The strengths and limitations of the SUSFANS metrics and models for assessing sustainable food and nutrition security in Europe

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SUSFANS DELIVERABLES

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Abstract The SUSFANS model toolbox comprises state-of-the-art foresight and newly developed diet models for a holistic sustainability and dietary assessment. The toolbox is ready to assess the food system transitions to support healthy and sustainable diets of EU citizens. A future research agenda for the modelling of food system properties is proposed regarding modelling of food supply, consumer choices, global impacts and for assessing and communicating complex model results.

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DELIVERABLE SHORT SUMMARY FOR USE IN MEDIA

The research conducted in the course of the SUSFANS project has contributed substantially to an improved understanding of sustainable food and nutrition security in the EU, its facets, current and potential future performance of EU's food systems, and how it will likely be influenced in various hypothetical scenarios.

Guided by a conceptual framework, a comprehensive set of metrics has been defined free from model-imposed constraints in order to assess social, environmental and economic sustainability concerns of potential food system changes.

In the SUSFANS model toolbox specialised and well-established state-of-the-art foresight models were advanced and linked to newly developed diet models to gather the expertise for a holistic sustainability and dietary assessment.

Considerable model differences in terms of product representation and agent behaviour were overcome while establishing exchange and linkages between the models. Despite remaining limitations in the coverage of some performance metrics of the food system, a broad quantification of sustainability and diet metrics was achieved.

However, significant limitations still remain with respect to model linking, gaps in quantified metrics, the representation of actor heterogeneity, and the pathways of intervention aiming to support sustainable food and nutrition security in the EU and globally. Based on those, a research agenda for improving the integrated assessment and modelling of food systems is proposed. We suggest steps forward in modelling i) food supply covering production, processing and retail, ii) consumer choices, intervention pathways and impacts of dietary choices across populations, iii) global impacts of EU food system changes, and iv) in assessing and communicating large and complex results from multiple models.

TEASER FOR SOCIAL MEDIA

The SUSFANS model toolbox is ready to assess transitions to healthy and sustainable diets of EU citizens with a targeted set of quantifiable metrics. Remaining limitations set the scope for a future research agenda of modelling sustainable food and nutrition security in the EU.

ABSTRACT

The research conducted in the course of the SUSFANS project has contributed substantially to an improved understanding of sustainable food and nutrition security in the EU, its facets, current and potential future performance, and how it will likely be influenced in various hypothetical scenarios.

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Introduction

The research conducted in the course of the SUSFANS project has contributed substantially to an improved understanding of sustainable food and nutrition security in the EU, its facets, current and potential future performance, and how it will likely be influenced in various hypothetical scenarios.

A conceptual framework (Figure 1) was set up guiding the analyses along social, environmental and economic sustainability concerns while considering the main food system actor groups (Rutten et al., 2018). To assess impacts from potential EU food policies, food system innovations and global macro developments, a comprehensive set of metrics has been defined free from model imposed constraints (Zurek et al., 2017 (D1.3)). This unbiased metric design comes however at a disadvantage. Despite model improvements and extensions, not all desired metrics can be quantified by the SUSFANS model toolbox. Nevertheless, the toolbox combines well-established macro-level foresight tools and newly developed micro-level models based on food intake data capturing differences in diets of individuals. Thus, the toolbox represents state-of-the-art foresight work and brings together expertise from different disciplines.

The report at hand aims at taking stock with respect to the achievements but also remaining limitations and scope for future research building on the foresight work in SUSFANS. We address the question whether our foresight modelling tools are ready to assess and chart transitions to healthy and sustainable European diets, as conceptualised by Zurek et al. (2018). In order to give a profound answer to this question we specifically assess to what extent we have been able to model the interaction between diets and food supply based on the framework developed in Rutten et al. (2018). Being clear about the inherent limitations of the implementation, we propose an ambitious research agenda for the future to overcome still existing deficiencies regarding the modelling of food system properties.

The reflections on strengths and limitations of the SUSFANS toolbox in this report are structured along the three key ingredients of an operational foresight exercise for the European food system, i) the representation of agents' behaviour and their interactions, ii) the quantification of the SUSFANS metrics supposed to track the performance of the food system, and iii) the translation of transition narratives to scenarios suitable for model assessments.

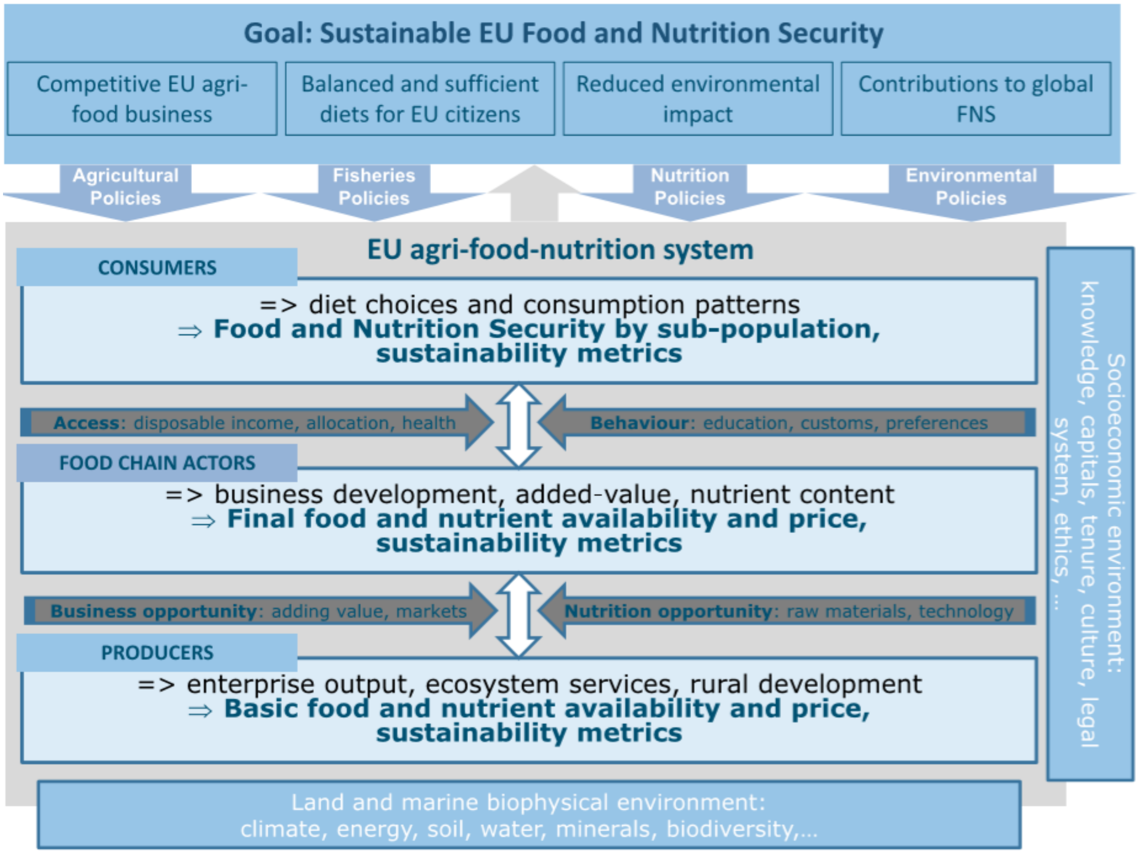

Figure 1 SUSFANS conceptual framework, Source: Rutten et al. (2018)

Representation of agent behaviour and their interactions in SUSFANS model toolbox

In the light of an increasing amount of food systems research, the novelty of the SUSFANS approach was to bring together specialised and well-established state of the art foresight models, improve their specification for the task at hand, and to develop new models to gather the expertise for a holistic sustainability and dietary assessment (Kuiper and Zurek, 2017 (D1.4)). Already at an earlier stage in the project, the complementarity of the models with respect to their actor representation has been stressed (D1.4). Combining the models in a toolbox had the additional advantage of avoiding the creation of an "unmanageable and overly complex model to capture the whole system" (Rutten et al., 2018).

The macro-economic models represent consumers, producers and food chain actors as utility- or profit maximizing agents primarily driven by price changes and only indirectly (via elasticities) driven by non-price attributes. The actors in the models are representatives of the respective regional average (at global, world region, national, sub-national level). Agent behaviour is calibrated with actual data and projected into potential futures.

SHARP is a new model that aims to identify improved diets from already observed (and hence attainable) diets among the wide variety of individual diet patterns. The model design is presented in Kanellopoulos et al. (2018, D7.3). An intermediate stock-taking on the development of the model is given by Mertens et al. (2019, D7.5).

The micro level diet model SHARP builds on individual person's food intake data collected under nutrition surveillance programs in four European case study countries. The data is reported in Mertens et al. (2018). Food intake and nutrition is related to demographic, physiological and socio-economic characteristics. For the purpose of this report we will refer to this consolidated database of food intake data as the "SHARP data". The limitation of SHARP data covering only the present situation could be overcome with an exchange between SHARP and MAGNET projections.

Creating the link between macro- and micro-models was a challenge due to their strong differences in agent and product representations that could only be partly overcome in the course of the SUSFANS project. To make sense of the data input derived by the respective other kind of model, a translation and (dis-) aggregation needed to be achieved while avoiding information loss as far as possible.

In particular it was necessary to map food commodities represented in the macro-models to the FoodEx2 classification of food items and food groups used in SHARP data. Based on such a mapping, food availability projections from MAGNET could be translated into food intake changes in the SHARP database, and resulting changes in diet metrics computed. This is a major achievement as it enabled conclusions regarding impacts on diets and nutrition on a much more reliable ground than if derived directly from macro-model food availability results. Further work is needed to realize a comparable exchange between SHARP results and the two other macro models CAPRI and GLOBIOM. This mapping is more complicated due to the modelling of demand in primary equivalents while many FoodEx2 products are processed foods combining multiple primary products.

However, the applied procedure of exchange between models has some inherent limitations. Due to the top-down implementation (from macro- to micro-models), dietary scenarios needed to be defined in a very coarse way at the level of aggregated food commodities. This has contributed to a rather limited response of diet and nutrition indicators provided by SHARP. The advantages of having a refined representation of food intake based on the FoodEx2 classification effectively got lost this way. Once the SHARP model becomes operational it can provide alternative diets at FoodEx2 level which would give a richer measurement of the diet metrics, while using the now established connection to define a coarser diet at MAGNET resolution to assess the food system implications of the diet shift (and possible send resulting changes in sustainability indicators back to SHARP which may affect the choice of diet). Future research along these lines can build on the conceptual thinking and implementation procedure provided in Kuiper et al. (2018a, D9.5). Thus, while a rather coarse scenario setting at system level will remain due to the commodity based set up of the macro models, a more detailed and sensitive response of the SHARP diet and nutrition indicators is then expected. Having the bottom up approach established, the link of SHARP indicators to agricultural price and environmental indicators derived by the macro models could also be facilitated. In addition to the divergences with respect to food representation, an aggregation of data points for different population groups accounted for in SHARP was needed to match the average national consumers in the macro models.

After the discussed challenges of linking models with differences in their agent representation, in the following we provide a closer look at specific issues regarding the representation of each agent group.

As summarized in Figure 2, consumer decisions are driven by food prices and the disposable income for food purchases. Besides that, consumer behaviour depends upon non-price motives and individual or household related attributes. While micro level models like SHARP and DIET are able to account for these differences as long as the required data is available, the macro models capture drivers of consumption behaviour very differently. Price and income related drivers can be modelled best and are either exogenously or endogenously available to the macro models. The remaining drivers are, if at all, implicitly captured in the calibrated elasticities.

	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).

Figure 2 Drivers of consumer captured by the SUSFANS model, Source: Kuiper and Zurek (2017, D1.4)

It remains a limitation regarding the modelling of consumer behaviour, that the macro modelling does not cover non-price determinants of dietary change like potential disutility from diet shifts. One important non-price driver for consumer food decisions is the consideration of one's health situation. At country level, nutrition influences the burden of disease of a society and related societal costs. The SUSFANS foresight work did not generally capture how the prevalence of diet-related diseases changes in response to the assessed food system changes. Work on the DIET model makes this connection using the DIETRON model, but only for marginal or short run changes in diets (see Irz et al. (2016)). A connection with DIET or a direct collaboration with a health model like the one used in the assessment of Springmann et al. (2018) would allow for extending the impact analysis in the foresight studies so far undertaken in SUSFANS. In a case study for Taiwan, the consideration of the age structure of the population and its forecasted development provides another basis for including such a link through its demographic implications in a general equilibrium framework (Chang et al., 2018). Such a connection would also allow better addressing demographic implications for changing diets by age group, for example along the lines of optimal diets for an ageing Taiwanese population (Liu et al., 2019).

	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.

Figure 3 Drivers of producers captured by the SUSFANS models, Source: Kuiper and Zurek (2017, D1.4)

Figure 3 summarizes drivers of agricultural producers and how they are captured by the SUSFANS models. Most drivers refer to production inputs, either in the form of prices or quantities. In addition, the overall economic performance (GDP), technological and regulatory changes as well as attributes related to individual farm characteristics affect producer responses. In contrast to the diet models, the macro models capture nearly all relevant drivers on the production side. Nevertheless, there is still scope for extensions in future research regarding the modelling of production drivers. Contract opportunities which can play an important role for the production decisions of agricultural suppliers are not represented in the models. More generally, the issue of imperfect competition in the food chain (see also below) continues to remain a challenge for implementation in these large-scale modelling exercises mainly because the empirical evidence is scattered and, if it is available, does not always directly translate into price transmission behaviour captured by equilibrium models. In addition, the empirical base of technology uptake is weak and the implementation of technological change is rather homogeneous and assumption-based in the macro models. Another critical point is that structural change of the primary sector in terms of farm numbers and size is not explicitly represented in the models. While the models capture related increases in efficiency in the projections, they are not able to predict transformative structural changes that break past developments.

	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

Figure 4 Drivers of food chain actors captured by the SUSFANS models, Source: Kuiper and Zurek (2017, D1.4)

Intermediate food chain actors play an increasingly important role nationally but also as players in global food markets (Rutten et al., 2018). Their general representation is limited to the MAGNET model (Figure 4), and to some processing chains (e.g. dairy and oils) in the CAPRI model. The potential emergence of new food chains and networks is missing in the modelling attempts. Future research in this area is, however, not likely promising by adjusting the SUSFANS macro models but rather by new innovative modelling exercises able to capture emergent phenomena in dynamic, interactive modelling setups like agent-based models (Utomo et al., 2018). Outcomes from such exercises would substantiate possible scenario formulations on structural breaks in the food chain for ex-ante assessments by the SUSFANS macro models. Research in SUSFANS made a first step in introducing a short-term volatility module to GLOBIOM based on empirical, time-series forecasting exercises on agricultural raw product markets and relating those volatilities to fundamental market drivers (Boere et al., 2018

(D8.6)). Future research should deepen such analysis and test its applicability in the context of large-scale foresight studies. Finally, a general limitation affecting all agent groups is the assumption of perfectly rational behaviour and that perfect information is treated as costlessly available. Future research should gather reliable assessments of non-price drivers of actor decisions and stronger reflect (and potentially represent) behaviour deviating from rationality as this would improve the toolbox ability to model policy interventions targeting consumer and producer behaviour beyond price-based instruments.

Quantification of the SUSFANS metrics by the model toolbox

Within SUSFANS, a suite of state of the art macro-models and newly developed micro-models, the so-called SUSFANS model toolbox (Rutten et al. 2018, Kuiper et al. 2018a), was applied to quantify impacts of future scenarios on several dimensions that are key for a forward looking assessment of EU food system sustainability. The toolbox is comprised of economic agricultural sector models (CAPRI, GLOBIOM, MAGNET) and micro-level diet models (SHARP, DIET), that have complementary strengths with respect to sectoral coverage, spatially explicit detail and the way of representing food system interactions. An important strength of the toolbox is that it allows a wide-ranging sustainability assessment. The complementary nature of the applied models and the broad coverage of sustainability indicators allowed to assess diet shifts from a nutritional perspective next to their impacts on other sustainability dimensions – economics and the environment. For example, while the partial equilibrium models CAPRI and GLOBIOM have a very detailed – spatially explicit – representation of agricultural production and environmental impacts, MAGNET enables the comprehensive analysis of food demand and consumption accounting for general equilibrium feedbacks across all sectors of the economy. Applied jointly, this allowed to rely on the individual strengths of each model thereby providing a comprehensive multi-dimensional impact assessment. A detailed account of the model coverage of the SUSFANS metrics and their underlying variables and indicators is provided in Table 8 in Kuiper and Zurek (2017, D1.4). In Figure 5 the SUSFANS visualizer based on exemplary results from the assessment in Frank et al. (2019, D10.4) depicts the metrics coverage in an aggregated and easily accessible way (detailed information regarding the scenario analysis and the visualizer design can be found in D10.4 and Achterbosch et al. (2019, D6.3), respectively). The most complete model representation was achieved for the profit and planet dimensions. Those performance metrics are based on and influenced by a number of underlying variables and indicators provided by the macro models. The computation of reliable (intake-based) nutrition and diet metrics for the same scenarios achieved by linking macro- and micro- models is another great achievement of the SUSFANS project.

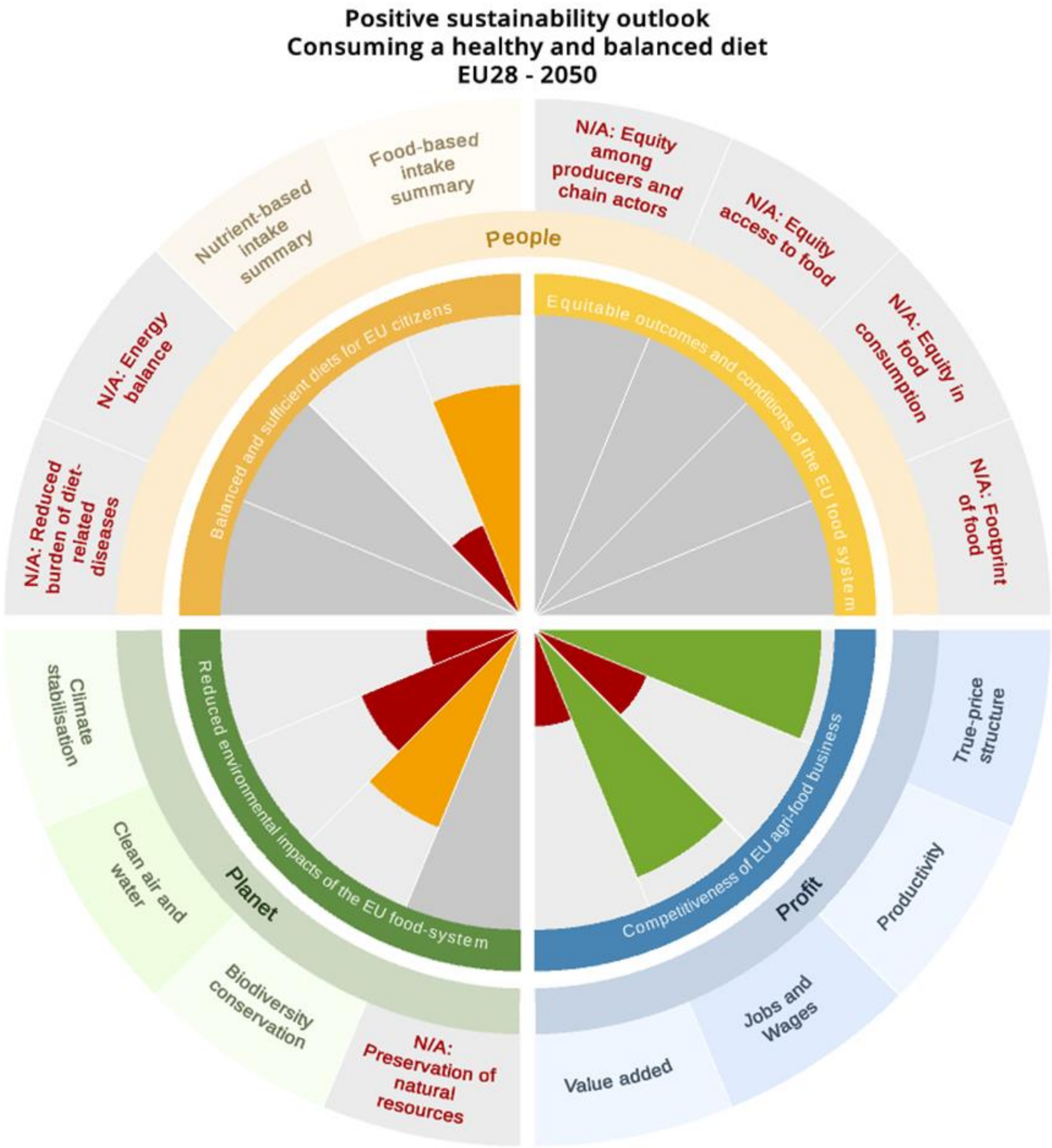

Figure 5 SUSFANS visualizer showing changes in performance metrics for the EU28 in 2050 compared to 2010 for the REF+ scenario with changing food patterns & BMI under 25. Source: Frank et al. (2019, D10.4)

Moreover, the toolbox allowed to assess sustainability implications across spatial scales. While focused around the EU, however also considering interactions with regions outside the EU, the toolbox provided results down to the EU country and even sub-national level (NUTS2). In addition, the project allowed further advances and extended the sectoral coverage of the applied models to represent also the fish sector (Heckelei et al., 2018 (D9.3)) and implement stochastic elements that allow to consider, for example, impacts of extreme weather events (D9.3). Further model extensions were developed regarding the representation of food loss and waste and modelling imperfect competition (Carmona-Garcia et al., 2017 (D9.4)).

One important limitation of all macro-models is the treatment of household heterogeneity. All these models assume a single representative household to describe consumer behaviour. This is one of the reasons why it is difficult to present detailed equity metrics that account for the differences in the distribution of income and wealth across households or persons.

Unfortunately, household level income data, which is typically drawn from nationally representative household surveys, is not easily available, in particular at global scale. There are a few examples in which household survey data was combined with global models to assess future poverty and income change, albeit often only covering a handful of countries. GTAP-POV (Hertel et al., 2015) is a macro-to-micro modelling approach in which a micro-simulation household model is embedded in the GTAP model. It simulates household welfare at the poverty line for different strata of the population. At the moment the GTAP-POV framework contains information on 31 countries. MYGTAP (Minor and Walmsley, 2013) is an approach to bridge the gap between the GTAP model and single country CGE models, which have a much richer representation of the household sector. It adopts a consistent approach to split the regional household and factors in the GTAP model into multiple households and factors using additional data. Model outcomes include factor income and consumption per type of household, which can subsequently be used to assess the impact of economic shocks on poverty, food security and nutrition. In comparison to GTAP-POV, MYGTAP requires even more detailed household level information, which makes it cumbersome to apply the model to multiple regions or the global level. The household module in MAGNET is based in MYGTAP and data for Czech Republic have been added Kuiper et al. (2018b, D9.2). Suitable data for the other case study countries was not available and the Czech household data were found to be lacking in terms of demand detail with all households having the exact same demand pattern. Therefore, this module was not used in the foresight exercises.

A notable exception to the specific country focus is the Global Income Distribution Dynamics (GIDD) model (Bussolo, De Hoyos, and Medvedev, 2010), which covers a much larger share of countries (132), representing about 91% of the total world population. This model has an explicit long-term focus and tries to capture the impacts of demographic changes, such as aging and the skill composition of the population by combining a database on income distribution with a global CGE model. Only a few studies have used the combination of integrated assessment models and household data to assess food security and nutrition and most of them cover only a small number of countries (e.g. Breisinger and Ecker, 2014). Similar approaches can be used to improve the SUSFANS toolbox in the future and present detailed equity metrics, which at the moment are largely missing.

Adding to the limitations of representing consumer behaviour by a regional representative household, further concerns led to a less than satisfactory coverage of equity metrics. Wages of agricultural employees and the mark-up of farming activities are unavailable from the model databases. Furthermore, most equity indicators refer to subnational level and distributional aspects which are hardly addressed by the macro models operating at national level and above. Even though some socioeconomic markers were collected in the food intake data and available for the SUSFANS case study countries, these mainly referred to age and gender and, with rather few observations, to education, so that the implementation of representative consumer groups in the macro models was not possible on this basis.

Furthermore, the data used for model calibration is subject to uncertainties and potential aggregation biases. For example, the food intake data used in SHARP is subject to considerable underestimation of actual intakes. By the end of the project, the used data appears to be somewhat dated so that recent trends, e.g. of reduced meat intake, are not well represented in these and therefore neither in the modelling attempts. Here, a continuous updating and extension of the collection of food-intake data is an important activity for informing future foresight studies.

A very promising line of future work would be to build on the work done for the DIET model (outside of WP9), which captures household diversity in income and responses to price changes using supermarket data, including the simulation of sustainability and health impacts using the DIETRON model (see for a French application Irz et al. (2016)). These additional (behavioural) features, however, come at the cost of a more aggregated representation of both consumers and products than in the SHARP model. For example, in the French application four household groups (based on income level) and 22 food groups are distinguished. Similar to the macro models, DIET uses purchase data and not intake. The individual detail and intake numbers were the key reason to focus the toolbox development on the link between MAGNET and SHARP, allowing SUSFANS diet metrics based on individual intake data using a much larger product variety than available in any of the other models. Building on the experience gained links could be established between the macro models and DIET, to get a better understanding of sub-national differences in responses. Another interesting, but more complicated avenue, would be to connect the very detailed supermarket purchases data to intake survey data to capture both, purchasing behaviour and resulting intake amounts. Achieving both could add DIET in between the macro- and SHARP model to enhance both, up- and downscaling of consumer food purchase decisions. Additional household income details available from DIET would also enhance the scope for equity metrics capturing impacts on different income-household-groups.

As mentioned earlier, the SUSFANS modelling assessment has focused on changes in and impacts on the EU food system, however, embedded in global food markets. In the analyses presented in the deliverables D10.2 (Frank et al., 2018) to D10.4, also effects on global diets and sustainability metrics derived by the macro models were computed. Due to the focus on the EU context, however, the contribution of the EU food system to global food and nutrition security received limited scrutiny for analysing and improving the results. Future research could provide a more in-depth analysis of the contribution to global food and nutrition security from EU policies and behavioural changes. A focus on world regions that are most vulnerable with respect to food and nutrition security would be especially interesting in this context and could add to revealing distributional effects, i.e. equity, at a global scale.

From a more technical point of view, a challenge that could be overcome in the course of the SUSFANS project was the harmonization and exchange of model results in the process of delivering a consistent set of metrics. A clear communication regarding the exchange of model inputs, outputs and results was achieved. For the purpose of between-model comparisons, indicator results were provided from all models capable and similarities and contradictions were investigated (e.g. D10.4). A more in-depth analysis of macro-model differences in future research, however, would provide a more profound understanding of occurring differences suggested by the models and with this an understanding of the impact of differing model assumptions and parameters. Multi-model applications and careful analysis of the results provide a potentially rich and still in parts untapped source of information for understanding complex foresight results. Some comparisons between macro- and micro-models for diet related indicators were included but remained limited due to the differences in agent and product representations. Additional work will be needed in the scope of further research to bridge the remaining gap between the macro- and micro-models.

For the representation in the SUSFANS visualizer (D6.3, D10.4) results from different models were combined to increase the indicator coverage for the scenario assessments. However, despite the benefits, this handling comes at the danger of presenting results from models with diverging projections of the underlying price-quantity framework for projection horizons. A visualizer extension accounting for uncertainties with respect to model projections could be considered to account for the range of model results for single indicators.

Translating food system change narratives into quantifiable SUSFANS model scenarios

Assessment of current diets (Mertens et al., 2018) and projections of EU food system developments (Frank et al., 2018 (D10.2)) show ample room for improvement in terms of both healthy diets and sustainability of European food production. The SUSFANS toolbox allows a quantified exploration of changes in the European food system to identify win-wins and trade-offs among the SUSFANS metrics. This requires a translation of potentially rich narratives of change into a limited operational set of parameters steering the projected developments by the models into a different direction.

In the context of SUSFANS this translation has been made for the contextual scenarios (D10.2) and for interventions in primary production or at the demand side (van Zanten et al., 2019 (D5.4), Latka et al., 2018 (D10.3) and D10.4). The contextual scenarios provide the backdrop capturing key macro-economic drivers like population growth (affecting total food demand and resource pressure) and income growth driven by expected trends in technical change. All three macro models use the same quantification of drivers. Projected changes are, however, not uniform due among other things to different focus and set-up of the models. The harmonization of large food system drivers across the models thus provides an assessment of changes of the European food system through different lenses with European agriculture and agricultural policy focus in CAPRI, extensive environmental assessments of primary production in GLOBIOM and an economy-wide view including income feedbacks in MAGNET. Jointly they provide a more robust assessment of expected changes across the multiple dimensions of the metrics than each individual model.

When developing the intervention scenarios, different strategies in terms of model combination were used, ranging from a single-model- (assessing the impact of reducing animal density with CAPRI, evaluating market stabilisation policies with GLOBIOM-X), over a two-model- (changes in the common fisheries policies with CAPRI and GLOBIOM) to a multiple-model-application (diet changes imposed at the demand side with CAPRI, GLOBIOM, MAGNET-SHARP). From these various set-ups, the main lesson is that harmonization across multiple models, while adding robustness and a more varied perspective, also proves very taxing in terms of harmonizing the technical implementation in a sensible manner given the rather different set-up of each model. Furthermore, understanding diverging results is very time consuming due to the many potential sources of divergence. These costs of harmonization and mutual understanding of each other's model come at the expense of more in-depth analyses of the actual scenario. Such a trade-off of scope versus depth is inherent in any multi-dimensional assessment beyond the confines of a single model or discipline and has to be judged case-by-case.

A major contribution of the model applications (and part of the complexity of a harmonized scenario) is the need to be really explicit on both the size and causal mechanism of an intervention. For example in the case of the diet scenario, the nutritional assessment provided clues on the size of the diet shift both in terms of becoming more healthy and appearing feasible given past shifts in diets. No information on the intervention or causal mechanism for the desired diet shift was available, nor on the cost of these interventions. This raised a discussion on the appropriate instrument, resulting in the review of evidence of (large scale) interventions and a ranking of diet interventions in D10.3. In short, the technical implementation of the scenarios requires a very explicit definition of who will change their business-as-usual behaviour, how much, why, at which cost, paid by whom. Looking from such a macro modelling perspective revealed a lack of strong empirical evidence on the scope and costs of diet changes at national level targeting consumers.

With an operational scenario in place, the toolbox yields a wealth of information, effectively offering a laboratory to experiment with different interventions which may reveal links and trade-offs that cannot be derived from more in-depth, partial analyses. For example, the work on combining environmental and nutritional data in SHARP allows for a lot of detail on individual and product differences. Due to the nature of the model, however, it uses fixed environmental coefficients from life-cycle analysis (LCA) databases. Combining SHARP with the macro-models allows us to analyse the changes in environmental impact of food production due to general socio-economic changes (from the contextual scenarios) or as a result from diet changes at national level. This may reveal trade-offs or win-wins not available from a static LCA based assessment.

Using the toolbox, the environmental assessment method could shift from using constant coefficients from an *attributional* life-cycle analysis into a *consequential* life-cycle analysis (e.g. see Weiss and Jansson, 2017 (D4.3)). In the consequential approach, the quantity shifts from changes in demand and use of natural resources are factored into the environmental assessment. It is important to maintain system relations and feedbacks (e.g. through market dynamics) in the modelling of consequential LCAs. This can be illustrated with an example. The market impact of meat supply in response to a carbon tax on production will not affect all livestock production systems in similar proportion. To the extent that environmental performances differ by the characteristics of the various production systems – such as whether production systems are linked to dairy farming, use imported feeds or are mixed farming systems – this shift is important for assessing the environmental impact of a change in demand. The SUSFANS toolbox can deliver an assessment that accounts for these relations within the system boundaries represented in the models, even though the detail in terms of specific production and farming systems should be increased.

The SUSFANS toolbox also provides a capable platform for modelling the environmental footprints of food. As indicated above, the standard approach to assess footprints, in terms of land use, carbon emissions or water use from food, is based on production-accounting. Also, the current UNFCCC policy framework for the mitigation of carbon emissions takes production as the sole entry point. The difference is extremely relevant, as can be illustrated with data for The Netherlands. A significant part of the food and materials consumed in the Netherlands (and EU) is produced in other parts of the world. These imports imply that a large part of the environmental effects of European consumption occur in other regions. For example, about 80% of the land footprint of food and materials used in the Netherlands lies abroad (PBL, 2017). The total land footprint of consumption is about three times the land footprint of production in the Netherlands. Similarly, the greenhouse gas emissions of consumption in the Netherlands are substantially higher than emissions linked to Dutch production PBL (2017). The GLOBIOM model is already employed to assess the climate mitigation potential from changes in European diets, as part of ongoing research for DG Climate Action of the European Commission. A further development of the SUSFANS toolbox to account for the footprint of consumption – using linked

MAGNET-SHARP models – would allow to more comprehensively assess the merits of consumer versus producer policies. Also it will help to identify the leakage, rebound and backfire effects of consumer oriented policies versus producer oriented policies, and support the political economy dialogue between different departments and levels of decision-making. While allowing for a comprehensive assessment summarized by the array of SUSFANS metrics, the implementation of scenarios is bound by the "resolution" and modelling of the behaviour of agents. Here the conceptualization of agents and their interactions (discussed above) becomes key. For example, limited (MAGNET) to no detail on supply chains (CAPRI, GLOBIOM, SHARP) strongly restricts the scope for supply chain focussed scenarios. Furthermore, as illustrated by the mapping of a large variety of diet interventions (see Table 3 in D10.3) to model scenarios, widely different types of interventions like placement of food in canteens or providing healthy diet information would be generally captured by a taste shift in the macro models. Altering the demand responses of the single national representative consumer captures both interventions. A comparison of their effectiveness or an analysis with respect to the heterogeneity of responses across population groups is not possible.

In terms of the scenarios addressed in D10.2, D10.3 and D10.4, richness in narratives is lost concerning important aspects. For example, the contextual scenarios reveal an opportunity for European agriculture to shift from a quantity to a quality focus. The current models, however, do not account for explicit quality differences in products preventing an exploration of such a system change. One could explore, however, how changes in production activities and a larger share of consumers interested in high quality food would intelligently translate into a scenario increasing production cost and shifting the aggregate consumer's preferences. Another area are interventions to improve the sustainability of primary production. The missing heterogeneity of the farm distribution and their individual response behaviours to policy intervention requires again assumptions and/or complementary analysis when defining scenarios. For example, the aggregate macro models do not allow assessing how strongly farms are affected by new regulations tightening the management of nutrient balances on farm. The individual restrictiveness, however, does have direct impact on the aggregate effects at regional level.

The set-up of the diet side scenario in D10.4 could not make use of an alternative diet defined in terms of detailed FoodEx2 groups, given the current state of development of the SHARP model (D7.5). Lacking an alternative diet defined by SHARP in specific terms, a very aggregate diet scenario was imposed aligned with broad food definitions in the macro models. The changes in the broad MAGNET food groups where then mapped to the detailed FoodEx2 data to compute the diet metrics. Given the rather coarse product resolution and lack of socio-economic markers in the intake surveys the changes at FoodEx2 level are also very coarse and differentiation across population groups could be made. Using a full-fledge SHARP diet would allow a more refined assessment of the diet impacts, using the coarse mapping to the macro models only for the assessment of the system-wide changes in economic and environmental sustainability and equity.

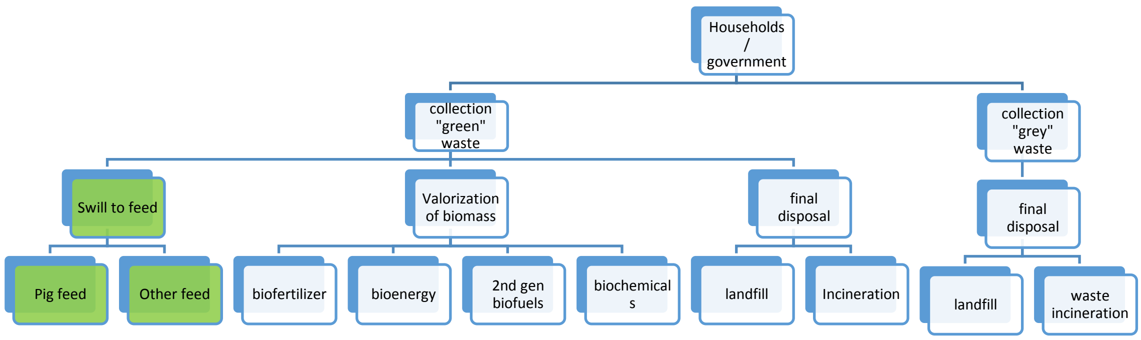

Figure 6. Concept for incorporating waste flows from consumption as source of feed in a circular bioeconomy and food system into the SUSFANS toolbox

Under a continued SUSFANS collaboration beyond the end of the project duration, food system innovation pathways presented in D5.4 will be translated into quantifiable model scenarios. For example, the insights derived on incorporating food loss and waste streams into animal feed is planned to be implemented in the CAPRI model. Since the utilization of food waste is not represented in the modelling system so far, further model advances are required to add this element of circularity. This is particularly relevant in an application of the SUSFANS toolbox in a wider bioeconomy perspective in which flows of nutrients and other biomass resources should be retained in economic system for use at maximum value. A conceptualisation of how the structure of MAGNET could be adjusted to reflect on the use of waste from consumption - including waste from catering industries, sometimes referred to as "swill" – in the bioeconomy and food system is presented in Figure 6.

Conclusion - the way forward in modelling sustainable food and nutrition security

The preceding recap of the SUSFANS modelling work reveals that the model toolbox is ready to assess transitions to healthy and sustainable diets of EU citizens to a considerable extent. One of the main strengths of the SUSFANS toolbox is inherent in the complementary nature of the combined macro- and micro-models. Extending model scopes, adding new features and establishing new linkages and data exchanges between the models are major achievements throughout the project life cycle. Combining models of very different foci and scientific background allows conducting a multi-dimensional impact assessment with a large coverage of sustainability and diet metrics across spatial scales.

The performed model collaboration also revealed difficulties and limitations of the current approach. The acknowledgement and description of these research gaps imply promising elements of a future research agenda proposed in the following. It covers the supply and demand side modelling of the food system, the impact dimensions of unhealthy diets and interventions to overcome them as well as the communication of complex modelling results.

Steps forward in modelling food supply covering production, processing and retail:

- Increase detail on actors and interaction in the food supply chain – A better capture of scope for interventions in the processing and delivery of foods through different channels could be achieved by increasing detail in the food chain model representation. This should also entail an enhanced representation of food quality differences going beyond generic food items. This would also require a fitting representation of quality differences in international trade rendering such advances clearly ambitious.

- Increase detail on regional and agent level impacts of production changes and their possible responses – The feasibility of transformative changes and the effectiveness of interventions in the production system cannot be fully assessed without considering farmer and processor heterogeneity.
- Advance the endogenous modelling of emergent food systems properties and innovations - The SUSFANS toolbox application requires to cover those largely with intelligent scenario formulations. A dynamic, interactive, agent-based modelling of the food system would be a promising step toward a complementary tool leading to potentially different results from what we have assessed in the scenario analyses.
- Extend the indicator coverage - Despite the broad range of sustainability indicators used in the SUSFANS toolbox, extending the coverage of indicators to encompass other elements of environmental impacts, for example related to aquaculture production and fish capture, would allow analysing risks and trade-offs across sustainability dimensions more comprehensively.

Steps forward in modelling consumer choices, intervention pathways and impacts of dietary choices across the population:

- Increase the representation of behavioural drivers in nutritional models like SHARP - A better understanding what interventions are suitable to achieve diet changes could be created by combining intake data with data from income surveys, detailed supermarket purchase data and consumer research.
- Include insights on behavioural drivers from behavioural economics - The behavioural drivers of changes in diets are poorly understood and captured in macro-economic models. Even though the effect of such diet shifts can be approximated using either scenario assumptions or economic price incentives (e.g. taxes), to endogenously model behavioural change, the incorporation of knowledge from behavioural economics would be helpful.
- Account for subnational differences and agent heterogeneity - Looking at an average consumer hides potentially severe impacts as the distribution of impacts across individuals is not considered, for example how a food price rise

caused by a fat tax impact on the poor, the elderly or women versus men. One first step in this direction could be to account for subnational differences and heterogeneity in the scenario development e.g. considering age and gender structure of the population, rural and urban when projecting future diets.

- Include feedback loops from (un)healthy diets - Through health impacts, diets affect labour productivity, health costs and demographic changes in various ways which has impacts beyond the food system.
- Quantify equity metrics - improving model representation of subnational levels and distributional aspects, impacts on equity arising from changes in the food system could be better quantified. Thus, a more holistic sustainability assessment could be provided.

Steps forward modelling global impacts of EU food system changes:

- Extend the spatial focus of the analysis – A more in-depth assessment of global impacts arising from changes in the EU food system could be undertaken, especially with focus on those regions that are most vulnerable with respect to food and nutrition security.
- Improve non-EU model coverage – Some indicators are only available at EU scale due to the regional focus of some of the used models (e.g. CAPRI and SHARP). If global impacts shall be analysed, either the employed models need to be extended or additional models that contribute the missing coverage could be involved in the toolbox assessment.

Step forward in assessing and communicating large and complex results from multiple models hailing from different paradigms:

- Improve understanding of model differences – A better understanding and deeper analysis of results from multi-model applications could provide a potentially rich and still in parts untapped source of information for understanding complex foresight results. This would also be a basis for adding missing model interlinkages and making even better use of complementary model strengths;
- Extend visualizer features - The SUSFANS visualizer is a useful tool for communication of results of these highly complex tools to policy makers and

the general public. However, further improvements could be envisaged such as providing additional information (on the metrics, decomposition of aggregated indicators etc.) and features (uncertainty ranges, statistical analysis etc.) to further facilitate the science-policy dialogue.

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