore, the detail in its database of individual consumption of a wide range of food products may allow uncovering drivers of consumer decisions (like habits, health status, meal composition etc.) not captured in the other models relying on price and income data to explain purchasing decisions.

In the SUSFANS context of searching for sustainable and healthy diets it is important to be aware of how rational utility maximization drives consumer behaviour in the long run modelling approaches. Being deduced from observable purchase decisions, relative prices and household income become the two key determinants of consumer decisions. Non-price considerations are not part of the datasets on which the functions are calibrated and thus implicitly lumped together in the price and income elasticities. These elasticities determine how strong consumers respond to changes in relative prices or income, but do not provide information on whether this is due to a preference for the taste of a product, the way it is produced (e.g. organic or not), traded (e.g. fair trade labelling), its packaging, etc.

This implies that, apart from price and income incentives or regulations directly affecting choices, the models (apart potentially from SHARP, but this cannot yet be assessed) do not provide clues on how to best steer consumer decisions, e.g. whether packaging or taste changes will be most effective. To explore non-price policy instruments the models need to be complemented by assessments of how the aggregate consumer response is influenced by interventions other than prices and regulations imposing product characteristics or availability. Translating these insights into adjustments of the models' price and income elasticities will then allow the assessment of the impact on the food system of these interventions.

3.4.3 So what drives consumer behaviour in SUSFANS toolbox models

The definition of the consumer, foods items and the way in which consumers decide among food items together determine the drivers of consumer behaviour and therefore leverage points for interventions. The SUSFANS models complement each other with varying detail in the definition of consumers and food items. In terms of behaviour there is more uniformity, with all but SHARP taking utility maximization under perfect information as the theoretical model of consumers' decisions. Table 1 summarizes key drivers of consumers captured by the SUSFANS models.

Prices are the key adjustment mechanism in the long run modelling tools as well as in DIET which focuses on short run marginal changes in behaviour. MAGNET is the only model where household incomes are endogenous, accounting for economy-wide feedbacks on consumption decisions through income changes. DIET focuses on short run responses to given (exogenous) price changes but then adds more detail on the demographic characteristics of representative household types when assessing health impacts at individual level. SHARP then adds even more detail operating on individual level data and taking health status indicated by (over)weight into account, in addition to more commonly used characteristics like age, sex and education. The other models only account for total population changes, or at best changes in sizes of representative household groups. The common reliance on the utility maximization paradigm implies that all non-price motives are lumped together in income and price elasticities.

Table 1: Drivers of consumers captured by the SUSFANS models

	SHARP	DIET	GLOBIOM	CAPRI	MAGNET
Income	P	-	X	X	E
Food prices	P	X	E	E	E
Non-price motives	P	L	L	L	L
Demographics	ASEW	AS	T	T	T
Household characteristics	P	R	N	N	R
Individual consumers	I	I	-	-	-

Notes: - = not applicable; E = endogenously determined inside the model; X = exogenously determined outside the model; L = non-price motives lumped in exogenous income and price elasticities; ASEW = age, sex, education and weight accounted for; AS = age and sex accounted for (in health assessments); T = total population changes accounted for (in per capita income calculations); I = individual households or household members distinguished; N = single national level representative household; R = representative household types varying in income sources and expenditure patterns; P = possibly, depending on available data (model not operational yet).

In terms of leverage points for interventions at the consumption side, the models are best placed to assess price and income incentives (taxes, subsidies) and regulations restricting consumption decisions (e.g. policies limiting the availability of specific products which will induce a substitution towards other goods). As SHARP is not yet operational its capability to capture non-price drivers of consumption decisions cannot yet be assessed.

Interventions targeting non-price motives can be addressed with the currently operational models only through complementary assessments. The simplest option is to impose a specific change in behaviour without making explicit how it comes about, for example a preference shift away from meat. Complementary assessments are then needed to determine how large a shift can be expected, possibly based on changes in past demand patterns, or sensitivity analyses can be done exploring the implications of a range of shifts. A more advance treatment would not only provide quantitative guidance on shift in consumption but also on the (monetary) costs entailed in achieving this shift and possibly on the allocation of these costs (i.e. who pays for the implementation costs of the intervention).

Since none of the models treats non-price motives in an explicit way they cannot be used to determine for example whether providing information will be a more effective way of altering diets than increasing the convenience of particular foods. If, however, from complementary studies both the impact on consumer decisions and the costs of a specific measure is known and which actor incurs this cost, the models can provide an assessment of its impact on the food system and rank the interventions. For example, if a change in packaging will increase attractiveness for the consumer (modified elasticities capturing increased demand) while also raising production costs (translating into higher consumer prices which lower demand), the direct impact on the product (demand and equilibrium price) as well as indirect impacts on demand for other products can be determined.

3.5 Drivers of primary producer behaviour

Similar to the variations in how consumers and food are defined the models differ in how they model primary producers, if accounted for at all. Another key point of divergence is in the inputs being explicitly considered, the production equivalent of the variation in food definitions for consumers. In terms of producer motivation the models are unanimously assume profit maximization as the sole aim of production, but vary considerably in operationalising producer decisions.

3.5.1 Defining the primary producer

Similar to defining consumers the models differ in how they define producers due to varying origins of the models. The two consumer-oriented models, SHARP and DIET, do not cover production of (primary) goods while in GLOBIOM and CAPRI it forms the focal point of the modelling effort.

GLOBIOM models global production at a high spatial resolution, using Simulation Units which are comparable pixels of land in terms of key characteristics (country, altitude, slope and soil class and located in the same 0.5° x 0.5° pixel). For the EU member states this can be further detailed in a 1x1 km grid, although typically a NUTS2 aggregation is used. Given a chosen aggregation, each of the simulation units functions as a producer choosing a combination of land management systems.

CAPRI has most of its detail in modelling EU agriculture at NUTS2 level while European environmental impacts can be further downscaled to a 1x1 km grid. Production in the rest of the world is modelled at national or larger aggregates. Again the simulation units, NUTS2 or more aggregated for the rest of the world, are treated as producers deciding on what to grow with which technology.

CAPRI has an option of disaggregating the NUTS2 regions into different farm types to capture heterogeneity in farm responses and income developments.

MAGNET has less detail on primary production (fewer products) and no spatial references apart from country delineations. The product or output is taken as the simulation unit, being it primary production, mining, manufacturing or services. For example, all wheat produced in a country is assumed to originate from a single national wheat producer. Variations in production circumstances within a country (land quality, water availability etc.) are thus not accounted for.

While farmers immediately come to mind when talking about producers of food, only CAPRI allows for a farmer-focussed assessment through its farm type layer for European farmers. More commonly producers are either bits of land (GLOBIOM and normally CAPRI) or national level sectors (MAGNET). Specific farmer characteristics, like education or preferences for specific production practices, are thus generally not explicitly accounted for. Characteristics like smallholder versus industrial production can be implicitly accounted for if these systems are characterized by different technologies or input use. Then the choice of production technology on a specific piece of land does implicitly say something about the type of producer involved.

3.5.2 Defining inputs

Where the consumer decides among foods (and other products) to buy, the producer decides among inputs for production. Again the level of detail has a strong impact on the type of assessments that can be made. To compare the scope for economic feedback mechanisms and environmental assessments it is useful to distinguish two types of inputs: intermediate inputs and production factors or endowments.

Intermediate inputs are produced by other sectors, for example fertilizers are an output of the chemical industry. Changes in the use of fertilizers in agriculture will thus have repercussions for the chemical industry with a potential feedback effect on agriculture. Apart from (economic) feedback loops with other producers, intermediate inputs are relevant for environmental assessments since there may be emissions and other environmental impacts in the production and transport of fertilizers.

Production factors, or endowments, are land or natural resources, labour and capital goods. They differ from intermediate inputs in that they do not become part of the product and generate income-related feedback loops to the owners of the factors (affecting income distribution). Generally, the production process is assumed not to change the qualities of the production factors, e.g. the number or productivity of labourers is assumed not to be affected by the work they perform. There is thus not feedback over time through production–induced changes in production factors.

The two spatially explicit models capture local variations in land quality and other location-specific production circumstances (climate, water availability etc.) not possible with the national representation of production in MAGNET. Spatial detail also increases the scope for environmental assessments which are often location-specific, and can be made at the 1x1 km grid in Europe and 0.5 degree globally (GLOBIOM) or for the EU (CAPRI and GLOBIOM).

Neither GLOBIOM nor CAPRI explicitly accounts for labour use in production and thus cannot trace changes in wage incomes nor employment. MAGNET in contrast distinguishes different types of labour (at least by two skill levels) both in primary sectors and in the rest of the economy, tracing changes in income distribution and employment by sector.

3.5.3 Production decisions

The theoretical basis for modelling the producer side by SUSFANS models is uniform; CAPRI, GLOBIOM and MAGNET all assume profit maximization by price-taking producers[1] under constraints on production factor availability. Thus prices are again the key mechanism for influencing production decisions and producers are assumed to act rational with full information on all relevant prices, as well as having full knowledge on the link between inputs and outputs. In the standard set-up of the models there is thus no uncertainty on agricultural yields, for example due to the weather impacts.

This determinism of yields, or absence of stochastics, is linked to the design of these models to study longer term reactions to changing circumstances as opposed to short run predictions of prices. With certain yields the models are thus not suited to analyse short run – less than one year - supply issues linked to a current drought or speculation in agricultural markets, but are designed to explore future developments in production and prices when for example climate change alters the production circumstances in a permanent manner.

Short-run volatility of agricultural markets can be a key concern for policy-makers - their impact on food prices can have large societal repercussions. If long run projections of prices are hiding strong volatility this may alter the policy implications for sustainable and healthy diets. Building on earlier work on uncertainty of future yields (Ermolieva et al. 2016, Fuss et al. 2015) the AGRIPRICE4CAST model is developed in WP8 of SUSFANS to establish future

[1] Over the course of SUSFANS an imperfect competition module will be added to MAGNET which will allow for producers in selected markets to affect the price.

volatility around the long run projections. It uses macro-economic variables from GLOBIOM at a high spatial and time resolution as input into a non-structural model estimating price volatility to forecast future volatility of prices. This combination of GLOBIOM and AGRIPRICE4CAST partly addresses the absence of stochastics in the long run modelling exercises.

Although the theoretical model of profit maximisation is shared across the models, the way in which production technologies are captured varies considerably. The economy-wide focus of MAGNET comes at the expense of technological detail which is subsumed in a nested constant elasticity of substitution (CES) production tree. This single national level production function summarizes all available technologies to produce a specific output through a (sometimes rather extensive) set of substitution elasticities among inputs.

In contrast CAPRI and GLOBIOM both have an explicit treatment of production technologies by specifying technical coefficients, i.e. the amount of inputs needed to produce one unit of output (Leontief production functions). By including multiple technologies, for example high and low intensity production, the models can adjust the yields based on relative prices of inputs. The explicit definition of technologies eases the link to sector specialists or engineers, more familiar with these descriptions of technologies than the implicit nested CES treatment in MAGNET.

Due to their different origins, CAPRI and GLOBIOM vary where production decisions are developed in more detail. CAPRI has been designed to assess the CAP and thus has most richness in capturing details of the CAP policies on European agricultural production decisions. In case the economy-wide implications of the CAP are of interest the dedicated CAP module in MAGNET (with less product and regulatory detail but including feedbacks into non-primary sectors) can be used. GLOBIOM is designed for studying the competition for land from a global economic and environmental perspective and thus has the same level of detail in representation of the EU agricultural sector as for the rest of the world, but also substantial detail on non-agricultural land uses, incl. forestry, and their environmental implications. MAGNET has the most extensive coverage of the economy adding the links between primary and non-primary sectors through demand for intermediate inputs (up-stream and down-stream links) as well as competition for labour and capital. If the economy-wide implications of emission restrictions are of interest the emission module can be used (with less detail and coverage for primary sectors than GLOBIOM but again capturing feedbacks beyond the primary sector).

While varying in amount of detail or sector coverage, all three models assume that production decisions aim at profit maximization constrained by technological possibilities and availability of resources having full knowledge on the link between inputs and outputs. Other possible drivers of producer decisions, like supporting biodiversity or animal welfare, are not accounted for unless they are explicitly introduced in (alternative) production technologies or imposed through regulations limiting the producer decisions when maximizing its profits.

3.5.4 So what drives primary producer behaviour in SUSFANS toolbox models

In terms of definition of primary producers and inputs the three models covering production complement each other with varying detail and emphasis. Table 2 summarizes the main drivers of producer decisions as captured in the SUSFANS toolbox. GLOBIOM is best positioned for global environmental analyses with a high spatial resolution, CAPRI captures best European agricultural production and its reactions to the CAP while MAGNET traces feedbacks between the primary sectors and the rest of the economy through intermediate input use and competition for labour and capital.

In terms of leverage points for interventions the models are naturally set-up for monetary incentives (taxes and subsidies) due to the pivotal role of prices in production decisions driven by profit maximization. Alternatively regulation can be implemented to steer producers in a desired direction, with the level of detail at which the intricacies of specific of policies can be captured varying by model.

The explicit descriptions of technologies in CAPRI and GLOBIOM among which a choice is made based on minimizing costs offers less obvious scope for incorporating non-profit drivers of producer decisions compared to the case of the consumer where non-price concerns are implicitly accounted for in all models through the price and income elasticities of demand. The implicit description of technologies with substitution elasticities in MAGNET would allow for an adjustment of price responses due to non-price concerns similar to the approach for capturing non-price consumer concerns (again based on complementary analyses supporting a change in elasticities to reflect non-price concerns), but with limited detail in terms of products and none at sub-national level.

New technologies can be incorporated in all models, albeit with varying detail. In CAPRI and GLOBIOM new technologies can be fully specified and offered as an alternative for currently used technologies leaving it up to the model to decide whether or not to adopt the innovation. The implicit treatment of technologies in MAGNET only allows imposition of an adoption through a shift in production functions and/or change in substitution elasticities, or through the definition of a (small but non-zero) new sector producing a distinct new product. None of the models as currently used, however, accounts for the costs and time-lags in developing and adoption of new technologies[2]. These costs (and possible time-lags which can be considerable) thus need to be imposed exogenously.

Table 2: Drivers of producers captured by the SUSFANS models

	SHARP	DIET	GLOBIOM	CAPRI	MAGNET
GDP	-	-	X	X	E
Price of land	-	-	E	E	E
Price of water	-	-	E	X	-
Price of labour (wages)	-	-	I	I	E
Price of capital	-	-	I	I	E
Agricultural land availability	-	-	E	E	E
Agricultural labour use	-	-	I	I	E
Production technologies	-	-	C	C	S
Farm characteristics	-	-	-	R	-
Contract opportunities	-	-	-	-	-
Regulatory environment	-	-	X	X	X

Notes: - = not applicable; **E** = endogenously determined inside the model; **X** = exogenously determined outside the model; **I**= implicit part of production cost lumped with other non-specified inputs; **C** = competing technologies explicitly defined; **S =** substitution elasticities implicitly define competing technologies; **R** = representative farm types can be included.

3.6 Drivers of the food chain actors

So far we discussed the two end points of the food chain, consumers and primary producers. The food supply chain links these two parts, transforming primary produce into food products delivered to consumers.

3.6.1 Defining the supply chain

The supply chain transporting and transforming primary products receives scant attention in long run modelling exercises. CAPRI and GLOBIOM focus on

[2] Outside of SUSFANS a module for endogenous technical developments linked to public R&D expenditures and accounting for time-lags in adoption and is being developed (Smeets Kristkova, Van Dijk, and Van Meijl 2016).

primary products, each having a limited number of processing sectors linked to biofuel or feed production. Using the FAO food balance sheets final demand is expressed in primary product contents without all detail in actual products holding these primary contents. This serves their needs of capturing consumer demand when analysing changes in primary production, but does not allow for an analysis of transformation and transport along the food supply chain.

MAGNET covers all production activities in the economy, including processing, transport and retail. Modelling of the food supply chain, however, has not been an explicit focus of the data collection nor modelling effort. The MAGNET database thus includes a limited number of explicit processing sectors with most detail in animal-based products. The majority of purchased food moves through a single processed food sector, severely limiting the ability to capture variations across processed food in quality or nutritional value. In terms of outlets there is also limited detail, retail and food related services are each part of a larger aggregate service sector thus hiding the details of the supply chain.

In short, the SUSFANS models reflect the traditional approach of equating primary products with food, a thinking which still dominates the policy and regulatory landscape. This makes the models less suited for capturing recent developments where food is becoming an industrial output, not only in Europe and other high income countries but increasingly also in the rest of the world (Gollin and Probst 2015; Reardon 2015). Complementary analyses of the missing or limited link between agricultural output and food on consumers' plates are needed for a full understanding of the food system dynamics and its implications for diet quality. Such analyses are however hampered by a lack of data on the development of the links between producers and consumers (Swinnen 2015).

3.6.2 Supply chain decisions

No or limited detail in the representation of the food supply chain actors also limits the scope for modelling decisions along the chain. MAGNET assumes profit maximization of price-taking producers (perfect competition assumption) for all producers and represents every sector by a single producer, as discussed above. Concerns regarding the concentration in food manufacturing and retailing creating monopolies (Swinnen 2015) cannot be addressed in such a set-up.

Complementary analyses of developments in the supply chain will be needed to assess how contract negotiations affect prices and/or production requirements (e.g. labelling of products based on production or trading practices). Their implications for primary production and consumers can then be assessed by imposing these outcomes on the producer and consumer focussed SUSFANS models as discussed above.

3.6.3 Drivers of change in the food supply chain

Limited representation of the food supply chain in the SUSFANS models also limits the ability of the current modelling toolbox to capture drivers of the food supply chain (see Apart from analysing how the functioning of the supply chain affects consumer and primary producer decisions, the limited product detail on processed food complicates establishing a link between the consumer models rich in product detail and the production focussed models rich in environmental indicators. The limited representation of food supply chain also hampers tracing of food and nutrition losses during different stages if transport and transformation.

This limited representation of the links between farmers and consumers is not specific to the SUSFANS modelling tools, but characteristic of data collection and research efforts as well as policy focus. For example, a recent paper by Reardon et al. (2016) shows that the agri-food processing sectors in Asia account for a larger share in energy use than primary production, which has been the focus of both energy saving research and policy interventions.

Table 3). Apart from the aggregate treatment in MAGNET none of the models explicitly models the transformation of primary produce into food purchased by the consumer. Models are either limited to modelling in detail consumption (SHARP, DIET) or model consumption by proxy of the primary equivalents of purchased food (CAPRI, GLOBIOM).

Given this limited representation the models need to be complemented by studies on the functioning of supply chains. If these can be translated into price and/or product characteristics relevant for primary producers or consumers their impact on the food system can then be assessed with the SUSFANS modelling toolbox.

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Table 3: Drivers of food chain actors captured by the SUSFANS models

	SHARP	DIET	GLOBIOM	CAPRI	MAGNET
Processing & retail sectors	-	-	-	-	E
Imperfect competition	-	-	-	-	D
Contract opportunities	-	-	-	-	-
Regulatory environment	-	-	X	X	X

Post farm-gate biomass and nutrient flows	-	-	-	D	E

Notes: - = not applicable; E = endogenously determined inside the model; X = exogenously determined outside the model; D = developed in course of SUSFANS, cannot be assessed yet

3.7 What drives the model-based SUSFANS metrics

The SUSFANS modelling toolbox allows ex-ante assessments of changes in metrics measuring European SFNS. This assessment hinges on the adjustment mechanisms incorporated in the models, driving the changes in the model variables feeding into the SUSFANS metrics. This first part of the model assessment focuses on how decisions of key actors are quantified: consumers, primary producers and the food supply chain. It is these decisions which ultimately drive the changes in the model-based SUSFANS metrics.

The models in SUSFANS are mostly complementary in their definition of the actors (who or what decides on food or input choices) and specification of the production possibilities. Combined the models offer a breadth of coverage with regard to consumer and primary producers. A limited or missing link is the representation of the food supply chain transporting and transforming primary produce in food. This not only limits the leverage points for interventions captured by the models, it also makes the linking of models with a producer and consumer background less obvious. This limited coverage of the supply chain reflects current research and policy discussions as well as data availability.

The standard neoclassical economic paradigm of utility and profit maximization dominates the modelling approaches. As a result prices are the key variable linking various actors to each other and being a first choice for steering the food system in a specific direction. Apart from (endogenous) prices the models can capture the impact of more or less autonomous macro developments like population and aggregate income growth (GDP) or climate change on food systems.

Being founded in the neoclassical economic paradigm additional studies are needed to study how non-price determinants of consumer behaviour (taste, convenience, health concerns etc.) affect the food system and may be altered by interventions. Similarly additional studies are needed on the workings of the food supply chain, how it affects the transmission of signals from consumers to producers (and vice versa) and how it affects production and consumption decisions.

The challenge with these additional studies is to generalize them to an aggregate impact which can be captured by the models. The first option would be in the formulation of alternative scenarios, imposing an alternative response by consumers or producers by (partially) disregarding their behaviour as captured in the models. An example would be imposing a reduced consumer demand for meat, all else held equal and studying its impact on production decisions and environmental impacts.

A second option would be to also specify the costs of achieving this changed behaviour and who bears these costs. For example, assume a massive and thus costly information campaign moves European consumers away from meat. If the campaign is financed by taxing the retail sector it will (through upstream linkages) affect all meat producers (EU and non-EU), while financing through a tax on European meat producers will put them at a disadvantage compared to non-European meat suppliers.

A third and more challenging option would be to translate the additional studies into modified behavioural responses at the aggregate level at which the models operate. To continue the meat example, a translation of an information campaign into an altered price and income elasticity for meat consumption. If the costs of the campaign are also included the models can then fully explore its implications for the food system and trade-offs with other policies. Translation into changed behavioural parameters instead of imposing a specific demand pattern also allows capturing of rebound effects where feedback loops may (partially) undo an initial change in demand.

USING THE SUSFANS MODELLING TOOLBOX TO QUANTIFY THE SUSFANS SFNS METRICS

The SUSFANS project developed a set of performance metrics allowing an assessment of the sustainable food and nutrition security (SFNS) status of the EU food system (see D1.3). SUSFANS detailed in its conceptual framework (D1.1) that SFNS is constituted of four societal policy goals that shape the food system as different actors inside and outside the system push for change. The performance metrics were selected to show how the EU food systems fares with respect to achieving the targets that the policy goals have outlined, now and in the future. In addition they can be used to monitor if and how any of the measures introduced to the food system to achieve the outlined policy goals show results across all four sustainability spheres, thus also revealing not anticipated and/or unintended consequences across policy goals.

The performance metrics are based on a hierarchy of indicators and variables which aggregate into a small number of metrics that are easy to understand and communicate and give a quick overview of food system performance. This hierarchical approach is summarized in Figure 2 while details of the approach are described in deliverable D1.3.

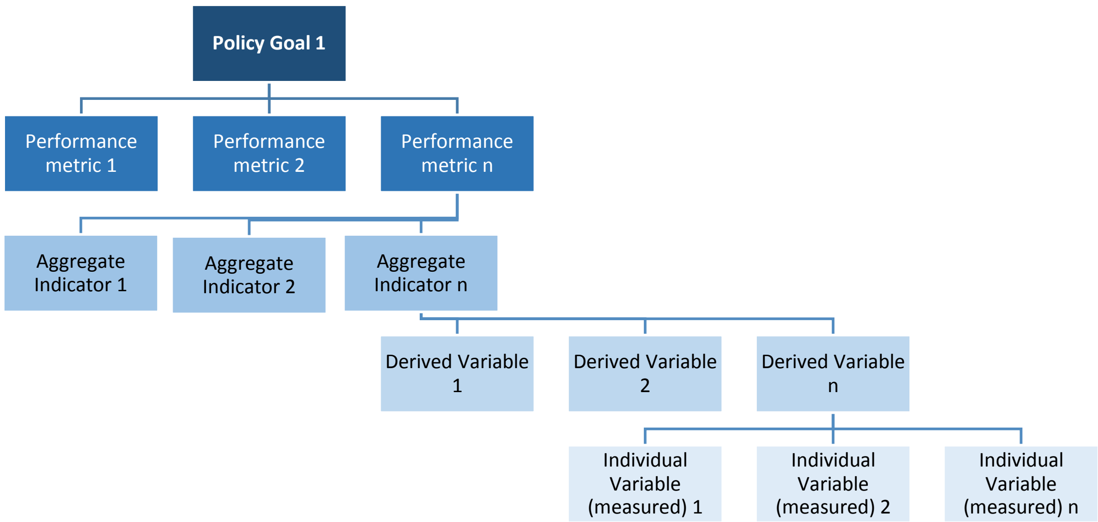

Figure 2 The SUSFANS hierarchical approach to metrics for assessing SFNS in the EU

Underlying each performance metric are a large number of variables based on an even larger set of data needed to quantify the variables. As described in Section 2 SUSFANS has five different models in its toolbox to assess the performance metrics. Based on the purpose for their development and their history the models cover different domains (also see **Error! Reference source not found.**, introduction) and therefore can be used to estimate different metrics. For example, GLOBIOM and CAPRI were both developed to report on agricultural production questions and incorporate a large number of environmental issues related to agricultural production such as land cover or GHG emissions. Thus there is quite a bit of overlap between these models, at least for Europe, in that the same variables and therefore performance metrics can be covered by two or more models (Table 8). As the performance metrics cover people, planet and profit dimensions (see **Error! Reference source not found.**) none of the models though can be used to estimate all performance metrics (Table 8). But the SUSFANS toolbox as a whole, combining the strength of each model, will be able to quantify almost all performance metrics.

To gauge the scope of each model to assess the different performance metrics we will first discuss the model coverage of the individual variables constituting each of the four policy targets, referring back to the strengths and weaknesses of the models discussed in Section 2. We then take a step back, summarizing the coverage of the metrics by the models and identifying areas where complementary analyses are needed to arrive at a complete assessment of (future) EU SFNS.

3.8 Balanced and sufficient diets for EU citizens

Three performance metrics are used to assess the diets of EU citizens (

Table 4). The first is food-based, assessing per capita food consumption for key food groups using generalized dietary guidelines (derived in D2.2) as cut-off points. SHARP not only covers all variables[3], it is also the only model which uses individual level intake data and can thus also take diverging diet needs of sub-groups into account. All other models rely on household level purchases (DIET) or production side calculations of available food (CAPRI, GLOBIOM, MAGNET).

[3] In the case of salt and vitamin D only the food-based intakes are taken into account, excluding for example salt added during cooking or consumption and vitamin D availability from sun exposure.

Table 4 Individual variable coverage for balanced and sufficient EU diets

Performance metric	Individual variable	SHARP	DIET	CAPRI	GLOBIOM	MAGNET
Food based summary score based on 5 key foods	Vegetables (≥200 g/d)	I	P	A	A	A
	Legumes (≥150 g/week)	I	P			
	(Unsalted) nuts and seeds (≥15 g/d)	I	P			
	Fruits (≥200 g/d)	I	P			
	Fish (≥150 g/week)	I	P	A	A	A
	Dairy (≥300 g/d)	I	P	A	A	A
	Red/ processed meat (≤500 g/week)	I	P	A	A	A
	Hard cheese (≤150 g/week)	I	P			
	Sugar sweetened beverages (≤500 mL/week)	I	P			
	Alcohol (≤10 g/d)	I	P			
	Salt (≤6 g/d)	Ip	P			
Nutrient based summary score	Energy	I	P	A	A	A
	Protein	I	P	A	A	A
	Mono-unsaturated fat	I	P	D		
	Fibre	I	P	D		
	Calcium	I	P	D		
	Iron	I		D		
	Magnesium	I		D		
	Potassium	I		D		
	Selenium	I		D		
	Iodine	I				
	Zinc	I		D		
	Vitamin A	I		D		
	Vitamin C	I		D		
	Vitamin E	I		D		
	Vitamin B1	I				
	Vitamin B2	I				
	Vitamin B6	I		D		
	Vitamin B12	I		D		
	Folate	I		D		
	Vitamin D	Ip		D		
	Sodium	I	P	D		
	Saturated fat	I	P	D		
	Total sugar	I	P	D		
	Protein, plant	I	P	A	A	A
	Protein, animal	I	P	A	A	A
	Saturated Fatty Acids (SFA)	I	P			
	Mono-Unsaturated Fatty Acids (MUFA)	I	P			
	Poly-Unsaturated Fatty Acids (PUFA)	I	P			
Energy Balance	BMI (body mass index of each country)	I	P			

Note: I = based on intake data; Ip = variable only partially measured by the computations from food intake; P = based on household purchase data; A = based on aggregate availability from production data; D = under development

Although SHARP is clearly the preferred supplier for the EU diet related metrics, it can only provide these for the current (observed) situation as a stand-alone model. To assess the adequacy of future EU diets inputs from the other models on changing consumption patterns in relations to changes in the food system or overall economy are needed. Furthermore, in the context of SUSFANS SHARP is parameterized four case-study countries out of the 28 EU member states. Although these are chosen to reflect contrasting diets in the EU, an aggregation procedure is needed to arrive at an EU-level assessment.

By establishing a link between SHARP and the other models the mutual strengths of the models in assessing EU diets can be exploited. In this context the partial overlap in indicators across the models will be pivotal by providing common ground to connect model results. Both for the aggregation to EU level as well as for future diets the production based assessments from CAPRI, GLOBIOM and MAGNET provide the total availability of foods with varying nutrient content which can be used as control totals for the SHARP results, whereas DIET provides an idea of purchases and likely substitutions at a detailed product level to aid the translation from the macro to micro level. The overlap of several indicators using current data allows for a correction to intake and nutrition assessments of the macro models using the SHARP results to compare the macro production side estimates to actual intakes.

3.9 Competitiveness of EU agri-food business

A second EU-focused set of performance metrics is linked to the economic performance of the EU agri-food business (
Table 5). SHARP and DIET are not included in the table. Being consumption side models they do not provide production side variables.

There is quite an overlap in the coverage of the competitiveness metrics, with CAPRI and MAGNET both covering all variables for EU member states. The main difference between the models is the varying level of detail, as discussed above in Section 2. CAPRI and GLOBIOM both have a higher product resolution for the agricultural sector, allowing more sector detail when assessing competiveness. MAGNET has less primary sector detail but captures economy-wide feedbacks, like the impact of growth in other sectors on input costs for agricultural sectors. All three models can provide assessments at both EU and member state level.

A clear limitation of the three models is the lacking, or very aggregate in the case of MAGNET, representation of the supply chain beyond the primary producers, as discussed in Section 2. This implies that the detailed assessments of competiveness are only available for the primary producers and not for sectors further along the supply chain towards the consumers.

Table 5 Individual variable coverage for competitiveness of EU agri-food business

Performance metric	Individual variable	CAPRI	GLOBIOM	MAGNET[A]
Production and trade	Openness of country i for sector k (%)	G	G	G
	Self–Sufficiency ratio of the country i for sector k (%)	G	G	G
Trade	Export share of country i of sector k to the world (w) in year t	E	G	G
	Trade balance of country i in period t is the sum of export minus all imports of sector k (US $)	G	G	G
	Normalized trade balance of country i in period t is the sum of export minus all imports of sector k	G	G	G
	Revealed Comparative Export Advantage (RXA) indicator for sector k, country i in period t	G	G	G
	Revealed Comparative Import Advantage (RMA) indicator for sector k, country i in period t	G	G	G
	Revealed Net Trade Advantage (RTA) indicator for sector k, country i in period t	G	G	G
Production	Real value added for sector k in in country i for period t (US $)	G		G
	Total factor productivity for sector k in in country i for period t	G		G
	Real labour productivity for sector k in in country i for period t (US $ VA per US $ E)	G		G
	Ratio real value added for sector k in benchmark sector b in country i for period t	F		G
	Ratio real total factor productivity for sector k in benchmark sector b in country i for period t	F		G
	Ratio real labour productivity k in benchmark sector b in country i for period t	F		G

Note: G = global assessment possible based on model's regional aggregation; E = assessment for the EU only; F = assessment only against a food sector benchmark; A = assessments can be made for all sectors in the economy.

For assessing the future competeviness of the EU agri-food sector a combination of CAPRI and MAGNET offers the capacity for sector detail while capturing details of (changing) CAP policies (CAPRI), while at a more aggregate level not losing sight of the impact of changes in the rest of the economy (including an aggregate representation of the entire supply chain) on the agri-food sectors (MAGNET).

3.10 Reduction of environmental impacts

While sufficient food for EU's consumers and decent living for EU's primary producers have always been central pieces of EU policies, environmental objectives have been added when negative impacts of a production focussed policy become more and more obvious. These relate to environmental impacts on European natural resources, but also to global impacts of EU primary production.

All models capture environmental impacts (see Table 6), but with widely varying level of detail and scope for capturing changes. SHARP and DIET include some environmental impacts through indicators linked to food products. These are derived from LCA analyses, assigning observed environmental impacts of production processes to the produced food items. The consumption focussed models do not capture changes in production processes and thus environmental impacts linked to consumer decisions.

Table 6 Individual variable coverage for environmental impacts

Performance metric	Individual variable	SHARP	DIET	CAPRI	GLOBIOM	MAGNET
Climate Stabilization	CO2	I	I	E	E	E
	CH4	I		E	E	E
	N2O	I		E	E	E
Clean air, soil and water	NH3 and NOx			E		
	Emissions of nitrates and organic nitrogen to the water			E		
	Nitrogen balance			E	E	
	Phosphorus balance			E	E	
	Non-mechanical plant protection			E		
Biodiversity conservation	Land use			E	E	N
	The Shannon's entropy index (Hr)			E	E	N
Preservation of natural resources	Green water consumption					
	Blue water consumption				W	
	Fishing pressure					
	Loss of soil with soil erosion.			E		

Note: I = impacts captured by fixed indicators linked to food products; E = impacts modelled endogenously; N = land use not spatially explicit but based on national land availability; W = irrigation water only.

The other three models all have a production focus and capture endogenous changes in environmental impacts when producers change their activities, for example in response to a change in consumer demand or in legislation. CAPRI offers the broadest and detailed assessment of the impact of EU agricultural production, either on EU natural resources or in terms of contribution to global GHG emissions. GLOBIOM complements CAPRI by its global focus, allowing an assessment of the environmental consequences of food products consumed in the EU but produced outside of the EU.

The aggregate representation in MAGNET which is not spatially explicit does not add to these two models in terms of primary production assessments, but it does cover the (considerable) GHG emissions of all economic sectors, including manufacturing and transport. Again the overlap across the models can be used when combining the models to assess divergence in initial assessments due to different data sources and/or processing of raw data, to aid a harmonized implementation of different scenarios.

3.11 Equitable outcomes and conditions

The final set of performance metrics covers the social impacts of EU food consumption and production. Similar to the environmental impact these can be social impacts in EU supply chains for foods consumed from the EU, but it can also refer to conditions in supply chains outside the EU in case of imports or effects of EU consumption and production on the food security in the rest of the world through global market effects.

Table 7 presents an overview of a wide range of variables underneath each of the four equity metrics. The coverage by the models reflects their origins in either nutrition (SHARP) or coming from a production focus (CAPRI, GLOBIOM, MAGNET) - none of the models is explicitly developed to asses equity issues.

That being said, partial coverage of all but the supply chain related metric can be obtained. As discussed before none of the models has been explicitly developed to capture the workings of the supply chain and this is reflected in their coverage here. A second reason is that the models do not take farmers as the simulation unit when modelling decisions (as discussed in Section 2), but either a unit of land (CAPRI, GLOBIOM) or the total national production (MAGNET. Equity considerations linked to farmer characteristics are thus not captured.

Table 7 Individual variable coverage for equitable outcomes and conditions

Performance metric	Individual variable	SHARP	DIET	CAPRI	GLOBIOM	MAGNET
Equity among consumers: food system outcomes	Calorie availability by region (EU, non-EU)			N	N	N
	Share of nutritious food by region (EU, non-EU)			N	N	N
	Reduction in share of protein of animal origin by region (EU, non-EU)			N	N	N
	Domestic food production per capita by region (EU, non-EU)			N	N	N
	Share of food expenditure in total expenditures by region (EU, non-EU)			N		N
	Food affordability by region (EU, non-EU)			N	N	N
	Consumption per capita by region (EU, non-EU)			N	N	N
	Share of calories from fruit and vegetables by region (EU, non-EU)			N		N
	Cereal import dependency ratio by region (EU, non-EU)				N	N
	Value of food imports over total merchandise exports by region (EU, non-EU)					N
	Share of population with BMI <18.5	Ie				
	Share of children < 5 years with stunting					
	Share of children < 5 years with iron deficiency					
	Share of children < 5 years with vitamin A deficiency					
	Share of women at reproductive age with iron deficiency					
	Share of women at reproductive age with vitamin A deficiency					
	Share of population with insufficient dietary supply adequacy	Ie				
	Share of population with insufficient protein supply	Ie				
	Share of population with BMI >25	Ie				
	Share of population with BMI >30	Ie				
Equity among consumers: Food system conditions	National income per capita by region as % of EU national income per capita			X	X	N
	Household income per capita by region as % of EU household income per capita					D
	Share of population with less than 1$ a day					
	Share of population that has no access to a health care centre					
	Share of population without access to sanitation facilities					
	Share of female population without primary education	Ie				
	Share of population living in a political unstable surrounding	Ie				
	Share of population without right to social security					
	Share of population that has no access to a safety net (food assistance, pension)					
	Share of population without access to a fresh food shop					
	Share of population whose food preferences are not met by food supply					

Equity among producers and chain actors	Share of farmers without legal status of ownership of the farm land					
	Share of farm women without access to agricultural land					
	Share of farmers without access to microfinance					
	Share of farm women without access to saving and credit					
	Share of farmers without primary education					
	Share of farmers without access to vocational training					
	Share of farmers who are faced with a monopolist downstream industry					
	Share of farmers who are faced with a monopolist upstream industry					
Equity in footprinting of food	Ha of land per calorie consumed	X		S	S	N
	Kg of fertilizer per calorie consumed			S	S	N
	Litre of water per calorie consumed			S	S	
	Unit of emissions per calorie consumed	X		S	S	N
	Share of farmers applying no organic production methods					
	Share of farmers without education in the use of pesticides and fertilizers					
	Share of farmers not applying emission reducing techniques					

Note: N = national level estimates available for all EU, national or supra-national data available outside the EU depending on model's regional aggregation; Ie = data from individual intakes available for EU only; X = exogenous to the model (i.e. adjustments in these variables is not endogenously captured by the model); S = data are spatially explicit.

3.12 Performance metrics model coverage

Stepping back we now turn to an overview of coverage of the four policy goals by the models in the SUSFANS toolbox. Table 8 summarizes coverage of the performance metrics associated with each policy goal by the models, implied by the coverage of individual variables discussed in the previous sections. Aggregation from the individual variables to the performance metrics will be done on the basis of the aggregation pathway described in deliverable D1.3 when the models are run as part of the case studies (WP5) and forward looking scenario work (WP10). The CAPRI team has done an experimental assessment of how to model the environment related set of metrics described in deliverable D4.7.

Both SHARP and the DIET model can estimate the individual variables associated with all three performance metrics for the 'Balanced diet' goal based on different datasets (individual intake data in SHARP versus household supermarket choices for DIET). Although SHARP is clearly the preferred supplier for the EU diet related metrics, it can only provide these for the current (observed) situation as a stand-alone model.

The quantification of performance metrics for the 'Competitiveness goal' can also be done by a number of models. CAPRI can cover the full range of variables needed for all metrics while GLOBIOM and MAGNET can cover all the trade related ones and MAGNET can estimate in addition the 'economic performance of a sector'. The models complement each other in terms of detail of primary sector (here CAPRI and GLOBIOM are strongest), economy-wide coverage (MAGNET) and impact of (changes in) the CAP (CAPRI).

For the 'Reduced environmental impacts' goal the estimation gets more difficult in that there are a number of variables in two of the performance metrics that the models can not cover well. The 'climate stabilization' metric is the best one covered and all five models in the toolbox can estimate the needed variables. The 'clean air and water' metric can be covered by CAPRI and partly by GLOBIOM. The metrics related to 'biodiversity conservation' and the 'preservation of natural resources' cannot be assessed in all their associated variables. 'Biodiversity conservation' can still be estimated through a number of the needed variables but not completely while the 'preservation of natural resources' can currently not be modelled and will have to be assessed qualitatively and using expert judgement.

The performance metrics describing the 'Equity' policy goal are the most difficult ones to model. Of the four metrics only one can be fully quantified while for one metric some partial estimations are possible. This reflects the issue that work done on social justice and equity issues related to food are still a relatively young topic and are hard to quantify with currently available data. MAGNET, CAPRI and GLOBIOM can be used to estimate the variables related to 'equity among consumers: food system outcomes' metric which included all the standard variables used to model FNS. The' 'Food footprint' metric is partially covered by MAGNET, CAPRI and GLOBIOM as deal with various climate and water related variables. 'Equity among consumers: food system conditions 'and 'Equity among producers and food chain actors' will have to be assessed using qualitative methods as none of the model cover at least one of the needed variables. The SUSFANS team still needs to decide when implementing the estimation of all metrics how to do the qualitative assessment, especially when moving from the current status quo to future SFNS.

Table 8. Model coverage of the SUSFANS performance metrics

Policy goal	Performance metrics	Models able to assess performance metric[1]
Balanced and sufficient diet for EU citizens'	Food based summary score based on 5 key foods (0-100): fruits, vegetables, fish, red & processed meat intake, sugar sweetened beverages)	SHARP, DIET, CAPRI
	Nutrient based summary score (0-100): NRD 9.3 and NRD 15.3	SHARP, DIET, (CAPRI, GLBIOM partly)
	Energy balance: % of population with normal weight: 100% is 'ideal'	SHARP, DIET
Reduction of environmental impacts	Climate stabilization	GLOBIOM, CAPRI, DIET, MAGNET (SHARP)
	Clean air and water	CAPRI (GLOBIOM)
	Biodiversity conservation	(CAPRI, GLOBIOM, MAGNET)
	Preservation of natural resources	(GLOBIOM)
Competitiveness of EU agri-food business	Production and trade	GLOBIOM, CAPRI, MAGNET
	Trade - Export flow orientation	GLOBIOM, CAPRI, MAGNET
	Trade - Trade orientation	GLOBIOM, CAPRI, MAGNET
	Trade - Trade specialization	GLOBIOM, CAPRI, MAGNET
	Production - Economic performance of a sector	CAPRI, MAGNET
	Production - Productivity cross-sector benchmarking	CAPRI
Equitable outcomes and conditions	Equity among consumers: food system outcomes	MAGNET, CAPRI, GLOBIOM (SHARP)
	Equity among consumers: food system conditions	No model
	Equity among producers and chain actors	No model
	Equity in food footprint	(GLOBIOM, MAGNET, CAPRI)

[1] Model names in brackets signal that model cannot quantify all individual variables composing the performance metric.

CONCLUSIONS AND OUTLOOK

In this paper we examine the models in the toolbox of the SUSFANS project in terms of their ability to quantify the metrics selected to assess the performance of the EU food system with respect to achieving SFNS. As the selection of the metrics was not based on the premise to select only metrics that could be modelled, but rather arose from a normative perspective of what should be assessed in order to provide a balanced perspective to decision makers of the status of the EU food system (also see D1.3), the SUSFANS team assess in this paper the strength of the five models in the SUSFANS toolbox based on their history and development objectives.

The models in SUSFANS are mostly complementary in their definition of the actors (who or what decides on food or input choices), ranging from individual level consumption decisions to detailed spatially explicit production decisions and global economy-wide feedback mechanisms. While none of the models can assess all policy goals on its own the SUSFANS toolbox as a whole, combining the strength of each model, will be able to quantify almost all performance metrics. A partial overlap in indicators across the models will be pivotal by providing common ground to connect model results.

The models in the SUSFANS toolbox have two important limitations that need to be acknowledged as these affect the metric assessment and show where future research is needed. First, prices (and incomes) play a key role in the model responses and thus in the quantification process of changes in the metrics, while assuming perfectly rational behaviour of actors having perfect information (see the discussion on drivers in section 2). Non-price considerations (like taste, social norms, sensitivity to health issues, convenience etc.) are captured by their combined impact on estimated consumer and producer responses to price changes, and summarized by the elasticities used in the models to quantify reactions to price changes. This focus on prices is due to a lack of data on consumer and producer responses to non-price incentives with the product and regional coverage needed by the models. This lack of comprehensive data prohibits a disentangling of the impact of different non-price incentives on observed consumption and production decisions. As outlined in more detail in section 2, complementary analyses on how non-price incentives affect behaviour are needed to be able to assess their implications for the food system. While counterfactual analyses with the models allow exploration of potential impacts of non-price drivers, a key future research challenge is to get reliable assessments of non-price drivers of actual consumption and production decisions with a coverage (products and regions) comparable to the models' scope. Unpacking the various non-price drivers not only deepens the understanding of consumption and production decisions, it also allows identification of the most effective non-price leverage points for steering the EU food systems towards the policy goals.

A second issue is that the models in the SUSFANS toolbox cover the primary producer as well as the consumer end of the food system well, while the food chain actors are not very well represented. This limited representation of the value chain may affect the accurate quantification of a number of the performance metrics, for example around the competitiveness of the agri-food businesses or with respect to the environmental impacts when emissions along the chain are missed in the calculations. As with the focus on prices, the SUSFANS models reflect the current state of research and data availability. Properly addressing the large heterogeneity across supply chains in applied simulation models is challenging both in terms of capturing strategic behaviour as well as data needed to quantify each step in the chain, let alone their power over price formation up and down-stream.

While fully addressing the non-price drivers of decisions and detailed modelling of supply chains falls beyond the scope of the SUSFANS project, advances will be made in both areas by incorporating insights from the work packages focussing on consumer (WP2) and supply chain (WP3) drivers, specifically when defining the case studies and scenarios to be analysed with the models in WP5 and WP10, and by placing the changes in metrics in context of data availability and model abilities.

Overall the SUSFANS modelling tools allow for a comprehensive assessment of the SUSFANS performance metrics and the corresponding individual variables in a quantitative manner. In the majority of cases the variables needed to quantify specific performance metrics can be derived from more than one model. This allows the team to choose the most appropriate model for the estimation, based on the particular strength of each modelling tool. It furthermore allows using results from other models to cross-check results or aggregation procedures, especially in cases where different data sources are used.

That said there are a small number of variables and with that performance metrics, particularly associated to the goal of 'Equitable outcomes and conditions of the EU food system,' where none of the models can quantify all variables. This leaves the team with the challenge to find ways to qualitatively derive the variables needed from a variety of available data, as well as exploring options for forward looking assessments of these variables. In the implementation of the modelling strategy to present an integrated set of metrics (to be laid out in D1.5) the SUSFANS team will decide how to proceed on this front. One possibility would be to map out a set of causal relationships between the proposed variables, indicators and performance metrics using expert knowledge, literature reviews and/or Bayesian Belief Networks. These could be captured by developing causal maps, influence diagrams or System Dynamics Models (personal communication A. Helfgott, Hester and Adams 2017). Then existing data could be used to test hypotheses about these causal relationships and variables could be aggregated up to performance metrics in the same way as presented in D1.3 for all performance metrics.

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ANNEX – DETAILED DESCRIPTION BY MODEL

SHARP

Information for SHARP model provided by Marianne Geleijnse (WUR), Anneleen Kuijsten (WUR), Pieter van 't Veer (WUR).

Theoretical framework

Most models on SFNS focus on the average production and per capita consumption, with the latter sometimes modelled for specific households. This serves to model and evaluate potential for sustainable production. However, this approach is not refined enough to model and evaluate nutrition security and dietary quality for public health in EU Member States. To arrive at models that account for the dietary quality and the potential impact on public health few models are available. The aim of the SHARP model is to enable modelling and evaluation of consumer diets for impact on public health and environmental sustainability, taking into account food consumption data rather than food production data.

SHARP models diet for EU consumers in sub-regions are based on individual-level data; such diets are environmentally Sustainable, Healthy (nutritional adequacy), Affordable (within the financial means of people), Reliable (secured access to the food supply via food outlets, retail, supermarkets, etc.), and Preferred by consumers (consistent with cultural norms and preferences). Designing a SHARP diet requires quantitative methods and models to evaluate the relationship and trade-off between multiple conflicting indicators that represent adequately the environmental, economic and social nature of a SHARP diet. To achieve this, existing diet models are extended to account for multiple objectives (Gerdessen, 2015a; Gerdessen, 2015b). Several mathematical techniques will be used to quantify trade-offs between important health, economic and environmental indicators. The trade-offs will provide information about how much one indicator can improve without worsening the value of other indicators.

First the dietary patterns will be evaluated from what is feasible from the viewpoint of Sustainability and Health. This will be based on indicators that reflect planetary boundaries (like GHGe, land use, etc.) and nutritional adequacy (nutrient requirements, food based dietary guidelines, energy balance, etc.). This will help to identify inefficiencies of current diets and identify the potential for improvement in these two SHARP dimensions simultaneously (win-win situations). Moreover, the model will be generic and applicable in higher level application using information and data available at national, EU or global scale.

Second, the model will explore options to incorporate consumer's dietary choices using constraints on affordability, reliability and preferability (ARP). The challenge here is to identify datasets and/or elicit heuristics to formulate realistic constraints to the model. This second modelling phase will assess the potential of a diet to be adopted by different groups of consumers, and could be modelled using indicators like food prices, meal composition, changeability of diets, etc. Alternatively, these analyses could also be conducted based on demographic factors (like age, sex, socioeconomic level) that tend to reflect lifestyles of consumers groups at a higher level of aggregation. The analyses will be addressing questions like: will specific consumer groups take the additional costs of a more environmental friendly diet?

To develop the SHARP-model, existing Mathematical Programming diet models will be adapted and new methods will be developed to enable calculation of efficient alternative diets and at the same time provide support on appropriate diets for different target groups. The models will be calibrated to observed dietary choices of individuals using existing (multi-objective) techniques. Optimization of a utility function can be used to articulate the preferences of a decision maker and provide insights in scenario studies and forecasting. Determining the unknown parameters of the utility function, likely to be non-linear, is a challenging process that involves substantial interaction with decision makers.

In the case of designing SHARP diets the consumer is not available for participating in such interactive processes. Kanellopoulos et al. (Kanellopoulos, 2015) proposed a non-interactive calibration technique based on Compromise Programming to recover unknown coefficients of a non-linear approximation of utility function using a limited dataset of observed historical decisions. The non-interactive calibration technique will be explored when developing the SHARP diet model. The calibration and forecasting capacity will be evaluated in ex-post exercises i.e. the model will be calibrated for observed historical decision and used to forecast changes that occurred also at the past (Kanellopoulos, 2010). Comparing results of the model with observed historical decisions provide information about the capacity of the calibrated diet model to forecast dietary changes in different scenarios. The challenge will be to deal with discrete (integer) variables that are very common in existing optimization diet models

Direct drivers of food system actors

Consumers habits play a key role in driving the demand of food. Mediated by the supply chain actors, they indirectly influence the food processing and production. Determinants of nutritional exposure have recently been reviewed and conceptualized in the DONE framework (Stok, 2017). This framework categorizes over 50 types of determinants that were sub-classified into 4 main themes (and 12 subgroups), i.e. individual level (biological, demographic, psychological), interpersonal level (social, cultural), (food) environment (product, micro, meso/macro) and (food) policy (industry, government). Incorporating such (categories) of determinants into modelling is hindered by lack of (international) standardization of assessment tools. International comparisons tend to be limited to social surveys, whereas associations between determinants and dietary patterns tend to be limited to (few) multicentre studies. Thus, to describe dietary patterns the focus is necessarily limited to (1) meal composition combined with expert knowledge on food intake data, (2) changeability of food pattern over long period of time (FAO per capita data), and (3) (emerging) data on food intake based on purchase records of individual consumers.

Apart from consumer habits, health status of people is a determinant of food and nutrient intake. In apparently healthy people, a disturbed energy balance is an indicator of an unbalanced diet and/or food environment and can be summarized by BMI as a summary indicator and risk factor for a number of diet-related chronic diseases, among which diabetes (type 2), cardiovascular and some malignant diseases.

From an economic perspective, government policies that affect the market environment tend to show positive results and modest effects were seen for fruits in school environments. Effects of taxing (e.g. on foods high in salt, sugar and fat) and subsidies on (healthy) foods may influence food choice and are potentially cost saving, but may be less effective in the lower income groups; moreover, they need to account for undesirable substitution effects in the dietary pattern as a whole. Food reformulation by food chain actors is another potentially cost-effective way to enhance dietary quality re salt intake, and might become more relevant for micronutrients in case severe environmental constraints would be used (McDaid, 2015). For modelling the consumer aspect of healthy and sustainable diet, food prices and socio-economic class are considered the most feasible indicators.

Indirect drivers of the food system

The indirect drivers of the food system refer to long run changes in society. SHARP is not designed for changes in the long run and therefore these indirect drivers are not accounted for.

Nevertheless, long term changes in the food system will affect food production and processing and thus the sustainability indicators. Moreover, health considerations and regulatory processes will affect the nutrient composition of foods, e.g. for salt, sugars, fats and possibly also for micronutrients. In addition, an altered food system will lead to changes food prices. Thus, although the targets regarding sustainability and health will remain similar over time, the food-based indicators in the SHARP model are time dependent; thus, the outcome of the model in terms of nutritional adequacy may change along with the food system transition itself.

Data sources

The SHARP model builds on health indicators (nutritional adequacy, adherence to food-based dietary guidelines, BMI), sustainability indicators (GHGe, land use, fossil energy use), economic indicators (e.g. product prices; to be identified), and consumer preferences (e.g. sensory and cultural aspects; to be identified). Such data will be made suitable for linkage to individual-level food intake data. Environmental and economic (income, prices) indicators will also be obtained from SUSFANS WP9. Usual food intakes in different EU regions will be characterized for these sustainability metrics, overall and in relevant population subgroups.

Nutritional data

Individual-level data are obtained from four EU Member States representing the diversity of food habits in the North, East, South and West of Europe, i.e., the Scandinavian (Denmark), CEE (Czech Republic), Mediterranean (Italy) and Western (France) regions of the EU (Ruprich, 2006; Dubuisson, 2009; Lioret 2009). They were selected to capture a wide range of food and agricultural commodities that are incorporated in the dietary patterns to supply the required nutrients, not as a representative sample of the EU as a whole. They illustrate the geographical diversity of dietary patterns that will enrich the foresight scenarios. These four countries participate in the emerging pan-European Nutrition Surveillance. The dietary assessment in these four countries is done by either food records or 24-hour recalls, all aiming at a complete picture of food and nutrient intake, and covering at least two non-consecutive days. This allows grouping of foods into commodities that can be linked to indicators of environmental sustainability, to other quantitative models in the 'toolbox' and that can be used to describe the sustainability indicators and nutrient intake for various diets modelled according to optimal health, optimal sustainability or their combination.

The nutritional adequacy of the diet will be defined using EU dietary guidelines and nutrient reference values by the European Food Safety Authority (Boer, 2011). Individual-level food intake data will be modelled together with sustainability metrics in a model framework (SHARP) for obtaining realistic sustainable FNS diets that fit the EU consumer, and which can be fine-tuned on the basis of various constraints (Gerdessen, 2015a; Gerdessen, 2015b). Using stakeholder input, different plausible scenarios will be developed, depending on priority settings (e.g. health impact vs. consumer preferences vs. environmental consequences vs. economic impact).

Sustainability data

Publicly available databases are used that characterize foods of food groups for environmental impact indicators. For the SHARP diet, the following sustainability indicators are considered:

- Global warming potential (GWP). This indicator is used to indicate climate change and is expressed in the emission of the greenhouse gases NOx, CH4 (methane) and CO2. The unit is CO2-eq/kg product, in which the other gases are recalculated to CO2.
- Land use. This indicator shows how much land was used to cultivate crops for food, feed and energy and is expressed in m2 or ha per kg product. It usually indicates the efficiency of a product.
- Fossil energy use. For every kg of product that is produced for human consumption it is measured how much fossil energy was used. This indicator is expressed in MJ/kg product.

Research on the environmental impact of diets is increasing the last 10 years, however the results are often very location-bound and the data is not publicly available.

To assess the environmental impact of the SHARP diet environmental data will be collected on the primary commodities that have not been processed yet into foods, such as wheat, maize, oil seeds, etc. These data can be obtained from JRC, but this type of data is also available in the LCA software Simapro, in which databases such as Ecoinvent and Agrifootprint are accessible. The data from these different sources will demonstrate the range of the environmental impact of the primary food products in Europe. When the primary data has been collected, the primary commodities will be converted in ingredients (i.e. wheat flour, sunflower oil, etc.). The ingredients will then be mapped to the FoodEx2 system developed by EFSA, as the consumption data of the participating countries will also be linked to this system. This will accommodate the sustainability assessment of the diets. Recipes for composite dishes will be collected with the different countries so that the environmental impact of the ingredients can be combined to a recipe. Gaps in the data will be filled with data from literature studies.

Key contributions, limitations and links

Contribution to SFNS assessments

The SHARP diet model is used to describe dietary patterns under constraints for environmental sustainability and anticipated public health relevance.

In addition to (most) other models, SHARP includes a wider set of nutrients and food (groups) that are closer to consumers' dietary practices, and it includes BMI as a measure of long term energy balance.

Moreover, SHARP incorporates the consumer dimension based on observed data rather than on modelled data. This includes indicators for affordability (e.g. consumer food price, SES), reliability (to be explored) and preferability (social and cultural acceptance).

Finally, the data underlying the SHARP-model are based on individual consumption data on a daily basis, rather than aggregate data. As a result, the analyses can include the population-distribution of long term energy balance, food and nutrient intake and performance metrics in the study populations. This implies that the results are more suitable to evaluate the nutrition security dimension of the diet and that recommendations for healthy and sustainable diets can be better aligned with the state-of-the art approaches in nutrition and health research and policy.

Key limitations

SHARP is not suitable for developing long-term scenarios.

The SHARP model can be relatively easily developed for sustainability and health. The operationalization of the consumer-related ARP-dimensions is an explorative part of WP7. The explorative nature of this part is a result of limitations regarding the availability of (internationally comparable and standardized) data on determinants of consumer behaviour.

Links to other models in the toolbox

Possible complementarity with DIET and CAPRI/MAGNET models is not yet analysed. Next, starting from long term agro-economic models, the model can be re-run to evaluate the nutritional adequacy under future scenarios of the food system. This can provide feedback for further fine-tuning of the agro economic models.

DIET

Information for DIET model provided by Xavier Irz (Luke) & L.G. Soler (INRA)

Theoretical framework

Economic model of diet choice

The standard economic theory of consumer behaviour assumes that an individual chooses the amounts of goods she is going to consume in order to maximise a function–named 'utility'— subject to a budget constraint. The utility function describes the preferences of a consumer which, in the case of food choices, relate to the taste of the goods, their convenience, and many other attributes. The budget constraint takes into account the prices of goods and available income. This optimisation program is referred to as the 'nutritionally unconstrained problem'. Its solution, in the case of food choices, defines which goods are eaten and in which quantities.

In this context, the adoption of a nutritional recommendation, such as eating a minimum quantity of fruit and vegetables per day, is conceptualized as the integration of an additional constraint in the previous program. The additional constraint leads the consumer to modify her choices in order to comply with this new constraint and thus choose a modified set of goods (or the same goods but in different quantities). We call this new optimisation program the 'nutritionally constrained problem'.

Comparison of the solutions of those two programs provides two key results: (i) First, the impact of the adoption of a nutritional recommendation on the entire diet, and hence a full characterization of the substitutions among foods that the recommendation has induced. (ii) Second, an estimate of the loss of utility, or taste cost, that the consumer incurred in the short term by adopting the nutritional recommendation. Adoption always reduces utility of the consumer because, if it was not the case, the consumer would have complied with the recommendation in the unconstrained situation.

An empirical difficulty arises because the utility function is not observed. However, assuming rational behaviour as is standard in most analyses of consumer choices, observed consumption, given market prices and income, is just the solution of the 'nutritionally unconstrained program'. This property is used to infer preferences from actual consumption data. Once the utility has thus been revealed and summarized in the form of price and income elasticities, economic theory is used to determine how a nutritional constraint affects choices and utility.

The taste cost of complying with a nutritional constraint is measured by the 'compensating variation' (CV) of the dietary adjustment, defined as the amount of additional money a household would need to reach its initial utility after complying with the recommendation. The CV is calculated as the difference between observed expenditure (the food budget in the unconstrained situation) and the corresponding expenditure (i.e., food budget) that would be necessary to hold utility to its initial level when the nutrition constraint is imposed. This taste cost should be interpreted as a measure of the short-term loss of utility of the consumer which is a way to evaluate how costly/difficult it is to deviate from the unconstrained situation ignoring the long-term health benefits of compliance, which are considered separately in the analysis.

Health impact assessment

The health effects of consumption changes induced by the adoption of a nutritional recommendation are assessed with the DIETRON model. The DIETRON model provides estimates of the number of deaths avoided due to diet-related chronic diseases (Scarborough et al. 2012). The DIETRON model uses age- and sex-specific estimates of relative risk drawn from meta-analyses of trials, cohort studies and case–control studies, to estimate the impact on chronic disease mortality of counter factual population dietary scenarios". The inputs of the DIETRON model are 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.

Direct drivers of food system actors

Drivers considered in this model are consumers' preferences expressed by own- and cross-price elasticities. Scenarios reflect changes induced by information campaigns. The model only refers to consumer decisions; food chain actors or producers are not considered.

Indirect drivers of the food system

The indirect drivers of the food system refer to long run changes in society. DIET is not designed for changes in the long run and therefore these indirect drivers are not accounted for.

Data sources

The empirical implementation of the economic model requires different sets of data. To determine the initial consumption of foods and the economic parameters (elasticities), we use the source of data and results of the most recent available econometric analysis of food demand in France. That study is based on data from a representative panel of French households (KANTAR World panel). The participating households record weekly all their purchases of foods, using bar code scanning technology whenever possible, but foods without bar codes are also recorded. The information provided includes the characteristics of the purchased product (e.g., brand, size), the quantity purchased as well as related expenditure. KANTAR also provides the main socio-economic characteristics of the panel households, including household size, region of residence and income class.

The nutrient contents of the 22 food aggregates are calculated by combining the food composition database of the French dietary intake survey INCA2 and average adult intakes of the component foods of each aggregate drawn from INCA2 (which stands for "Étude Individuelle Nationale des Consommations Alimentaires 2006–7"), which are freely available from the open data platform of the French government (https://www.data.gouv.fr/fr/datasets/donnees-de-consommations-et-habitudesalimentaires-de-letude-inca-2-3/). The model is applied to estimate the variations in households' purchases induced by the adoption of nutritional or food-based recommendations taken one at a time. The effects of dietary adjustments are calculated under an "as if" assumption, i.e. assuming that the households comply with a 5% change in the constraint level (for example in the case of fruit and vegetables, we assume that a consumer has to increase his consumption of fruit and vegetables by 5%).

To simulate the health effects, changes in food purchases at household level, as calculated by the economic model, are translated into changes in individual intakes, distinguishing between males and females and using the INCA2 dietary intake database. This is accomplished under the assumption that (i) all household members experience the same relative changes in intakes, and (ii) the relative changes in consumption of food-at-home and food-away-from-home are equal. Variations in nutrient intakes are then calculated from variations in food intakes by using the nutritional coefficients of the 22 aggregates. Finally, the changes in nutrients are fed into DIETRON model so as to estimate the health effects of the dietary adjustments.

Key contributions, limitations and links

Contribution to SFNS assessments

The model is used to predict (i) changes in consumers' diets induced by the adoption of dietary recommendations, (ii) and their impact on nutritional (energy, nutrients), public health (diseases and mortality), and environmental (GHGEs) variables. Results may contribute to the benefit-cost assessment of dietary recommendations.

Key limitations

The theoretical background is relevant for moderate modifications of diets and thus short and medium-term scenarios. Not relevant for long-term scenarios.

Links to other models in the toolbox

The possible complementarity with other models from the SUSFANS toolbox, such as SHARP and CAPRI/MAGNET models, has not yet been analyse.

GLOBIOM

Information for GLOBIOM provided by Andre Deppermann (IIASA), Petr Havlík (IIASA), Hugo Valin (IIASA).

Theoretical framework

The Global Biosphere Management Model (GLOBIOM, Havlík et al. 2014) is a global recursive dynamic bottom-up partial equilibrium model integrating the agricultural, bioenergy and forestry sectors. It 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.

The standard version of the model represents the global agricultural, bioenergy and forestry sectors at the level of 30 regions, either representing single countries or country aggregates. A European version of the model depicts in addition all EU member states as single regions. Goods are assumed to be homogenous and bilateral trade flows between individual regions are determined by marginal cost of production in the different regions and transportation costs (Takayama and Judge, 1973, Schneider et al., 2007). GLOBIOM is calibrated to FAOSTAT data for the year 2000 (average 1998 - 2002) and runs recursively dynamic in 10-year time-steps up to 2030/2050/2100.

Direct drivers of food system actors

Consumers. On the demand side, a representative consumer is modelled for each region via a set of stepwise linearized isoelastic demand functions. Food demand projections are based on the interaction of three different drivers: i) population growth, ii) income per capita growth, and iii) response to prices. Price effects (iii) are endogenously computed while drivers (i) and (ii) are exogenously introduced into the model. Because food demand in developed countries is more inelastic than in developing countries, the value of the demand elasticity is assumed to decrease with the level of GDP per capita. The applied rule is that the price elasticity of other countries converges to the price elasticity of the USA in 2000 at the same pace as their GDP per capita reach the USA GDP per capita value of 2000.

Consumer preferences can be included endogenously as far as they reflect reactions to price signals as provided by the model. All changes caused by other reasons than price changes have to be implemented exogenously and are usually represented by scenario assumptions, e.g. through income elasticities.

Food chain. GLOBIOM represents the full supply chain in terms of primary commodity equivalents in line with FAOSTAT Commodity Balances. Processing activities are included for vegetable oils and biofuel products. Waste reduction in the supply chain can be represented in an exogenous manner.

Producers. Primary production has been the focal point for GLOBIOM and thus most richness in terms of drivers is captured here:

1. *Regulatory environment.* Regulatory policies can be implemented exogenously, for example via hard constraints or taxes/subsidies. Examples are emission taxes, prohibition of deforestation, protection of land with high biodiversity, producer subsidies etc.
2. *Input and farm gate prices*. The model is calibrated to FAOSTAT Producer Prices for 2000, but they are part of the solution as a result of demand and supply interplay. Input prices for land and water also adapt endogenously, while all other costs of production are exogenous.
3. *Natural resource availability*. Land resources are represented in a very detailed way. 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. For most EU member states a more detailed structure is available, building on 1 x 1 km pixels, which are typically aggregated to NUTS2 level in the model. For simulation runs, similar pixels are usually clustered and can represent different levels of aggregation.

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. Transition is modelled between the first six land cover types, while the remaining three are assumed to be constant over time.

Besides land also water availability for irrigation purposes is represented in GLOBIOM in a spatially explicit way on a monthly resolution. It is calculated as the difference between runoff and water demand by other sectors, such as industry.

Climatic conditions and impacts and other environmental characteristics regarding crop production are taken into consideration by the biophysical process based crop model EPIC (Williams, 1995; Izaurralde et al., 2006), which provides Leontief production functions for 4 different management systems (irrigated – high input, rainfed – high input, rainfed – low input and subsistence) in a spatially explicit manner (by Simulation Unit).

For the forest sector, primary forest productivity such as mean annual 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).

4. *Available technology*. Each crop can be produced with different technologies depending on profitability: subsistence, low input, high input, and irrigated, when water resources are available. Within each management, input structure is fixed following a Leontief function. Yields therefore react only through change in management system and spatial reallocation. Technical change over time is exogenously specified and depends on the scenario assumptions. A similar mechanism is implemented for the livestock sector by representation of different production systems (Herrero et al. 2013). As part of the SUSFANS project an improvement of the crop sector representation towards more flexibility is being undertaken.
5. *Producer and farm characteristics*. Farms are not explicitly represented in GLOBIOM, but production structure is reflected by different management systems at high spatial resolution.

Indirect drivers of the food system

Indirect drivers of the food system are usually implemented as exogenous changes over time. An example for a comprehensive implementation of coherent scenarios in GLOBIOM are the so-called Shared Socio-economic Pathways (SSPs, O'Neill et al., 2014), which describe plausible alternative trends in the evolution of society and natural systems over the 21st century. SSPs consist of narrative storylines and a set of quantitative and semi-quantitative drivers, which have been either directly implemented (GDP changes, population growth) or have been translated into quantitative information before implementation (Fricko et al. 2017). This application covered GDP growth, population growth, technological change in crop and livestock sectors, incl. loss and waste reduction.

Environmental issues in terms of policies or impacts of environmental change have been covered in the past. Climate change impacts on crop yields were derived from the crop growth model EPIC. Also, climate change impacts on water availability are included. In the SUSFANS project, a new module is being developed which should allow looking also at the effects of climate variability.

Data sources

Production

GLOBIOM represents 18 crops globally and 27 crops for the European Union. Harvested areas are based on FAOSTAT statistics but spatially allocated using data from the Spatial Production Allocation Model (SPAM). In the case of the EU, crops are allocated across NUTS2 regions using data from EUROSTAT. Yields for all locations and crops are determined in a geographically explicit framework by the Environmental Policy Integrated Climate Model (EPIC, Williams et al., 1995). The yields are distinguished by crop management system and land characteristics by spatial unit.

The livestock sector relies on the spatially explicit dataset from the Gridded Livestock of the World database (Wint and Robinson, 2007) and represents eight animal types spatially distributed, and producing seven animal products. Livestock productivity for ruminants (buffalos, cows, sheep, goats) is estimated in GLOBIOM on the basis of animal feed ration using RUMINANT, a digestibility model. The use of this model ensures consistency between the livestock sector input (grass, grains, stover, etc.) and output under different management systems. For monogastric animals (pigs, poultry), a same consistency has been achieved using the results of a literature review to estimate average pigs and poultry feed conversion efficiencies under two management systems (industrial and smallholder). Production costs for these systems are all based on FAOSTAT producer prices for product output and for grains input. A grassland map indicating levels of biomass production in the different regions is used to determine possible stocking densities of animals. The link between animals and land is therefore fully consistent, allowing the need for additional land to be traced in response to changes in the livestock sector.

Information for the forestry sector is sourced from the global forestry model G4M. Locations of forests are supplied to GLOBIOM at a half degree resolution. Harvest potentials of stem wood are determined based on net primary productivity (NPP) maps and combined with maps of forest biomass stock such as the Global Forest Resources Assessment provided by FAO (FRA, 2010). The information on forestry harvest potential from G4M allows four main primary woody resources to be represented in GLOBIOM: industrial roundwood, non-commercial roundwood, harvest losses and branches and stumps. Harvesting costs include logging and timber extraction and depend on harvesting equipment, labour costs and terrain conditions.

World markets and consumption

Trade in GLOBIOM follows a representation where products are all expressed in physical units (tonnes) across localization and are exchanged as homogeneous goods. Net trade data flows are based on FAOSTAT and bilateral trade relations are sourced from the UN COMTRADE database for main crops and livestock products. Tariffs information is sourced from the MAcMap-HS6 database (Bouët et al., 2008).

Food demand is based on Food Balance Sheets from FAOSTAT and depends on population size, gross domestic product (GDP) and product prices. When population and GDP increase over time, food demand also increases, putting pressure on the agricultural system. Change in income per capita in the baseline drives a change in the food diet, associated to changing preferences. Product elasticities are based on USDA data (Muhammad et al., 2011), estimated per categories of product (e.g. cereals, sugar or vegetable oil) at the consumer level. These elasticities are applied in GLOBIOM to the demand in each crop providing the product.

Land cover data

Land cover at the global level is based on the Global Land Cover 2000 dataset (GLC2000) but more detailed land cover maps exist for the EU. The European Environment Agency in particular disseminate the CORINE land cover maps, that provide information on base year 2000 land cover for Europe at a 1x1 km resolution. We build on this information to represent the land cover in Europe at a detailed level. GLOBIOM cropland areas mainly include CORINE class 210 arable land and heterogeneous areas (class 240) and is adjusted in Europe to match the harvested area in GLOBIOM (including fallow). Forest areas in GLOBIOM consist of total forests (class 310) harmonized with forest areas from the G4M model. For grassland, pastures (class 230) is used. However, these areas are then adjusted in relation to grazing quantities to represent only productive grassland. This allows to represent the possibility of expansion of livestock within the current grassland areas, and the possibility to convert unused grassland to other uses. The heterogeneous areas cover (class 240) is then used as a buffer for this adjustment. Other cropland which represents crop not covered currently by the model is calculated using EUROSTAT data. The remaining CORINE land cover classes artificial areas (class 100), permanent crops (orchards, vineyard, etc., class 220), open space (i.e. natural land with sparse or no vegetation, class 330), wetlands (class 400) and water bodies (class 500) are kept constant over time.

GHG emissions of agriculture and land use change

A dozen different GHG emissions sources related to agriculture and land use change are represented in GLOBIOM. Agricultural emission sources covered represent 94% of total agricultural emissions according to FAOSTAT and land use change emissions are consistent with recent reporting (Valin et al., 2013). All GHG emissions calculations in GLOBIOM are based on IPCC guidelines on GHG accounting (IPCC, 2006). These guidelines specify different levels of details for the calculations. Tier 1 is the standard calculation method with default coefficients, whereas Tier 2 requires local statistics and Tier 3 onsite estimations. Seven from eleven GHG sources in GLOBIOM are estimated through Tier 2 or Tier 3 approaches.

Key contributions, limitations and links

Contribution to SFNS assessments

GLOBIOM as a partial equilibrium model of the global agriculture and forest sector with detailed representation of the land and water resources and various production systems with their environmental impacts will contribute mostly to the environmental sustainability assessment of food production in the global perspective, where in particular it can account for potential leakage effects of European policies to the rest of the world.

For internal European analysis, it contributes the non-agricultural land use part. The model allows also to account for key indicators of food security. In the framework of this project, it will be expanded by the fish module and climate variability module. The latter can contribute the assessments of market volatility on food availability.

Key limitations

GLOBIOM is a partial equilibrium model and hence cannot take into account endogenously some of the macro effects, which can be better assessed with a model such as MAGNET. The model is global, and hence less detailed in some aspects, such as the representation of the European Common Agricultural Policy, than for example the CAPRI model.

Links to other models in the toolbox

GLOBIOM has already long history in soft linked assessments together with the CAPRI model which allow to get the best in terms of European and Global agricultural production sustainability analysis. In several projects, the model has been also applied together with the MAGNET model, which substantially enhanced the sustainability aspects coverage by both models through the detailed production side representation in GLOBIOM and the rest of the economy effects in MAGNET.

In this project in addition link with the DIET model would allow to improve the dietary scenarios in GLOBIOM. Finally, the AGRIPRICE4CAST model should inform the stochastic version of GLOBIOM for a realistic representation of market volatility.

AGRIPRICE4CAST

Information for "Short-term forecasting commodity prices" provided by Jesus Crespo Cuaresma, Jaroslava Hlouskova and Michael Obersteiner

Theoretical framework

The short-term forecasting model uses multivariate time series modelling combined with model combinations techniques aimed at assessing specification uncertainty. Short-term econometric forecasting models are used and combined to provide best forecasts of agricultural commodity market prices and their volatility. The forecasting models are not structural models such as the partial or general equilibrium models in SUSFANS, but rather of non-structural nature. Market behaviour is typically summarized in the parametrization of multivariate autoregressive structures rather than explicit theory-driven modelling of economic agents. These models are suited more for forecasting using historical information rather than modelling leverage points for interventions based on agriculture specific policy instruments. Their ability is focused on short-term and in combination with SUSFANS long-term models we anticipate to be able to infer on market volatility behaviour in the long-run through market pressure proxy variables.

The short-term model does not distinguish between direct and indirect drivers as suggested for the long-run modelling. In the econometric models used for the price and price volatility forecasting the following driver variable categories can be established (see also table 3):

- Own price history
- Macroeconomic variables
- Financial variables
- Fundamental agricultural production and market variables
- Weather variables

Data sources

- Coffee price and coffee production data from the International Coffee Organization (ICO)
- Production data from the Food and Agriculture Organization of the United Nations (FAO)
- Weather variables from National Climatic Data Center (NCDC)
- Weather variables from the National Oceanic and Atmospheric Administration (NOAA)

- Price information and financial variable from Thomson Reuters (Datastream), Worl Bank and USDA
- Production data from the United States Department of Agriculture (USDA)
- Macro-economic variables from the World Bank World Development Indicators (WDI)

Key contributions, limitations and links

Contribution to SFNS assessments

The short-term prediction model mainly aims to contribute to improved assessments of food security. In particular, in terms of food access and food system stability. Food access is related to levels and volatility of food prices, which is modelled through food pressure indicators provided by the long-run models (GLOBIOM) and short-term macro-economic and financial market indicators.

Key limitations

The short-term market models are by themselves not suited for long-term projections under policy or any other major structural changes in the food system. However, through linkage with food system pressure indicators it carries to potential for improved descriptions of food system states in long-run scenarios.

Links to other models in the toolbox

The short-run agricultural price forecasting model will be linked to the long-run model GLOBIOM through a common food market pressure variable. In this way price and price volatility conditions can be investigated also in long –run scenarios. Furthermore, food system states can also be better embedded in wider storylines of macro-economic and financial market conditions.

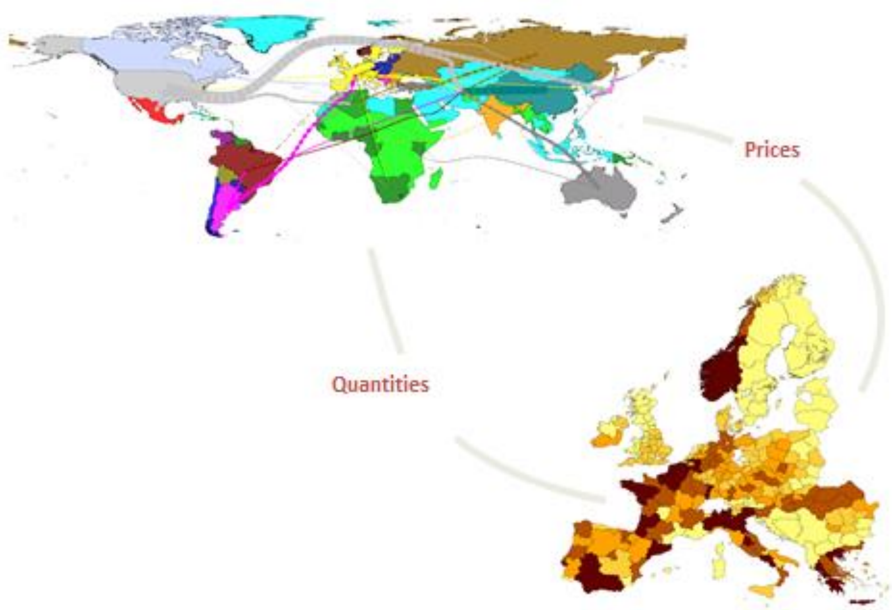
CAPRI

Information for CAPRI provided by Andrea Zimmermann (UBO), Adrian Leip (JRC), Christian Götz (UBO)

Theoretical framework

CAPRI (Common Agricultural Policy Regional Impact) is an agricultural sector model covering the whole of EU27, Norway and Western Balkans at regional level (250 regions) and global agricultural markets at country or country block level. It consists of a European supply and a global market module that interact through the exchange of quantities and prices (Figure 3). The European supply module consists of non-linear programming modules for about 280 NUTS2 regions featuring a profit maximisation under constraints. It has a very detailed policy representation (e.g. premiums, quotas) and links to the environment. The global market module is a so-called spatial multi-commodity model. Supply and demand for a large number of agricultural raw and processed are determined simultaneously with market clearing prices. It covers bi-lateral trade flows.

Figure 3. CAPRI European supply and global market module



The supply, processing, feed and final demand function in the CAPRI market model are flexible in the sense that they comprise enough parameters to be calibrated to any regular set of own and cross price elasticities. Regular means that the parameter set is calibrated as to be in line with the assumption of profit maximising producers and utility maximising consumers. Consumers differentiate products by origin and their willingness to pay depends on the product's origin, for example wine from Europe differs in quality and price from US wine. Import shares depend on import prices.

In a typical model set-up, the following are exogenous drivers of the model:

- Technology
- Population and GDP developments
- Climate change
- Agricultural and trade policies
- Culture and lifestyle changes (consumer preferences)

while these are computed endogenously by the model:

- Prices
- Partly management (land allocation, intensity)
- Environmental indicators
- Natural resource availability indirectly considered

Direct drivers of food system actors

Consumers are modelled as utility maximisers in CAPRI using a single level representative consumer. Consumers differentiate products by origin and their willingness to pay depends on the product's origin, e.g. wine from Europe differs in quality and price from US wine. Import shares depend on import prices. So, main drivers for consumers are prices and product origin. Other drivers (e.g. demographics, attitudes) are modelled exogenously through the parameterisation of demand functions which can be adjusted in line with scenario narratives.

Food chain assessments are limited in CAPRI which emphasizes detailed modelling of European agricultural production. In the context of SUSFANS the modelling will be extended beyond primary production through a module capturing post-farm gate biomass and nutrient streams (D9.4). This module builds on a literature review of available information on post-farm gate biomass flows, documented in D3.3.

Producers, and especially farmers in the European Union, have been the focal point in CAPRI's development. As a result, there a wide range of drivers of producer decisions is included:

i. *Regulatory environment:* The CAP (Common Agricultural Policy) is treated in detail in CAPRI. This allows to consider CAP reform scenarios in the SUSFANS scenarios. The CFP (Common Fishery Policy) is planned to be considered in the new CAPRI fish module that currently under development.

ii. *Input and farm gate prices:* Producer prices are endogenous in CAPRI reflecting the interplay between supply and demand. Input prices are partly endogenous, partly exogenous depending on the type of input.
iii. *Contract opportunities:* Contract opportunities are not explicitly considered in CAPRI.
iv. *Natural resource availability:* Natural resource availability enters CAPRI in terms of path dependence in the data base, partly it is modelled endogenously (e.g. land use), and partly it is reflected in the scenarios and/or exogenously provided by other models (e.g. climate change).
v. *Available technology:* Technical progress is exogenous and will be explicitly considered in the scenarios affecting agricultural productivity in an aggregate way. However, the process of technology development and adoption is not explicitly modelled. Thus, costs of development of new technologies are not accounted for.
vi. *Producer and farm characteristics:* In CAPRI, individual producer and farm characteristics are typically not considered due to their complexity. However, producers are also consumers and affected by general lifestyle changes as considered in SUSFANS, which in turn might affect their production decisions in line with price changes transmitting signals of changes lifestyles and diets.

Indirect drivers of food system actors

The indirect drivers of the food system, like developments of the wider economy, demographic changes etc. are not modelled in CAPRI but taken on board as part of scenario assumptions, i.e. modelled exogenously.

Data sources

CAPRI is a spatial, global multi-commodity model for agricultural products. The main databases used in CAPRI are 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 Heckelei, 2011). The parameters of the global market model are synthetic, i.e. to a large extent taken from the literature and other modelling systems. The international trade model is globally closed according to FAO data.

CAPRI has a European focus. Model results are typically available at NUTS2 level for Europe (280 NUTS2 regions in the EU27, Norway, Western Balkans and

Turkey). A spatial downscaling method module allows representing environmental indicators up to 1x1 km resolution (see D4.6). For the rest of the world, indicators are typically available at national or country aggregate level (77 countries in 40 trade blocks).

CAPRI covers around 50 agricultural products, covering all of agriculture according to the definition of the Economic Accounts for Agriculture. On top, there is a limited number of processed products included (dairy, oils and cakes, bio-ethanol and bio-diesel and the related by-products).

Input coefficients in CAPRI. Inputs as feed, N,P,K fertilizer, diesel or plant protection costs are allocated to individual production activities. CAPRI covers and allocates all intermediate inputs according to the definition of the Economic Accounts for Agriculture.

Regional prices in CAPRI. Prices for all outputs and inputs are identical for all NUTS II regions inside of one Member State as they are derived from the Economic Accounts for Agriculture. The only exemptions are fodder prices which reflect production costs.

Data consolidation in a single CAPRI database. CAPRI has its own database which is built by the CAPRI software packages CoCo and CAPREG. CoCo, the acronym for "Complete and Consistent", is the name for the software package which builds up time series at national level (areas cropped, herd sizes, output coefficients, prices, market balances). The main data sources for CoCo are statistics from EUROSTAT. CAPREG is the name for the software package which builds up time series at regional level (areas cropped, herd sizes, output and input coefficients). The main data sources for CAPREG are statistics from EUROSTAT. There is no central data base for EU policy instruments. Most data have been manually edited based on EU legislation. Data for the rest of the world are mainly based on FAOSTAT (market balances, trade flows, estimation of transport costs from bi-lateral import and export unit values). Tariffs are based on AMAD.

Key contributions, limitations and links

Contribution to SFNS assessments

In relation to the spider diagram, CAPRI will be strong in assessing food production and environmental goals. It will also be able to provide assessments of farm income, but less so in assessing the viability of the agrifood business along the supply chain. CAPRI is currently being improved to provide basic (simplified) assessments of balanced and sufficient diets for an average consumer and a fish module is being developed. Equity issues cannot be addressed with CAPRI.

Key limitations

Equity issues will be difficult to assess with CAPRI. In general, CAPRI refers to the agricultural sector only and all issues beyond that cannot be considered.

Linking of CAPRI-GLOBIOM

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.

Linking of CAPRI-MAGNET

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, scenario results from MAGNET on some macroeconomic factors (e.g. energy prices) could be used in CAPRI.

Apart from transferring these variable changes that are endogenous in MAGNET but exogenous in CAPRI, one could also envisage a more involved process of aligning key output variables that are endogenous 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 are 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 defining 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 endogenous responses, such linking can also be connected with the transfer of, for example, primary factor price changes that are endogenous in MAGNET and exogenous 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 macro and micro models

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 so that the latter can optimise the diet taking into account economic and environmental attributes, next to nutritional attributes.

MAGNET

Information on MAGNET provided by Marijke Kuiper (Wageningen Economic Research)

Theoretical framework

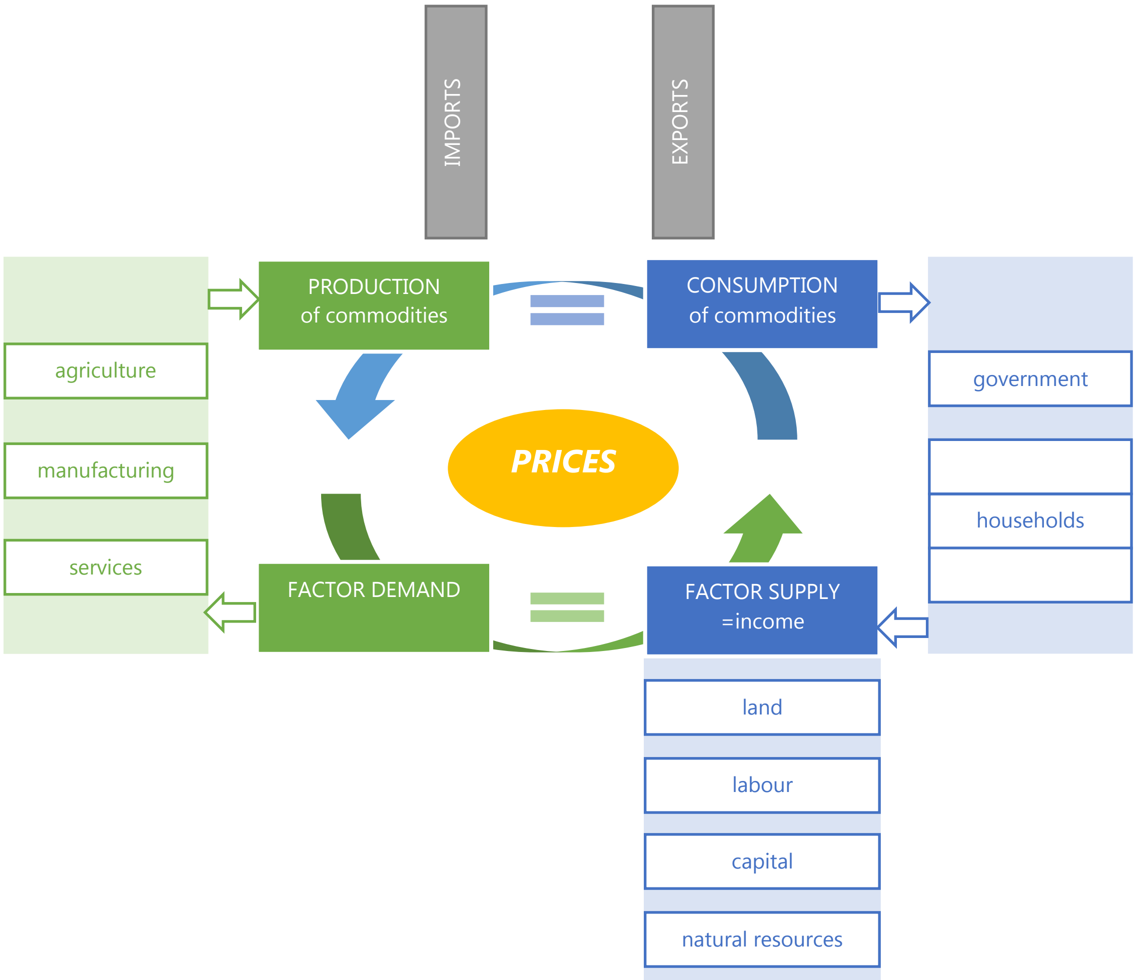
National policies almost by definition have an economy-wide impact, aiming at shifting a national economy towards a more desirable point. This will result in economy-wide adjustments, the net effect of which cannot be analytically derived. Computable General Equilibrium (CGE) models are simulation models designed to quantitatively trace such direct and indirect economy-wide adjustments. MAGNET is a global CGE model based on the GTAP standard model (Hertel 1997) with a modular set-up allowing us to include more detail or specific extensions where needed (Woltjer et al. 2014). Like other GTAP-based CGE models MAGNET covers the global economy, tracing all economic transactions captured by national statistics[4].

MAGNET traces domestic links between sectors (Figure 4), through use of output from other sectors (intermediate demand), competition for agricultural land (which can expand, possibly at the cost of deforestation), labour or capital (factor markets, segmented for agricultural and non-agricultural use in the case of labour) and by substituting commodities in the consumption of private households or government (final demand). Intermediate and final demand are linked to developments in other countries through bilateral international trade. Products are distinguished by origin (Armington assumption), with the ease of substitution across regions varying by the importance of quality or taste differences. Homogeneous products often traded in bulk, like rice, are more easily sourced from elsewhere when prices change than fruit and vegetables which covers a wide range of diverging products across regions.

Prices play a pivotal role in a CGE model, adjusting until in all markets demand equals supply. This holds not only for commodity markets, but also for the demand for factors like land and labour. Production and consumption are linked through commodities, but also through factors (land, labour, capital and natural resources) for which sectors compete to produce commodities. Factors then provide households and governments with income to purchase the commodities, thus affecting the demand for the produced commodities.

[4] Being derived from national statistics, the GTAP databases excludes economic activities not registered by statistical offices. Activities in the informal economy or farm production directly consumed by farm households may thus not be accounted for.

Figure 4: Schematic representation of national economies in MAGNET



Production structures can be made sector-specific in MAGNET to capture sector-specific substitution possibilities. For example, crop production can substitute different types of fertilizers with land, while livestock sectors can substitute feed and land to capture intensification versus extensification of production.

Sectoral shifts may alter the returns to different types of factors, e.g. increase the value of land through an increased demand for agricultural products. This may result in an expansion of agricultural land and alter the relative income of household groups when these are distinguished. For selected countries (currently Ghana, Kenya and Uganda, India, Indonesia and China to be expanded with EU countries in the course of the SUSFANS project) MAGNET includes different household types as well as a finer distinction of factor endowments (Kuiper and Shutes 2014). The latter allows us to better capture the link between specific sectors and factor incomes, tracing differential income developments of household types.

Available policy instruments are a range of taxes or subsidies (with government budget implications), imposing production quota or setting mandates on biofuel use.

Direct drivers of food system actors

Consumers take their consumption decisions by maximizing utility while respecting their budget constraint. These decisions are assumed to be taken under perfect competition assumptions where prices carrying all necessary information and taken as given when each agent to optimizes its production or consumption decision. Factor mobility and elasticities play key roles, moderating the strength of the response to relative price changes, i.e. determining the ease with which consumption and production adjust to relative price changes. Specifically, income and price elasticities are key determinants of consumption decisions. These parameters implicitly carry information about taste, attitudes and interests being estimated on cross-country consumer expenditure data reflecting observed consumer choice s but lacking information on the relative importance of different drivers of this choice (e.g. price versus taste considerations when taking a purchase decision).

Consumption is modelled at national level, with a single representative consumer capturing all consumption decisions in a national economy. For selected countries, representative household types are distinguished, allowing a fine representation of decisions for example along the rural/urban or income gradient. Demographic trends only affect the consumption decisions in the aggregate, i.e. by changing the availability of labour and thus income earning capacity and by influencing the income per capita which affects the demand pattern (the CDE demand system is non-homothetic).

Being an economy-wide model the ***food chain*** is included in MAGNET, but with limited detail in terms of sectors or actors. All primary food production is traced throughout the economy, also capturing processing and sales through restaurants. The representation of production by a single producing sector for each product implies that no distinction is made between different types of products (apart from a regional distinction when tracing international trade). The impact of for example a specific label, like fair trade, on a part of the products is not captured. The modelling of the entire chain and all factor markets does allow tracing the impact of economy-wide changes on food prices and vice versa, separating changes in of primary products form other price changes (like changes in prices of processed food or factors of production) affecting the final consumer price of food.

MAGNET covers all **producers** in an economy, ranging from primary production to mining and industry. Being mainly deployed for agricultural and bio-based policy assessments MAGNET has enhanced the standard GTAP set-up with additional detail in land use modelling. MAGNET includes a land supply curve which specifies the relationship between land supply and a land rental rate in each region (van Meijl et al. 2006; Eickhout et al. 2009). Land supply to agriculture can be adjusted by idling agricultural land, converting non-agricultural land to agriculture, converting agricultural land to urban use, protection of forest areas, and agricultural land abandonment. The general idea is that as long as there is enough land available for agriculture the land price will increase modestly but if land becomes scarce its price increases rapidly.

Apart from land, other factor markets are modelled explicitly as well, with sectors competing for capital, different types of labour and natural resources. In the case of labour MAGNET distinguishes unskilled and skilled labour and includes a labour market segmentation between agricultural and non-agricultural demands. This module is developed to capture the empirical observed divergence where agricultural wages tend to lag behind non-agricultural wages.

Sectoral detail has been added to the standard GTAP set-up by adding different fertilizers types as inputs for crops, feed for livestock, first and second-generation biofuels including by-products, residue use, alternative sources of electricity and bio-based chemical products.

The aggregate representation of producer decisions in MAGNET does not explicitly distinguish different production technologies but represents the myriad of individual producer choices by a single national level nested CES production function. Technological change can be implemented in two ways. Commonly exogenous shifters are applied to the production function, either at the top level (input neutral technical change) or input specific (e.g., labour augmenting technical change). The size of these shifts are generally determined outside of the model and do not account for the cost of developing new technologies, i.e. they are modelled as “manna from heaven”.

Similar to the consumption side of the model, prices are key for producer decisions. Producers solve a profit maximization problem with a constant return to scale technology, or in other words are searching for the most cost-effective way to produce a single unit of output. As with the consumer side substitution elasticities are key in determining the ease with which shifts between inputs occur when relative prices change and are derived by a synthesis of estimates from the econometric literature and original econometric work using cross country data.

With prices of inputs and output taken as given and a constant return to scale technology, zero profits result. This means that all income earned by the producers is paid to the land, labour, capital and natural resource owners. In most regions, this is the regional household, representing both government and private owners of production factors. When different household types are distinguished factor ownership, and thus income earning possibilities, varies across household types. These factor payments generate the link between the production side, by providing the income for purchasing the produced outputs.

Indirect drivers of the food system

Economic development, summarized by GDP, is an endogenous outcome of MAGNET. In baseline development, however, an alternative model set-up is used where the model is calibrated to a projected GDP development from external sources through endogenous technology shifters. The rationale of this approach is the so-called Solow residual, i.e. observed growth in output that cannot be explained through increased input use and therefore ascribed to increased productivity of inputs. This calibration procedure allows harmonization of a key economic driver with other models, important when linking models. Together with the total population projections, also from external sources since MAGNET does not include a full demographic model, the technical change/GDP assumptions are the key drivers of long run changes as captured by MAGNET.

Outside of SUSFANS MAGNET is extended to capture environmental feedbacks by a simplified representation of how GHG emissions affect long run temperature changes which then affects yields and thus the food system. In the absence of these feedback loops exogenous environmental policies, like biofuel mandates, can be included. As can be agricultural and trade policies. A dedicated EU common agricultural policy module is available for MAGNET to capture in more detail these interventions in EU agricultural production.

Other long run changes, like culture and lifestyle, are not part of MAGNET but can be incorporated if expressed as changes in the consumer decisions, more specifically as changes in the substitution elasticities.

Data sources

As the starting point for quantifying the global economy MAGNET uses the GTAP V9.2 database with 2011 as reference year (Narayanan, Aguiar, and McDougall 2015). The GTAP database contains detailed bilateral trade, transport and protection data (import tariffs, export subsidies and subsidies to agricultural outputs, inputs and factor payments) characterizing economic linkages among regions, together with detailed country input-output databases accounting for domestic inter-sectoral linkages. The standard GTAP database distinguishes 57 sectors, of which 12 primary agricultural production (8 crops, 4 livestock related), 8 processed food commodities, 6 natural resource-based activities (like fishing and mining activities), 21 manufacturing and 10 service sectors. The 9.2 database distinguished 141 regions of which 120 are individual countries. Both sectors and regions need to be aggregated to achieve feasible runtimes. This aggregation is flexible in MAGNET and can thus be tailored to the question at hand.

Apart from a description of the entire world economy in the base year the GTAP database also includes key elasticities for consumption and production decisions. As discussed above these are based on a (synthesis) of cross-country econometric estimates.

MAGNET extends the GTAP model in several ways which in many cases requires additional data, either to split GTAP sectors for more detail, for more elaborate production structures including the option of by-products, alternative demand systems and for dedicated modules like the land supply function or different household types. These extensions are built on a variety of data sources, made consistent into a MAGNET database in the data module of MAGNET. The choice of adjustments and extensions of the GTAP database is modular and user-defined. A maximum of 33 sectors (some with additional by-products) can currently be added, most of which are bio-economy related.

Data sources vary depending on the type of extension. Key additional data in the current context are FAOSTAT data on land use, production quantities (GTAP only holds dollar values of production) and nutritional value of production (macro nutrients of primary products). For the bio-economy splits a key source of data is the International Energy Agency (IEA), while for the household types national SAMs from IFPRI and other sources are used.

Key contributions, limitations and links

Contribution to SFNS assessments

The key strength of MAGNET is its ability of capturing economy-wide feedback mechanisms which may alter the impact of interventions towards more sustainable diets. For example, household income is a key determinant of consumption decisions and endogenously determined in MAGNET depending on demand for factors (labour, land, capital) owned by the households from the production sectors. Furthermore, the global and economy-wide scope accounts for interactions between countries and sectors allowing MAGNET to trace impacts outside of the primary sector and on households in non-EU countries. Apart from covering all production and consumption with associated nutrient consumption indicators, MAGNET also computes changes in environmental indicators like land use and GHG emissions.

Key limitations

The complete coverage of global economic transactions comes at the cost of limited detail. Especially in the case of consumption the standard specification is severely limited by aggregating all consumption in a single national household. For regions where additional household detail is added different representative households are distinguished, but this remains a very aggregate representation compared to the individual level intake data used in nutrition focussed models. Furthermore MAGNET is firmly grounded in the neoclassical economic tradition assuming rational decision-making under full information and perfect markets.

Links to other models in the toolbox

MAGNET is complementary to the other models in the SUSFANS toolbox by providing an aggregate but comprehensive assessment of economy-wide changes. Combing MAGNET with the partial equilibrium models CAPRI or GLOBIOM enhances the non-spatial representation of production in MAGNET while providing economy-wide feedback impacts not captured by these partial models. Combing with DIET enhances the modelling of consumption response in MAGNET while again providing macro-economic feedback effects not captured by DIET. The combination with SHARP provides most scope to enhance the nutrition indicators both in terms of products and associated nutritional qualities as well as consumer detail. MAGNET can then provide the food system implications of changes in diets, albeit for aggregate products but encompassing the entire economy. Combining with SHARP will be the most challenging connection, however, not only in terms of largest step in terms of detail but also in terms of theoretical divergence with SHARP being the only one not modelling consumer decisions in a neoclassical framework.

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