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Agricultural Systems, *163*, 45–57, doi: 10.1016/j.agsy.2016.10.014

Metrics, models and foresight for European sustainable food and nutrition security: the vision of the SUSFANS project

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Abstract
This paper defines the research agenda of the SUSFANS project, describes its history and its potential societal impacts. It contributes to balanced and encompassing views on how to strengthen food and nutrition security outcomes in the EU and how to improve the performance of the food system in the EU from the perspective of social, environmental and economic sustainability. The research is led by the notion that improvements in the diets of the European consumer must come from, and be supportive of, sustainable food systems. Its holistic, integrative approach builds a set of metrics, models and foresight tools, useable for navigation on sustainable food and nutrition security. This results in a coherent and supported vision on sustainable food and nutrition security in the EU and globally, and underpins a perspective on how EU policies on farming, fishing, food and nutrition could contribute to that vision with greater efficacy than today.

Keywords
Sustainable food and nutrition security, diets, food system, metrics, modelling, foresight, multi-criteria analysis, policy, EU

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Citation:

Rutten, M., Achterbosch, T. J., de Boer, I. J. M., Cuaresma, J. C., Geleijnse, J. M., Havlík, P., Heckelei, T., Ingram, J., Leip, A., Marette, S., van Meijl, H., Soler, L. G., Swinnen, J., van't Veer, P., Vervoort, J., Zimmermann, A., Zimmermann, K. L., Zurek, M. (2018). Metrics, models and foresight for European sustainable food and nutrition security: The vision of the SUSFANS project. *Agricultural Systems*, 163, 45–57. https://doi.org/10.1016/j.agsy.2016.10.014

1. Introduction

In the second half of the twentieth century, European agricultural and fisheries policies – aimed at fostering agricultural productivity, securing fair living standards for farmers and ensuring food availability for its population – resulted in massive productive capacity and a strong knowledge and innovation base in Europe. The EU agri-food sector, including fisheries and aquaculture, now delivers a wide variety of products, creating convenience for consumers, cushioning risks to producers and generating jobs in rural and urban areas. Access to safe and nutritious food is, however, not guaranteed for all of Europe's consumers. Firstly, food quality and safety have sometimes been compromised, for example by outbreaks of BSE, salmonella, campylobacter and E. coli (Trienekens and Zuurbier, 2008). Secondly, despite improvements in overall living standards, food poverty is still experienced across certain sections of the population (Cockx et al., 2015).. At the same time, a high and rising proportion of the European population, close to 50 per cent in 2010, is overweight or obese (Elmadfa et al., 2009; Gallus et al., 2014), making them prone to chronic diseases (Finucane, 2011). As a flip side of increased European affluence, over a 100 million tonnes of food are wasted annually in the EU, a figure expected to rise to 126 million tonnes in 2020 (BIO Intelligence Service, 2013). This represents a waste of scarce resources, but also poses an ethical problem given the prevalence of hunger and undernutrition elsewhere. Moreover, environmental concerns are on the rise, with climate change having differentiated impacts on agriculture in Northern and Southern Europe through changing land, water quality and yields (Leclère et al., 2013), but with agriculture also contributing to climate change, in the form of GHG emissions (Bindi and Olesen, 2011; Ciscar et al., 2010).

Maintaining the agri-food sector's beneficial services to society is increasingly challenging in the face of ever-changing economic, social, political and environmental conditions (Foley et al., 2011; Rockström, et al. 2009). In the short-term, food crises – which may arise due to weather extremes or financial downturns – need to be guarded against, and the growing pressures on the natural resource base need to be reduced. In the long-term, the EU agri-food sector needs to be competitive and sustainable in the global setting of climatic, geopolitical and socioeconomic change if it wants to maintain a strong European production base. At the same time diets should become more healthy and nutritious, whilst remaining affordable and allowing for cultural diversity (Agrimonde, 2011; UK Foresight, 2011).

EU policy makers increasingly recognise that European diets need to become more environmentally and economically sustainable, ánd more healthy and nutritious, as evident from recent policy documents on the CAP (COM (2010) 672), nutrition, overweight and obesity-related health (COM (2007) 279), resource efficiency (COM 2011) 571) and the circular economy (COM (2014) 398). The majority of research on FNS has however historically been relatively disparate, either focusing on food production by agricultural and fisheries sciences, or on consumption patterns, diets and health by the nutrition sciences (Harris et al., 2013). Whereas there is a growing body of literature that calls for bridging this disciplinary divide to make agriculture more nutrition-sensitive (Chicago Council, 2011, 2015; Fan and Pandya-Lorch, 2012; FAO, 2013; Gustafson et al., 2016; Jaenicke and Virchow, 2013), and arguably vice-versa, common metrics, methods and foresight on the basis of which programs and policies can be designed and implemented that address the nexus of agriculture and health in support of sustainable FNS are thus far lacking.

This has led to the development of a new, transdisciplinary research project, SUSFANS, which develops metrics, identifies and analyses drivers, integrates data and modelling and formulates foresight for EU sustainable FNS, building on a common scientific evidence-base which accounts for the perspectives of the various actors and factors that play a role in the food system.

Box 1 SUSFANS project details

Objective: To build the conceptual framework, the evidence base and analytical tools for underpinning EU-wide food policies with respect to their impact on consumer diet and their implications for nutrition and public health in the EU, the environment, the competitiveness of the EU agri-food sectors, and global food and nutrition security.

Duration: 2015-2019

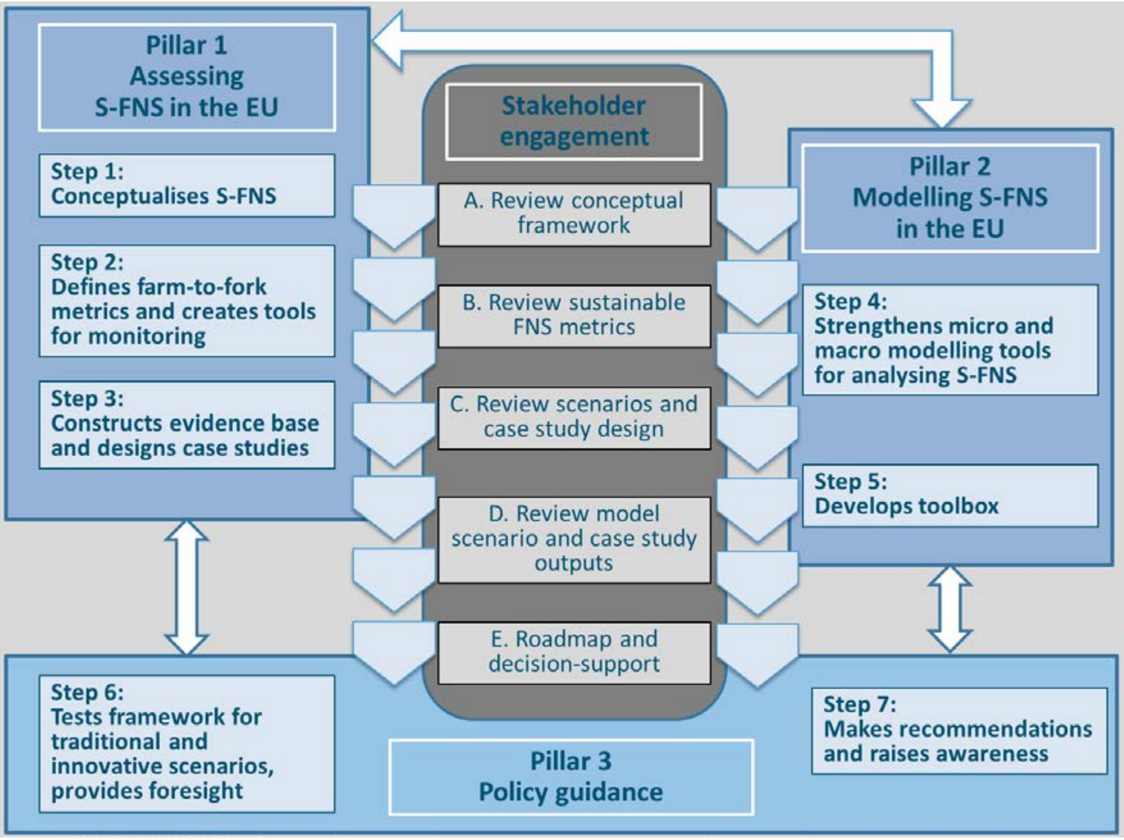
Coordination: LEI Wageningen UR (LEI-WUR)

Partners: Wageningen University and Research Centre (WUR); Institute for Food and Resource Economics, University of Bonn (ILR); the French National Institute for Agricultural Research (INRA); Centre for European Policy Studies, University of Oxford (CEPS); International Institute for Applied Systems Analysis (IIASA); Czech National Institute of Public Health (SZU); French Agency for Food, Environmental and Occupational Health & Safety (ANSES); Consiglio per la Ricerca e la sperimentazione in Agricoltura (CRA); Technical University of Denmark (DTU); International Life Sciences Institute (ILSI)-Europe; Swedish Institute for Food and Biotechnology (SP); European Commission – Joint Research Centre (JRC); National Taiwan University (NTU), National Resources Institute Finland (Luke); DSM Nutritional Products; Dutch Dairy Association (NZO); and Unilever (R&D).

Funding: €5 mln. under contract H2020-SFS19A-2014, Grant 633692

This paper presents the vision of SUSFANS on how to advance research in support of policy and practice on sustainable FNS in the EU, as developed by its partners from academia, public and private sectors (Box 1), and how this vision came into being in response to and improves upon current approaches.

Figure 1 The three pillars of the SUSFANS project



The structure of the paper is organised along the lines of the three pillars of SUSFANS (Figure 1), each of which will be elaborated in the sections to come. A preparatory Section 2 gives a summary of how the SUSFANS project came into being, identifying key points where SUSFANS addresses shortcomings and/or improves upon currently available approaches. Section 3 discusses SUSFANS' approach to assessing sustainable FNS, including a conceptual framework, metrics and analytical tools for measuring, assessing and monitoring the current state of FNS in the EU and underlying drivers of change. Section 4 elaborates on new and improved models combined in a SUSFANS toolbox for quantification of future scenarios. Section 5 describes the process of foresight and policy guidance for effective EU-wide farm, fish, food and nutrition policies using both scenario analysis and case studies, with stakeholder engagement effectuated in the design of policy interventions and innovations as well as in the evaluation of outcomes via a participatory MCA. Section 6 illustrates how the project envisages to have impact by means of its outputs. The final section summarises and concludes.

2. History of the SUSFANS project: towards an integral, participatory and forward-looking assessment method of sustainable FNS in the EU

Sustainable food and nutrition security has been described as a key aspect in the research and innovation strategy for Europe. In the European Commission's work program for Horizon 2020, the concept pertains to securing food production from agriculture and marine resources for a healthy life and wellbeing while ensuring global competitiveness, nutrient availability, resource efficiency, environmental protection, and innovation potential in the EU in the long run. Call no. SFS-19A solicited proposals for analytical tools that support foresight on future reforms of the Common Agricultural post-2020, the management of short term food crises in European markets and regulation of supply chains, and consumer & health policy related to food and nutrition. Several directorates of the European Commission, notably Agriculture & Rural Development, Health and Food Safety (referred to as SANCO at the time), Growth, and International Cooperation and Development were foreseen to benefit from the knowledge and innovations developed under this grant.

Funded under this grant, the SUSFANS project brings together researchers from the more macro-oriented agri-food production and supply sciences and environmental sciences - who are increasingly interested in incorporating nutrition and health impacts into their integrated assessments - and researchers from the more micro-oriented nutrition and health sciences – increasingly interested in food systems and wider economic tendencies explaining nutrition and health outcomes. The team jointly developed the multidisciplinary research framework that is presented in this paper.

The macro-level orientation is well-established in policy research on food and nutrition security and sustainable food production systems in Europe. Researchers in the FOODSECURE project demonstrated that the drivers of European FNS and global FNS need to be analysed in a single framework in order to assess the impact of European policies on global food security (Pieters et al. 2012). Laborde et al. (2013) argue that a "toolbox" of integrated assessment models with harmonised data inputs provides a useful instrument for this purpose, in particular for analysing FNS in the long term under climate change. Pangaribowo at al. (2013) underpinned the toolbox with a basic theoretical model for the system that produces FNS, derived from existing framework of health production functions. SUSFANS follows up on both advancements though an operationalisation of a similar modelling tool in the European context.

With a micro-level orientation, nutritional epidemiology contributed to the concept of food and nutrition security (FNS) by taking the nutrient adequacy of a typical European diet as a requirement per se. This basic principle of sustainable FNS had been substantiated by members of the SUSFANS team in previous and related EU-funded projects. The EURRECA Network of Excellence explored the process of setting micronutrient recommendations to address the variance in recommendations across Europe (Dhonukshe-Rutten et al., 2010). The EU Food Consumption Validation (EFCOVAL) validated dietary assessment in 5 EU countries (Crispim et al., 2011). The recognition that behavioural factors are strong determinants of diet and health outcomes in the EU was examined in a project on the determinants of diet and physical activity (Lakerveld et al., 2014). Results from FOODSECURE point to the need to understand social dynamics, such as exclusion and discrimination, in relation to the prevalence of chronic calorie deficiency and child malnutrition in the EU which, though decreasing over time, remains cause for concern in particular among ethnic minorities (Cockx and Francken, 2015).

The food systems literature provides an overarching framework that integrates these levels of analysis. SUSFANS refines and operationalises the conceptual framework for assessing sustainable FNS from a previous construct (Acharya et al., 2014) in the European context. The European context is characterised by relatively long and complex supply chains, diverse diets and relative openness, implying strong interdependencies with the rest of the world. The SUSDIET project identifies targets for a sustainable European diet, and designs a mix of policies to drive dietary change towards those targets. About 45% of the EC-budget is currently allocated to agriculture and fisheries but the underlying policies are currently poorly connected to the nutritional needs of the population. Based on the SUSFANS framework, a more extended policy debate around food and nutrition can be informed, that includes an orientation on both consumers and producers.

A novelty in SUFANS' approach of analysing FNS is the broadening of the concept of sustainability, which incorporates, next to the traditional environmental dimension, also social (health), economic and global FNS dimensions, with inherent synergies and trade-offs involved (Masset et al., 2014a; Wursthorn et al., 2011). These dimensions followed from discussions with stakeholders across the various disciplines, representing the actors and stakeholders in the food supply chain. They reasoned that those who produce or supply food in the EU should be able to make a decent living (economy) and that those who consume food in the EU should benefit from a nutritious diet now and in the future implying that our natural resource (environment) and human capital base (health) should not be implicated but sustained. Moreover, the perception was that on the whole this may not go at the cost of the rest of the world and developing countries in particular (global FNS).

The participatory approach of SUSFANS ensures an active involvement of stakeholders from the food supply chain, public sector, research communities and civil society throughout the project in support of a shared and sustained view (Rounsevell and Metzger, 2010; UK Foresight, 2011).

SUSFANS's approach to sustainability is in line with calls from a recent and rapidly growing body of literature for research and evidence-based policies on how to make diets more sustainable (Bajželj et al., 2015; Garnett, 2014a,b), human diets being where the various dimensions of sustainability of FNS come together. SUSFANS runs parallel to the work in this area by Bioversity International and CIHEAM-Montpellier, which places relatively more emphasis on integrating biodiversity and nutrition, the developing country context, and the angle of vulnerability (Allen et al., 2014; Johnston et al., 2014; Prosperi et al., 2014). SUSFANS however has a broader scope and goes further by defining desirable and feasible sustainable diets for the EU population, following a vision of what current and future diets may look like, and how to get there (foresight), using a combination of scenario modelling (e.g. Nelson et al., 2013) and participatory multi-criteria analysis (MCA) (Kowalski et al., 2009).

The forward-looking scenario modelling is carried out by developing a consistent and coherent, analytical toolbox, which integrates new and improved micro-level models of nutrient intakes, habitual dietary patterns, preferences of individual consumers and health impacts (Gerdessen et al., 2014; Irz et al., 2015; Rutten and Reed, 2009) with enhanced macro-level biophysical, agricultural and economic models of food demand and supply often used in integrated assessments (Britz et al., 2012; von Lampe et al., 2014) in the context of economic, environmental and demographic changes over time (short- to long-term) and across various socioeconomic strata and spatial scales (global, national, regional). The toolbox provides the data for a consistent assessment of sustainable FNS in the EU in the future.

The framework for assessing FNS will tested using case studies for innovations in livestock-fish production and fruit-vegetable consumption, which serve as input for more broad-based scenarios for future FNS applied using the SUSFANS toolbox as well as form an input for refining the toolbox further.

The project focuses on five countries – Denmark, Netherlands; Czech Republic; Italy; France – representing the diversity of food habits in the North, East, South and West of Europe, as they participate in the emerging pan-European Nutrition Surveillance (de Boer et al., 2011).

3. Assessing sustainable FNS in the EU

An assessment of sustainable FNS in the EU starts with a solid concept and evidence-base consisting of metrics, data and an understanding of causal factors or driving forces that drive FNS outcomes. This consists of a framework of concepts and causal relationships (Step 1 of Pillar 1, Figure 1), metrics and tools by which we measure, assess and monitor these (Step 2 of Pillar 1), which culminate in a database for the quantitative assessment of sustainable FNS in the EU (Step 3 of Pillar 1).

3.1 Conceptual framework for assessing sustainable FNS

The concept of FNS has evolved over time from a combination of the concepts of food security and nutrition security (Pangaribowo et al., 2013), which in the EU are used by a broad range of stakeholders attaching different meanings and making different claims about the underlying causalities (Candel et al., 2014). SUSFANS employs the prevailing definition of FNS, which states that FNS exists when:

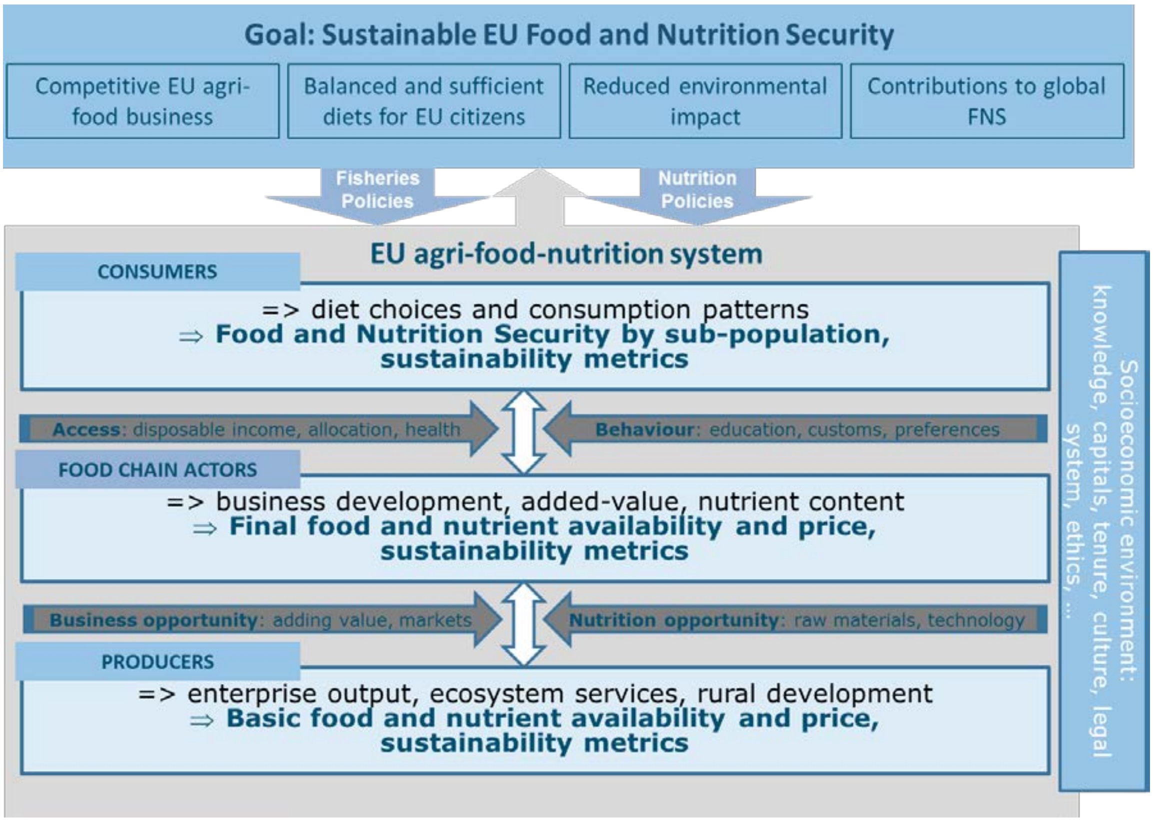
"all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life" (CFS, 2012).

This definition is taken to capture the simultaneous challenges of hunger/nutrient deficiencies and excess calorie intake – the "double burden of malnutrition" (WHO, 2003) –, and the underlying heterogeneity across socioeconomic and demographic strata and regions in terms of food availability, access, utilisation, and stability therein, influenced by variations in health services, health environment and caring practices.

SUSFANS extends the concept of FNS to include different dimensions of sustainability for the EU food system to reflect the EU Commission's policy goals. This includes the notion to reduce the environmental impacts of the food system (e.g. reduction in GHG emissions or soil fertility loss), but also economic and social dimensions. The economic dimension implies that those who produce food – be it an individual farmer or fisherman, a farm worker, an SME or multinational corporation, or even a cluster such as EU agri-food – should be able to run a viable business or earn a decent living. The social dimension ensures the diet is balanced according to nutritional standards, that health outcomes are satisfactory, and that cultural diversity and social capital are preserved. In addition, as about 75 per cent of EU citizens are concerned about feeding the world's population (European Commission, 2012), sustainability goals also include the contribution of the EU agri-food-nutrition system to global FNS. The sustainability dimensions that have been added to the definition of FNS can be interpreted as capturing impacts of diets on societal wellbeing.

Naturally, synergies and trade-offs between (and within) the sustainability dimensions (but also across actors) may be observed. For example, guidelines for a healthy diet generally advise EU consumers to cut down on the consumption of meat and processed foods, and to increase consumption of fresh fruits and vegetables. To the extent that this diet is culturally acceptable to adopt and in line with consumer preferences, it has implications for livestock farmers and the food industry in the EU and elsewhere, with some going out of business whilst others may reinvent themselves by innovating or shifting business. The environmental implications of this dietary change are manifold and involve trade-offs between the use of fresh water and land resources in livestock and horticulture, carbon emissions from handling, transport and packaging and so on. An integrated assessment of sustainable diets (Section 2.3 below) will reveal some of the key trade-offs – which could also occur across time and spatial scales. Assigning values on the relative importance of the various sustainability dimensions, elicited from different stakeholders from the government, private sector, research community and civil society, provides greater clarity on what they consider to be sustainable diets from a health, environmental, economic and global FNS perspective.

Figure 2 Conceptual framework for sustainable EU food and nutrition security



Source: adapted from Acharya et al. (2014) and Ingram and Porter (2015)

Having defined sustainable FNS in the EU context, SUSFANS follows a food systems approach for its assessment, building on the interdisciplinary conceptual framework of Acharya et al. (2014) and Ingram and Porter (2015). Given the scope of the project, other systems such as health and sanitation systems, whilst important, are not further examined. The current version of the conceptual framework

(Figure 2) includes relationships and interactions between policy goals as given by the four dimensions of sustainability (Figure 2, top); consumers, food chain actors and producers in the agri-food-nutrition system (Figure 2, horizontal boxes), as well as the short-term and long-term socioeconomic and biophysical factors that drive changes in the food system (Figure 2, boxes at the side and base, and horizontal arrows). Arrows from the bottom to the top summarise the flow of food, nutrients, value and other information through the food system, from farm (agricultural production), via the food chain (processing, packaging, shipping, storing, advertising, retailing, trading, etc.) to fork (consumers) at certain quantities, prices and levels of sustainability. This 'agri-food-nutrition' system contributes to the policy objectives for (a) the competitiveness of the agri-food business, (b) balanced and sufficient diets for EU consumers, (c) environmental sustainability of the system, and (d) FNS for the EU, its member states, and globally. Agricultural, fisheries, nutrition and environmental policies are in place to safeguard the public goals of the EU food system (arrows to the bottom). The external environment, both socioeconomic (including human capital, physical capital, institutions, ethics, culture) and biophysical (including soil, water, climate, biodiversity, minerals, energy), determine opportunities for business and innovations for improved nutrition on the supply side (bottom horizontal arrows) and access and behaviour on the demand side (top horizontal arrows).

The diagram presents two major hypotheses. First, consumer eating patterns are an important tool not only to improve public health but also other elements of sustainable FNS. The impact of consumer choice and diets on society is determined in the interaction of food choices of consumers and producer decisions along the entire food value chain (Verain, 2015). Second, observations on the current composition of diets and their food-system attributes can best be explained in a political economy framework, making this is also the basis for effective policy recommendations.

Part of the first pillar of the project is to further develop and enlarge the framework to lay out in more detail how the drivers influence the different food system actors and their activities and allow to map possible intervention points. Whereas the conceptual framework will be developed further in Pillar 1 of the project – fed by stakeholder input (Figure 1, grey column, element A) – it is instructive to see how one may operationalise and assess the current state of sustainable FNS in the EU using concrete metrics and tools.

Table 1 Preliminary operationalisation of sustainable FNS by the SUSFANS consortium

Elements in the definition of FNS	Operationalisation
When all people	Comprehensive analysis of nutrition status for all population groups (by age, gender, socioeconomic class) in five EU countries (Czech Republic, Denmark, Netherlands, France, Italy) Scaling up to EU-level
at all times	Time lens on current status (nutrition surveillance data), and future status five, ten, twenty and fifty years ahead (taking into account seasonal variations)
have physical,	Food supply from primary production in the EU, food chain activities from farm to fork, including imports into the EU and exports to the rest of the world and accounting for food loss and waste
social and economic access to food,	Income, prices and asset ownership; focus on less privileged socioeconomic strata and EU sub-regions (including the urban and rural poor)
which is safe and consumed in sufficient quantity	Sufficient energy intake levels in relation to individual needs, or aggregated measures derived from these Food safety is outside the scope of SUSFANS

and quality to meet their dietary needs	A procedure to set requirements for macro nutrients (proteins, fats, carbohydrates; energy) and a selection of micro nutrients (vitamins, iron) and nutrients with adverse effects on health (salt, saturated fats)
and food preferences,	Study of drivers for consumer choice based on typical diets, revealed consumer preferences (for example from retail data), and experimental study
and is supported by an environment of adequate sanitation, health services and care,	Outside the scope of SUSFANS
allowing for an active and healthy life.	Prevention of diet-related diseases as measured by prevalence and incidence of illness
Sustainability dimensions of FNS	
Economic/business sustainability	Competitive EU agri-food business (farm, fisheries, food industry), resilient to shocks and with potential for growth
Social/cultural/health sustainability	Nutritionally adequate diets for EU citizens, made available by the agri-food chain at affordable prices that are readily accessible and meet cultural needs
Environmental/climate sustainability	Addressing growing pressures on natural resources (land, water), at the level of farms, regions, countries in EU and beyond
Feeding the world's population	EU contribution to global FNS, i.e. to an improvement of individual status as well as improvements in underlying drivers

3.2 Metrics and tools for measuring, assessing and monitoring sustainable FNS

The SUSFANS consortium operationalises sustainable FNS by breaking up the FNS definition into its components, adding the four sustainability dimensions of FNS, and applying both FNS and sustainability dimensions to the EU (Table 1). The operationalisation addresses to what extent current EU diets fulfil nutritional requirements for population health (upper half of Table 1) and how environmentally, socially and economically sustainable EU food production at the moment is and whether global FNS is served (lower half of Table 1). Metrics and tools are sought to measure each element and underlying drivers of change, fed by stakeholder input from consumers, producers, food industry, government and the scientific community (Figure 1, grey column, element B).

In line with the flow of food and nutrients (Figure 2), measuring, assessing and monitoring of the state of FNS and underlying drivers of change is done from the angle of different actors in the food system: (primary) producers, food chain actors and consumers.

3.2.1 Primary producers and sustainable FNS

Metrics of the European's agricultural and fisheries sector contribution to FNS include production quantities, prices and nutrient availability (supply), income of entrepreneurs (economic sustainability), resource use and environmental externalities (environmental sustainability), and trade in food and so nutrients (contribution to global FNS). The current states of these indicators are assessed at different scales down to sub-regional level by a statistical procedure for disaggregating crop shares and input and output coefficients (Leip et al., 2008; Kempen et al., 2011). Concerning global environmental effects of food production in the EU, a special focus is put on emission leakages and respective consistent accounting systems (Leip et al. 2011b, 2015; Weiss and Leip, 2012). Regarding drivers, advances in EU agricultural productivity and resource use efficiency, i.e. a sustainable intensification, will be required to keep up with increasing global food demand and to stand up to climate change (Godfray and Garnett, 2014; Godfray, 2015; Hertel, 2011; Wheeler and von Braun, 2013). For understanding sustainable intensification paths, potentials and places as well as interactions between plant and animal production, the interplay between biophysical, managerial, economic and political drivers of food production and its sustainability are analysed based on quantitative methods for livestock, fish and crop production at the regional level in the EU (Hornborg et al., 2013; Licker et al., 2010; Neumann et al., 2010; Upton et al., 2015; de Vries et al., 2015).

3.2.2 Food chain actors and sustainable FNS

Metrics of the European food chain actors' contribution to FNS are the same as those for primary producers but then a step further down the chain. Food processors play a relatively influential role in the price and quality of food in terms of nutritional content (Haen and Réquillart, 2014). The processing, handling, storage and trade in food commodities also contribute significantly to employment in and the competitiveness of the EU agri-food sector (economic sustainability; Nowicki et al., 2009). And even though for many products the environmental impact is largest at the 'cultivation' phase (Castellani et al., 2016; FAO, 2010; Gerber et al., 2013; Pelletier and Leip, 2013), food loss and waste at the processing, retail, and consumption phase contribute significantly to the pressure that the food system exerts on the environment (Bellarby et al. 2013; Hiç et al. 2016; UNEP 2016; Vanham et al. 2015).In addition, there are several ways in which European food chain actors influence global FNS. With global value chains playing an increasingly important role in world markets, the standards set by modern retailing companies have significant implications for local producers in developing countries (Swinnen et al., 2015). While food quality and safety standards are sometimes considered as non-tariff trade barriers (Garcia Martinez and Poole, 2004; Unnevehr, 2000) and often believed to result in the marginalisation of small businesses in developing countries (Farina and Reardon, 2000; Gibbon, 2003; Asfaw et al., 2010), Swinnen et al. (2015) point out that there is considerable uncertainty and debate regarding the welfare implications of high-standards trade and global value chains. Although these standards can indeed exacerbate production costs, they increase the value of the products, potentially yielding higher profits (Maertens et al. 2012; Reardon and Farina, 2002; Swinnen and Vandeplas). Moreover spill-over effects to domestic production could enhance domestic food safety (Jaffee and Henson, 2005). Recent empirical studies suggest that smallholder participation in high-standards global value chains is more widespread than what was initially predicted (Reardon et al., 2009; Swinnen, 2007) and document mostly positive effects of high-standards trade on the welfare of small producers in developing countries (e.g. Dedehouanou et al., 2013; Rao et al., 2012; Maertens and Swinnen, 2009; Minten et al., 2009; Miyata et al., 2009). Finally, Beghin et al. (2015) conclude that the evidence suggests that the effects of standards are sector, country and standard specific. At the same time, these processes by means of physical movement and the perishable nature of food have resource use (waste) and environmental implications (environmental sustainability). Drivers for assessing European food chain sustainability are studied in relation to private food standards (Maertens and Swinnen, 2009; Marx et al. 2012; Vandemoortele and Deconinck, 2013), market power (Swinnen and Vandeplas, 2010) and policy (Duvaleix-Tréguer et al., 2012; Réquillart and Soler, 2014), on the basis of models of imperfect competition and life cycle analyses.

3.2.3 Consumers and sustainable FNS

Metrics of European consumer's FNS include actual consumption quantities and intake of macro and micro nutrients by population group, which – in comparison with EU dietary guidelines (Dhonukshe-Rutten, 2010) – signals whether nutritional requirements for an active and healthy life are met. Drivers of long-term consumption trends include demographics, asset ownership, consumer behaviour (habits), social environment (cultural beliefs) and socio-psychological factors such as attitudes, values and knowledge. Short-term drivers include availability and affordability (incomes and prices), which are affected by market shocks such as disease outbreaks and temporary food shortages (Sijtsema et al., 2012; Verain et al., 2012). Tools for analysing drivers and metrics at the level of consumers include experimental studies (Marette et al., 2008, 2011; Disdier and Marette, 2013), a consumer behaviour model (Bieberstein et al., 2013) and scenario analysis (Masset et al., 2014a, b; Vieux et al., 2012, 2013). The main scientific challenge is to know whether or not consumers have enough knowledge and motivation for changing their behaviour towards more sustainable eating habits, or, alternatively, whether or not regulation is necessary for thwarting "non-sustainable" consumption habits. Recommendations, product labelling or traffic lights mainly rely on consumers' sovereignty for reaching a sustainable world, with consumers supposedly to choose the most sustainable products after receiving relevant information. Alternatively, taxes or subsidies on products and/or minimum-quality standards can be imposed by a regulator, under the assumption that recommendations or labels are not read and/or recalled by consumers often overloaded with many messages. The impact of these different instruments on agents' surpluses and economic welfare will be estimated for helping public debates (Disdier and Marette, 2012).

3.3 Assessing sustainable FNS

The analyses of metrics for each dimension by actor come together in the overall assessment of FNS in the EU and its sustainability. Synergies and trade-offs, if present, become apparent here and manifest themselves in differences in the status of the different FNS components. The assessment uses stakeholders' input to determine the relative weights attached to the metrics of sustainable FNS. These weights are derived from a participatory MCA (See Section 4).

3.4 Database for a quantitative assessment of sustainable FNS

The results of the measurement, assessment and monitoring of FNS in the EU along its various dimensions and for the actors involved, and of the food system in total, are stored in a database containing data for metrics, drivers and outcomes of past and current sustainable FNS, which covers the sub-regional diversity of European diets and food systems. These are essentially the results of ex-post analyses. Projections and assessments over time are stored as well, and come from the ex-ante modelling of future sustainable FNS with the SUSFANS toolbox, which is the topic of the next section.

4. Modelling sustainable FNS: The SUSFANS toolbox

In order to assess the state of FNS in the EU and its sustainability over time, models are needed to project and/or predict food and nutrition supply and demand, taking into account complex market interactions and the impact of a wide array of drivers of change (Section 2.2) as well as policies on a wide array of sustainability outcomes (Section 2.1). The emerging science of integrated modelling increasingly used in assessments of agricultural and food systems (Britz et al., 2012; van Ittersum et al., 2008; von Lampe et al., 2014; Nelson et al., 2013) suffer from data limitations and model assumptions that have not yet been fully tested across systems critical to nutritional security (Acharya et al., 2014). These models are relatively poorly developed when it comes to nutrition and health impacts (Rutten et al., 2014) and have – with the odd exception (Tukker et al., 2011; Wolf et al., 2011) – not been employed in the analysis of healthy diets and/or health impacts. SUSFANS addresses these shortcomings by developing state-of-the art micro-level models of nutrition behaviour of individual consumers and macro-level models of food demand and supply, with short-term and long-term time horizons (Step 4 of Pillar 2, Figure 1). These models are combined in a toolbox for the quantification of future scenarios (Step 5 of Pillar 2). Such a multi-model approach benefits from the strengths of existing, leading world food system models and, at the same time, avoids the development of an unmanageable and overly complex model to capture the whole system.

4.1 Micro-modelling of current diets and health impacts using individual-level data

Based on individual-level data from five Member States (Denmark, Netherlands; Czech Republic; Italy; France), the nutritional adequacy of diets is modelled using EU dietary guidelines and nutrient reference values developed by the European Food Safety Authority (de Boer et al., 2011). A range of sustainability metrics is added to these individual food intake patterns (ex-post from Pillar 1, ex-ante as outputs from the macro-modelling), so as to model current and future diets that are environmentally Sustainable, Healthy, Affordable, Reliable and Palatable (SHARP), using a technique of Mixed Integer Linear Programming (Gerdessen et al., 2014). This allows for the fine-tuning of EU diets on the basis of the various SHARP constraints that reflect the sustainability dimensions of EU FNS (Section 2.1).

4.2 Macro-modelling of short- and long-term scenarios for food demand and supply

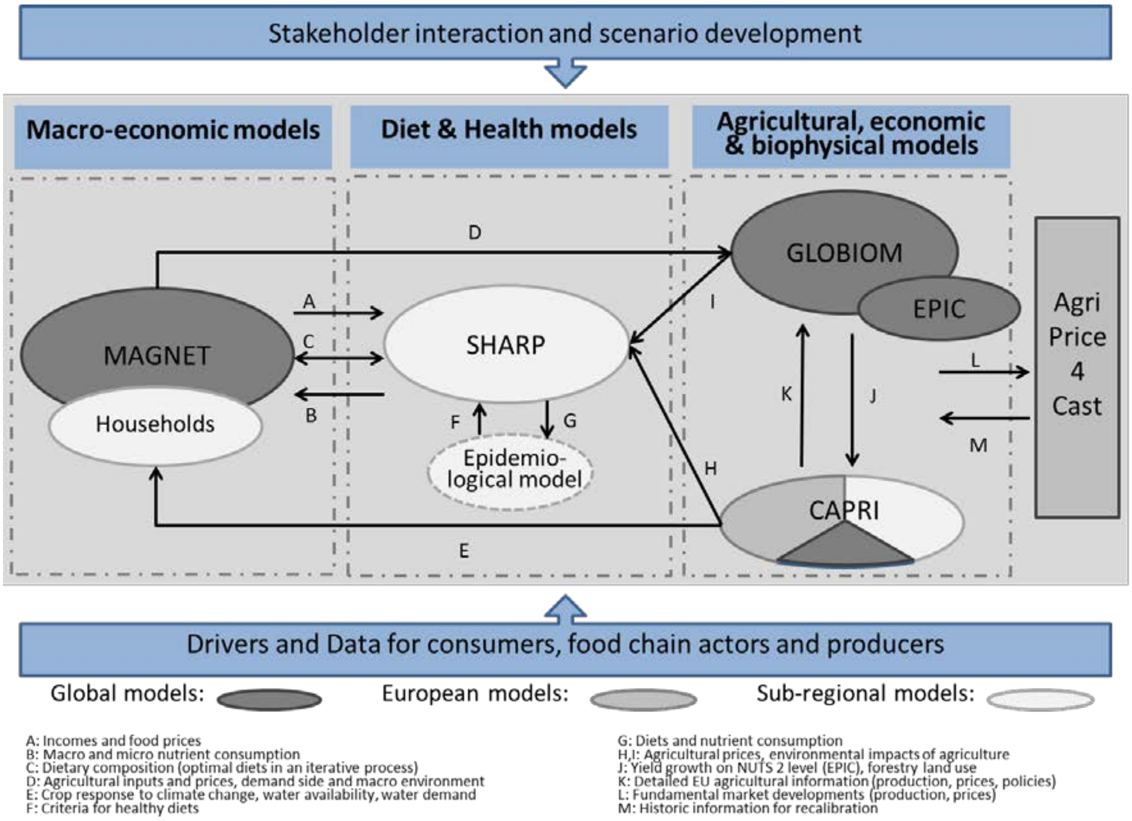
Regarding short-term modelling, SUSFANS develops an operational early warning system for agricultural commodity markets, AgriPrice4Cast, providing seasonal prices based on short-term yield forecasts. The seasonal price forecasts for the EU allows for the planning of emergency measures in cases of harvest outages in the rest of the world and/or designing storage and other stabilisation measures.

Regarding long-term modelling, SUSFANS further develops and uses a suite of well-established models commonly applied to trade, agricultural policy, biofuel policy and climate change issues for the European Commission and member states. The models include the economic model MAGNET (http://www.magnet-model.org/), the economic/biophysical models CAPRI (http://www.capri-model.org/) and GLOBIOM (www.globiom.org/), and the biophysical model EPIC (http://epicapex.tamu.edu/epic/). These models are strengthened with respect to the producer, food chain and consumer side behaviour, using the tools developed in Pillar 1. Specifically, with respect to producers, the supply response of farmers and the representation of fisheries and aquaculture will be improved (Section 2.2.1). With respect to the food chain, food loss and waste streams (Rutten, 2013; Vanham et al., 2015) and nutrient flows (Leip et al. 2011c, 2014; Rutten et al., 2014) are included, and imperfect competition is modelled to account for the importance of transnational food corporations (Section 2.2.2).With respect to consumers, macro and micronutrient intake of consumption are modelled (Rutten et al., 2014), population and health impacts (Irz et al., 2015; Rutten and Reed, 2009), and constrained optimisation on key sustainability criteria in line with the SHARP methodology (Section 2.2.3 and 3.1).

4.3 SUSFANS Toolbox

The coupling of the improved modelling tools, integrating micro-level diet and health analyses with macro-level agricultural, trade and environmental impact analyses, allows SUSFANS to move beyond the state-of-the art and create an innovative toolbox capable of assessing sustainable FNS in the EU (Box 2). The SUSFANS toolbox operationalises data and knowledge exchange between the various models, which enlarges the understanding of the driving forces and critical processes underlying short- and long-term dynamics of European and global food systems. The toolbox provides outcomes on indicators (metrics) on sustainable FNS for scenarios in a mutually consistent and coherent manner so as to signal whether EU diets become more or less food and nutrition secure and/or sustainable in the short-, medium- and long-term (monitoring) for use in foresight and policy analysis, which is the topic of the next section.

Box 2 SUSFANS Toolbox



Starting from the left, the macro-economic Computable General Equilibrium (CGE) model MAGNET captures the interactions of the agri-food and fish sectors with the energy sector, factor markets (land, labour, capital), labour supply and population well-being (health), international trade and the rest of the economy. It includes a household-level model of food demand and nutrition at sub-regional level in the EU. Detailed food consumption patterns are derived using information on incomes and prices, which feed into the SHARP model (A), with detailed nutrition patterns following from the SHARP model (B). The formulation of optimal diets from the various sustainability angles follows from an iterative process between MAGNET and the SHARP model (C), as the former captures consumer behaviour and interactions within the food system and the wider economy, whereas the latter doesn't, but provides more detailed information on dietary patterns, macro and micro nutrient intake.

On the right-hand side of Box 2, the global agricultural and forestry sector model GLOBIOM links Partial Equilibrium (PE) economic and biophysical models in the forest, crop, and livestock sectors so as to analyse the climate change impacts on global agriculture and food availability and resulting trade-offs. The biophysical crop growth model EPIC provides management system-specific yield information to GLOBIOM and CAPRI (J) based on weather, soil, and management information. In addition to yields, the model calculates the full nitrogen, phosphorus, and carbon balance, which serve as inputs into GLOBIOM and CAPRI to calculate environmental impacts in terms of pollution and GHG emissions. The EU-focused agricultural sector model CAPRI analyses the effects of supply side drivers on agricultural production (incl. fish), land use, environmental externalities, farms and trade in the medium- to long-term. CAPRI has a detailed geographic disaggregation covering an agricultural economic supply module at the EU sub-regional level (NUTS 2 level or farm level) linked to biophysical grid-level information (Leip et al, 2008; Leip et al. 2011a). CAPRI is able to provide detailed EU agricultural information to GLOBIOM (K) and crop responses to climate change, water availability and demand to the MAGNET model (E), with MAGNET providing information on agricultural inputs, prices and the wider economy to GLOBIOM (D). GLOBIOM and CAPRI provide agricultural prices and environmental impacts of agriculture to the SHARP model (H, I).

In the middle of Box 2, and at the core of the SUSFANS project, the SHARP model delivers options for sustainable FNS diets in the EU by combining real-life individual-level food intake data with sustainability metrics from SUSFANS, using Multiple Integer Linear Programming. The SHARP model is fed with information on prices, incomes and consumer behaviour from MAGNET (A) and product prices and environmental indicators from the agricultural and biophysical models (H, I). It returns detailed diet and nutrition patterns for different age groups, men and women, and other relevant population subgroups within the different EU regions (B, C). Health impacts, with potential feedback effects onto the economy, follow from a combination with an epidemiological model (G). Vice versa, criteria for healthy diets following from healthy diet guidelines can be used to determine what diets should look like from a health perspective for use in the SHARP model (F).

Finally, completely on the right-hand side of Box 2, the AgriPrice4Cast model provides short-term forecasts on the basis of information from historic and daily time-series from Thomson Reuters and the fundamental market projections from the economic/biophysical models CAPRI and GLOBIOM (L). The model will be calibrated by means of novel methods based on Bayesian model averaging techniques to improve on model-specific forecasts and explicitly quantify model uncertainties (M).

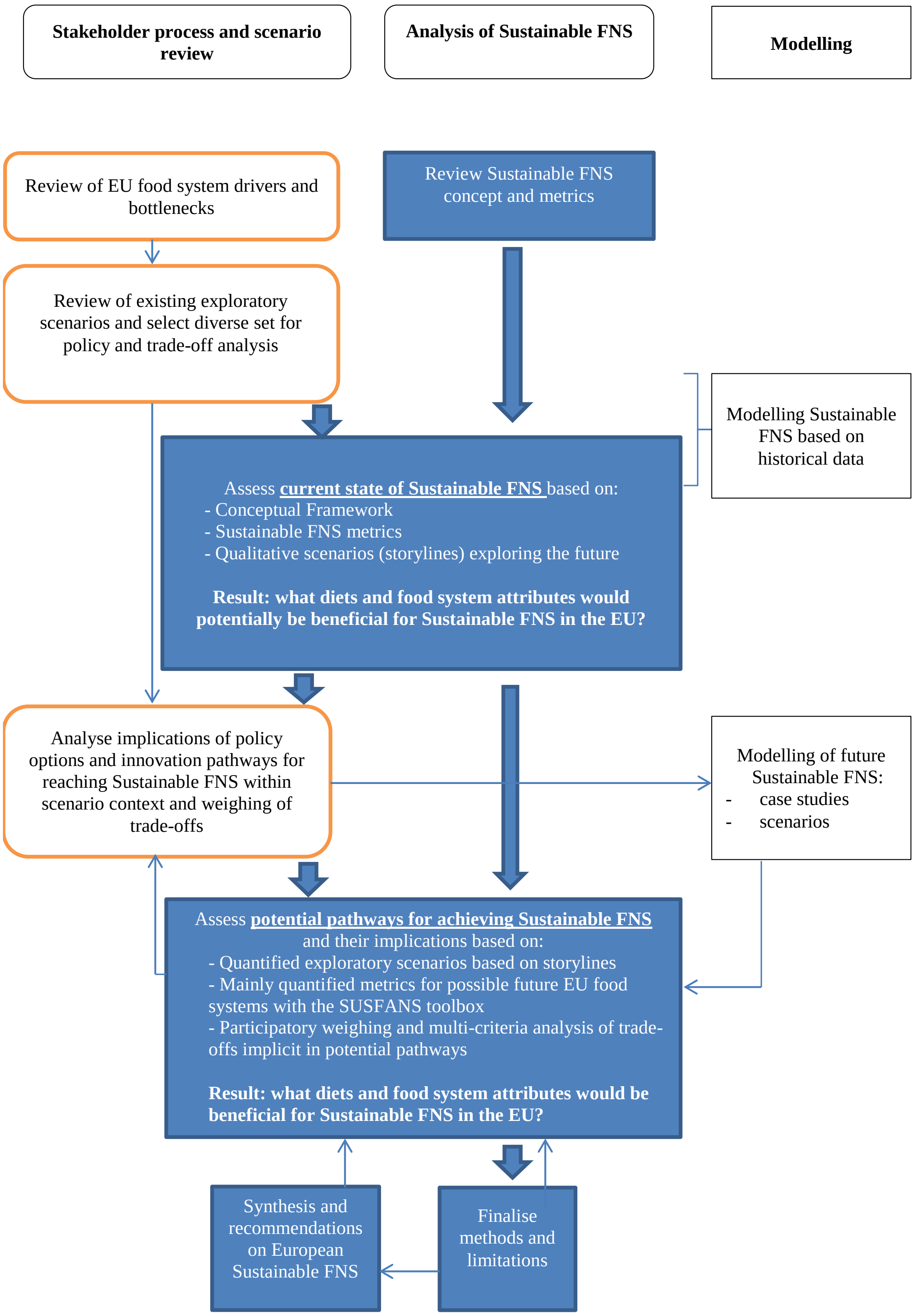
5. Foresight and policy guidance for sustainable FNS in the EU

The conceptual framework (Pillar 1) and modelling (Pillar 2) of sustainable FNS in the EU can be used to provide foresight on future pathways of EU food production and consumption (Step 6 of Pillar 3, Figure 1). This is done on the basis of two case studies and several EU-wide scenarios, which are determined in close collaboration with stakeholders and consider the impacts of sector, product, trade, consumer, nutrition and health policies and/or innovations. The results are used to formulate recommendations on using the SUSFANS framework to advance evidence-based food policy on sustainable FNS in the EU (Step 7, Pillar 3).

5.1 Stakeholder engagement

In line with Haen and Réquillart (2014), the SUSFANS consortium believes that foresight work and policy guidance should build on the evidence base to explore the scope for future gains in sustainability all along the food chain. By implication, engagement with stakeholders is intrinsic to SUSFANS's research strategy, and forms a common thread throughout the project's three pillars. Stakeholder engagement is effectuated by establishing a vibrant and active stakeholder core group (SCG) of around thirty stakeholders, balanced across stakeholder communities, food systems areas, countries and gender. The SCG (and optional members) meets in a coordinated series of workshops to review the SUSFANS conceptual framework and metrics, explorative scenarios, and outcomes so as to ensure that a range of stakeholder world views are embedded (Figure 1, grey column). The SCG also helps in designing the strategic dissemination of SUSFANS outputs. Figure 3 summarises the SUSFANS project flow discussed in the previous subsections (blue building blocks, with quantitative activities, i.e. modelling, displayed in transparent boxes on the right), but now from the perspective of stakeholders' involvement (orange building blocks on the left).

Figure 3 Stakeholder engagement in the SUSFANS project



5.2 Case studies

Two case studies are envisaged to integrate work under the different pillars in the project as a "proof of concept". The first case study focuses on the potential of using insects, reared on manure or household waste, as a livestock and fish feed. The second case study looks at the impacts of following the WHO recommendation of eating 400 grams of fruits and vegetables a day (Nishida et al., 2004) versus the alternative option of enriching foods with vitamins. The case studies incorporate innovation pathways that deviate from present-day practices and improve European sustainable FNS within a medium and long term time-frame (5, 15 and 30 years ahead). The case studies give insight into the balance of the various dimensions of sustainability throughout the chain, showing the trade-offs and complementarities at different actor levels, in the overall assessment of sustainable FNS in the EU (Pillar 1). The case studies are also a testing ground for the modelling (Pillar 2), particularly for the inter-linkages between production and consumption decisions. Case study design and results are reviewed by stakeholders (Figure 1, grey column, elements C and D) to make sure they support specific planning and policy processes.

5.3 Scenarios

Scenario approaches are increasingly used as a means of exploring uncertainties about the complex interactions that underpin FNS (UK Foresight, 2011). Many foresight analysis methods have used explorative storylines to provide scenarios of alternative plausible futures (Wilkinson and Eidinow, 2008). These scenarios can, in turn, be used to test and develop interventions, plans and policies, making them more robust under a wide range of futures (Vervoort et al., 2014).

A number of credible, legitimate scenario sets that explore contextual drivers of the future of food and nutrition security in Europe have been or are being developed already. Instead of creating yet another set of explorative scenarios, SUSFANS builds on these efforts and focuses primarily on exploring new "intervention scenarios", with pre-existing explorative scenarios offering a wider context. To do this recent and on-going scenario exercises are reviewed with stakeholders (Figure 1, grey column, element C). These include Agrimonde (2011), UK Foresight (2011), JRC foresight on foods and diets (Bock et al., 2014), OECD's long term scenarios for food and agriculture (forthcoming), the FAO "Agriculture Towards 2050" exercise (Alexandratos and Bruinsma, 2012), IFPRI's food security, farming and climate change to 2050 (Nelson et al., 2010), European Science Foundation/COST forward look on food (http://www.esf.org/food), FOODSECURE (http://www.foodsecure.eu), TransMango (http://www.transmango.eu/) and last but not least the new climate assessment scenarios (van Vuuren et al., 2014).

After drawing on such existing scenario sets to create a set of diverse future contexts for FNS, SUSFANS will identify, together with its stakeholders, interventions (by policy makers, private sector, civil society). The interventions include the development of policy and innovation strategies in consumption, farming and the food chain. These interventions will be tested in the context of the pre-existing explorative scenarios. An important consideration in the analysis is the understanding of different implicit and explicit trade-offs resulting from possible intervention options. They are translated into semi-quantitative parameters, quantified with the SUSFANS model toolbox, and subsequently run and analysed, and reviewed by stakeholders (Figure 1, grey column, element D).

In this process, the explorative scenarios do not serve as unchangeable contexts that planners simply accept and adapt to. Instead, the explorative scenarios function as 'multiple baselines' that can be changed by proposed interventions which aim to redress undesirable future paths outlined in the explorative scenarios. The intervention pathways aim for feasible diets over time while balancing the various sustainability dimensions. This combination of normative intervention pathways and explorative scenarios has been used successfully in a number of planning contexts (Kok et al., 2011; Robinson et al., 2011). It also corresponds to Kahane's (Kahane, 2012) notion of 'transformative scenarios'. In our experience (Herrero et al., 2014), the key to success with using explorative scenarios as a background to test and develop intervention pathways is to avoid diffuse, broad-stroke visioning, and focus on specific plans and strategies that key actors plan to take forward.

5.4 Policy guidance using participatory MCA

SUSFANS employs multi-criteria (decision) analysis (MC(D)A) to make sure that stakeholders' views on sustainable FNS in the EU along its various dimensions are reflected in foresight and policy guidance. This approach results in a common vision whilst doing justice to differing viewpoints regarding the sustainability dimensions, their synergies and their trade-offs. MCA originates from operations research and, whilst widely applied in environmental sciences (Huang et al., 2011), is relatively new to the analysis of food systems, food and nutrition security and diets (Alrøe et al., 2014). MCA establishes preferences between options relative to an explicit set of objectives and measurable criteria (i.e. indicators or metrics) to assess the extent to which objectives have been achieved. A fundamental feature is its emphasis on the views of stakeholders in establishing objectives and indicators, and in estimating the relative importance weights of each indicator so as to come to an aggregated overall assessment and ranking of alternative options. Based on each stakeholder's independent view – which may conflict with that of others –, a joint conclusion in a shared language may be reached with a coherent message for EU decision makers on how to achieve sustainable FNS, and what this may look like (Figure 1, grey column, element E).

6. SUSFANS impact: target outputs and implications

Two sample outputs that are foreseen, illustrate SUSFANS societal impacts. The first is the nutrient flow analysis (Section 4.2) by means of which full chain (cradle to grave) footprints can be calculated. This enables (i) to identify 'handles' across all food chain actors to reduce environmental impact and (ii) delivers a tool for communication with consumers, providing comprehensive information for both effects on health and environmental sustainability. The second is to use the outcomes of the modelling of current and future diets that are environmentally sustainable, healthy, affordable, reliable and palatable (SHARP; Section 4.1) to improve EU dietary guidelines.

6.1 Nutrient footprints

The Expert Panel on Nitrogen and Food (EPNF) of the Task Force on Reactive Nitrogen (TFRN) under the Working Group on Strategies and Review of the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) is currently working towards a more in-depth assessment of (i) the contribution of farm-level technical options, food chain mitigation and diet choices to possible reduction of Nr and GHG emissions in Europe, and (ii) the trade-off and win-win solutions for healthy and sustainable diets (TFRN, 2015). The assessment will be fed by the nutrient footprint developed within the SUSFANS project. Footprint analysis outcomes will further be used as a tool for communication with consumers. Those tools range from interactive 'food footprint' games (JRC, 2015) over representative national N footprint calculators (Leach et al., 2012) to concepts which engage the consumer (individuals or groups of persons) to reduce and possibly offset the environmental impact caused (Leip et al., 2014). Also concepts for multi-dimensional (yet simple) environmental labelling of food products are an option (Leach et al., 2016).

6.2 Sustainable and healthy diet guidelines

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7. Summary and conclusions

This paper defines the research agenda of the SUSFANS project, describes its history and its potential societal impacts. It contributes to balanced and encompassing views on how to strengthen food and nutrition security outcomes in the EU and how to improve the performance of the food system in the

EU from the perspective of social, environmental and economic sustainability. The research is led by the notion that improvements in the diets of the European consumer must come from, and be supportive of, food systems that contribute to public health, environmental protection and thriving enterprise in the long term.

The set of metrics, models and foresight tools currently available to analysts, decision-makers and stakeholders is considered inadequate for navigation on sustainable food and nutrition security in the public and private arena. The holistic, integrative approach taken up by SUSFANS, being transdisciplinary and including exchange throughout with all stakeholders, ensures a coherent and supported vision on what entails sustainable FNS in the EU and globally. It also underpins a perspective on how EU policies on farming, fishing, food and nutrition could contribute to that vision with greater efficacy than today.

Acknowledgements

The research leading to these results has received funding from the European Union's H2020 Programme under Grant Agreement number 633692 (SUSFANS). The authors only are responsible for any omissions or deficiencies. We are grateful to all members of the SUSFANS project and to participants of the 1st meeting of the SUSFANS Stakeholder Core Group (Prague, 30 October 2015), the 2nd Conference on global food security (Ithaca, 11-14 October 2015) and the EAAE seminar "Does Europe need a food policy?" (The Hague, 30 November 2015) for useful comments and suggestions.

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